Original: Fish Division
cc: Institute for Fisheries Research
Education-Game
Mr. V. C. Applegate (2)
Mr. J. T. Wilkinson
Dr. J. Van Oosten

INSTITUTE FOR FISHERIES RESEARCH
DIVISION OF FISHERIES
MICHIGAN DEPARTMENT OF CONSERVATION
COOPERATING WITH THE
UNIVERSITY OF MICHIGAN

ALBERT S. HAZZARD, PH.D.
DIRECTOR

ADDRESS
UNIVERSITY MUSEUMS ANNEX
ANN ARBOR, MICHIGAN

January 24, 1949

Report No. 1209

# SEA LAMPREY INVESTIGATIONS

## 3. BIOLOGICAL CHARACTERISTICS OF SEA LAMPREY SPAWNING RUNS IN CARP CREEK AND THE OCQUEOC RIVER, PRESQUE ISLE COUNTY, MICHIGAN.

by

Vernon C. Applegate

Sea Lamprey Investigations

3. Biological characteristics of sea lamprey spawning runs in Carp Creek and the Ocqueoc River, Presque Isle County, Michigan.

TABLE OF CONTENTS

TABLE OF CONTENTS

Sea Lamprey Investigations

3. Biological characteristics of sea lamprey spawning runs in Carp Creek and the Ocqueoc River, Presque Isle County, Michigan.

## I. Introduction

This report is concerned primarily with the findings of several investigations of the sea lamprey undertaken in the field between April 1 and September 1, 1947, and between March 15 and September 1, 1948. The first section of this report is concerned with the biological characteristics of, and factors affecting the spawning run of sea lampreys entering Carp Creek, Presque Isle County, in 1947. Supplementary information of a similar nature was collected on the Ocqueoc River, in the same locality, and is included. The spawning run of sea lampreys captured in Carp Creek in 1948 will be the subject of a separate report. Certain sections, particularly that dealing with the spawning habits and spawning requirements of the sea lamprey are based on data collected in both years. Numerous observations and lesser investigations conducted during all periods are incorporated in various sections of this report.

These studies were undertaken in an effort to obtain more precise information than heretofore existed of that phase of the life history of the sea lamprey when it enters streams to spawn. The procurement of this knowledge has become of paramount importance because of the widely publicized demands for control of this fish predator which have specified the construction of "lamprey weirs" for the capture and destruction of spawning populations. The investigations as undertaken at Carp Creek were designed to provide information as to the requisites of an effective sea lamprey weir on a small stream, the cost of such a structure and problems in its maintenance--in addition to the biological information which would be forthcoming through the operation of this structure. It was also intended that the repeated use of this weir in succeeding seasons might provide some index of the relative abundance of the sea lampreys in the general area of northern Lake Huron in those years. It would be of obvious value to know if the population is increasing, decreasing, or has become relatively stable in numbers. Furthermore, continued use of this weir over a period equivalent to at least one larval cycle might provide a test as to whether the "home stream" or "parent stream" theory applies to this species in any degree.

The general area of the Ocqueoc River--Carp Creek watersheds was selected as the locus of investigations because of the intense local interest in the sea lamprey problem. This interest was engendered by the large runs which entered the Ocqueoc River in increasing numbers during the past decade. In the spring of 1944 and again in 1945, the East Presque Isle County Sportsman's Association operated a weir in the lower Ocqueoc River in cooperation with the Department of Conservation. In each year, a fair proportion of the sea lamprey run was captured. A complete report of these operations has been made by Shetter (1948? and I. F. R. Repts. 1015 and 1086).

Neither in 1946 nor in 1947 was a weir operated in the Ocqueoc River. The construction of a permanent sea lamprey weir in this river in the spring of 1947 was to have been undertaken by the United States Fish and Wildlife Service but did not materialize due to a delay in the requisite funds becoming available. Plans for a temporary weir to serve only until the permanent structure became a reality were drawn up by the Department of Conservation but installation was rendered impossible by sustained high water conditions during the practicable period of construction. A permanent structure was installed in the river during September, 1948.

That period when a sea lamprey enters a stream to spawn and then dies represents but a brief span in the life cycle of the species. In order to better relate the present account to the entire life cycle and to provide some understanding of the organism itself, a description of the species and a generalized account of its life history follows.

## The sea lamprey--description and life history

The sea lamprey, Petromyzon marinus, is one of the most primitive living fish-like vertebrates. Its body is eel-shaped, somewhat flattened in the head region and compressed towards the tail. It is often confused by fishermen and laymen with the true eels (Anguillidae) with the result that two of its most common names are "lamprey-eel" and simply "eel." Other common names are "lampher," "lampher-eel" and "lamper." It has no visible paired fins nor any vestiges of these. Median fins are present--two dorsal fins and a rounded caudal fin. The posterior dorsal is well separated from the anterior one and is continuous with the caudal fin. The anal fin appears as an almost indistinguishable fold. No bony skeletal parts are present. A cartilaginous cranium protects the brain and a "basket" of cartilaginous rods supports the branchial region. The main axial support is the notochord which is present as a continuous, unconstricted rod encased in a fibrous sheath. Instead of the characteristic gills of higher fishes, seven pairs of sac-like gill pouches open to the outside by as many small rounded apertures (Figure 1). The gill pouches open internally into a median branchial canal, which opens into the mouth and lies below the esophagus. A single, median nostril on the top of the head terminates internally in a blind chamber. The eyes

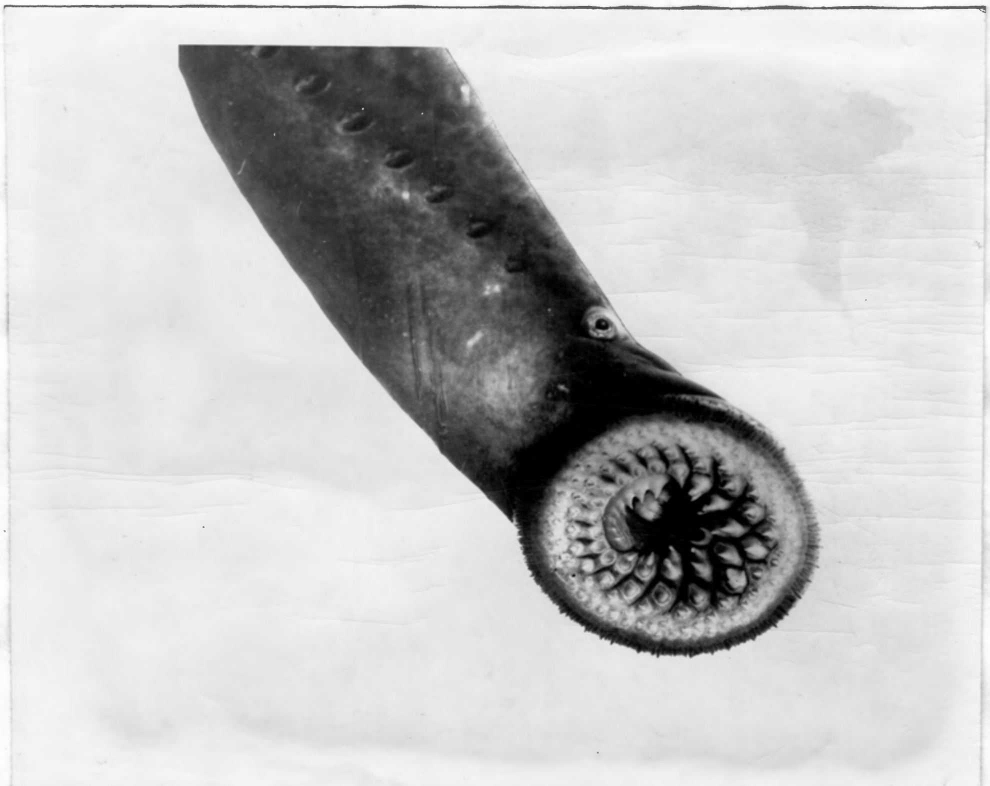


Figure 1. Head and branchial region of an adult sea lamprey.

are small. The most striking feature of the species is its mouth. True jaws are lacking and instead, a disc-like sucking mouth, studded with horny teeth is found (Figure 2); the tongue is similarly toothed.

Sexually immature individuals after metamorphosis are parasitic and are blue-gray to dark blue in color dorsally and as a rule are white on the ventral surface. Sexually mature sea lampreys exhibit a variety of color phases the most striking being those individuals which become a golden-yellow in color--the epithelium having become suffused with a golden lipochrome creating a golden irridescence upon a mottled, black background.

The life cycle of the species is somewhat complex but it may be summarized in general terms as follows: In the spring of the year, sexually mature adults migrate into streams to spawn. After constructing a nest of gravel and small rocks, the eggs are fertilized and deposited in it. Very soon thereafter the adults die.[1] The eggs hatch in about three weeks and the larvae, called ammocoetes, drift downstream until they find quiet water and a silted bottom. Burrowing into this silt, they live as blind, wormlike creatures for a number of years, feeding upon microorganisms. At this stage they are not parasitic. At the end of their larval cycle a transformation occurs--the eyes become fully developed and the mouth grows into a circular sucking disc within which many horny teeth develop. Other less obvious changes also take place and finally, fully equipped to prey upon other fishes, the metamorphosed lampreys leave the mud and migrate downstream to a large

---

[1] Many commercial fishermen and some fishery technicians are of the opinion that the sea lamprey does not die after spawning. Data presented subsequently in this report provide very strong evidence that they do die after spawning is completed.

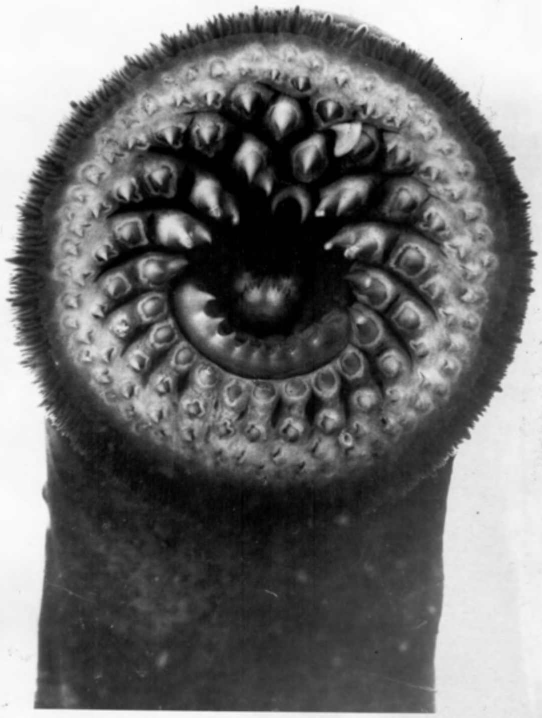


Figure 2. Close-up of the sucking disc (mouth) of an adult sea lamprey.

body of water and begin their parasitic life. For this life they are well fitted by being strong, vigorous swimmers. On becoming attached to a victim, they rasp away the body covering and the scales and work into the muscle tissue with the horny teeth of the mouth-disc and tongue. They then proceed to withdraw the blood and body fluids of their victim (Figure 3). When the lampreys are satiated or when the victim is weakened or perhaps dead, they drop off leaving large, raw wounds on their prey (Figure 4). The parasitic period is ended with the advent of sexual maturity when the adults migrate to, and enter, a stream to spawn and then die, completing the life cycle.

## II. Carp Creek investigations

### Carp Creek

Carp Creek is tributary to Hammond Bay of northern Lake Huron, flowing into that bay about four and one-half miles north of the outlet of the Ocqueoc River. The entire drainage area of this creek lies within Sections 1, 2 and 3, T. 36 N., R. 2 E., Presque Isle County. Carp Creek proper is 1.5 miles in length (Sections 1 and 36) between its estuary and its origin in Carp Lake. The latter is about 70 acres in surface area and has a maximum depth of 24 inches! The shoreline on nearly all sides may be termed encroaching. Approximately six square miles of swampland drains into Carp Lake primarily as surface drainage. No discrete year-around streams flow into the lake, as many recent maps would lead one to believe. In former times, when water tables were higher these may have existed but at present writing there is little trace of such watercourses.

The potential sea lamprey spawning areas of the Carp Creek drainage basin lie in the 1.5 miles of the creek proper between Carp Lake and

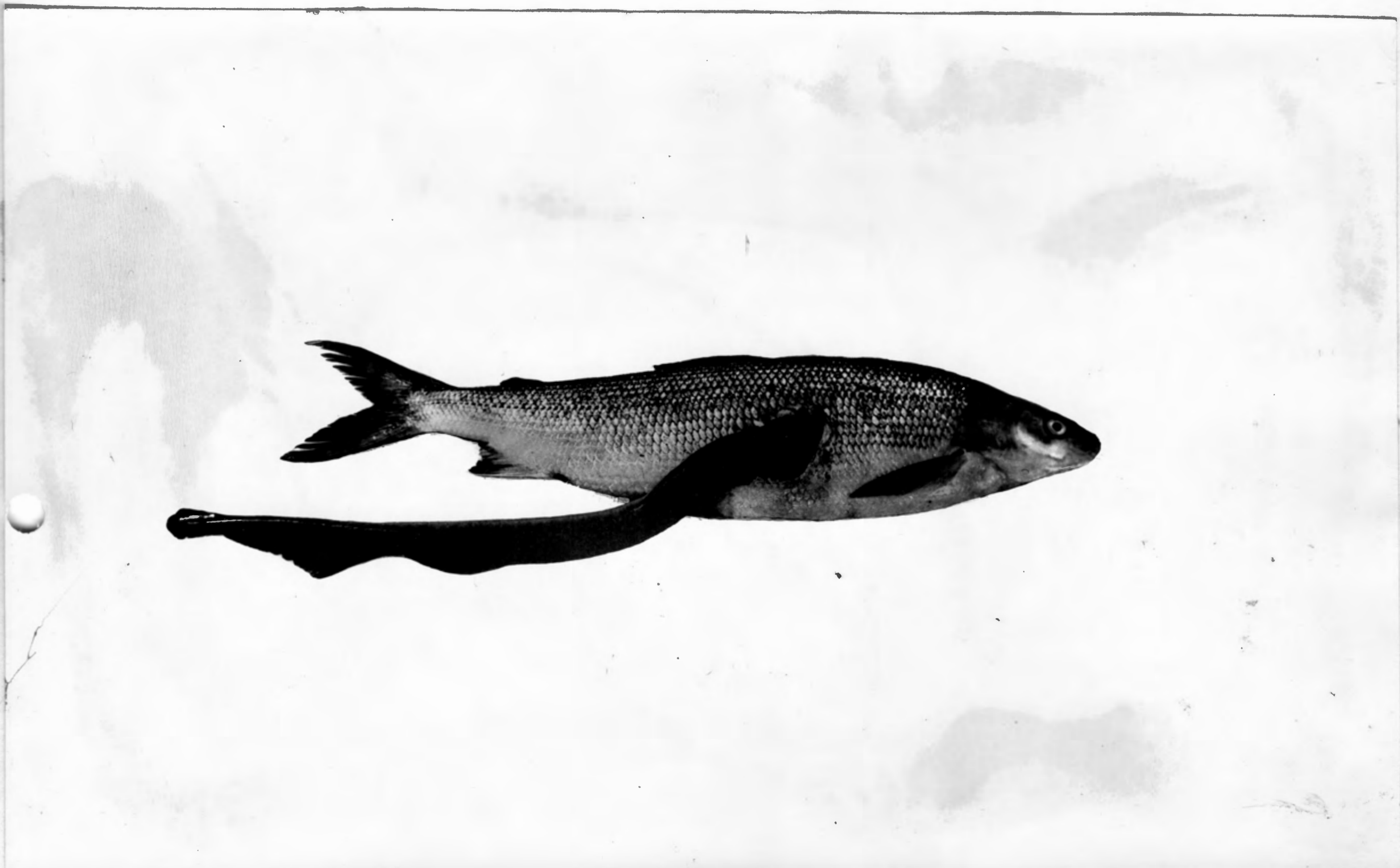


Figure 3. Adult sea lamprey attached to a whitefish taken in Lake Huron.

Figure 4. Typical lamprey scars on whitefish taken in northern Lake Huron.

its mouth. This portion of the stream has a moderate overall gradient. Gravelly riffle areas alternate with deeper pools (1 to 4 feet) which have a barren sub-stratum clay bottom. Little shifting sand is present until the creek enters the beach line just upstream from the estuary. Cover, composed predominantly of cedar and birch, is heavy and more than a mile of the stream lies in dense shade. Reportedly, in very dry years Carp Creek is reduced to a mere trickle in midsummer but local opinions on this matter are very conflicting. During 1947, a moderate volume of flow was present throughout the entire summer months. Although classified as a "trout stream," high water temperatures in summer (78° F. to 82° F.) give little evidence of suitable trout habitat. The color of the water is typical of many northern streams draining swampland, being generally quite tea-colored. Water chemistries varied little during the spring months. A typical analysis on June 29, 1947, a windless, partly overcast day, was as follows (previous weather clear):

| | |
|---|---|
| Station------U. S. 23 Highway Bridge | $CO_2$-------0.0 ppm. |
| Time---------9:45 A. M. | phth------2.0 ppm. |
| Air temp.----70° F. | M.O.----118.0 ppm. |
| Water temp.--72° F. | $O_2$--------7.3 ppm. |

Sea lamprey runs had been noted in this stream by conservation officers and local residents for several years prior to 1947. I strongly suspect that its history in this regard dates back to the first runs noted in the neighboring Ocqueoc River (circa 1934-35?) for both streams undoubtedly draw from a common stock of adults living in, or entering, Hammond Bay. Being thus assured of a run upon which we could experiment, a site for the construction of a sea lamprey weir was selected just below the U. S. 23 highway bridge crossing the stream. This site, located within the highway right-of-way, was easily accessible for construction and maintenance, and was but several hundred feet above the estuarine waters of the creek. This latter point is of importance in control since to be most effective, a sea lamprey weir should be placed ideally below the lowest potential spawning area.

The Carp Creek sea lamprey weir

The weir and trap constructed in Carp Creek was of the single "V" type with the trap placed at the apex of the "V." The stream is 22 feet wide at the point of construction and each wing of the "V" was 18 feet long (Figure 5). This structure was originally built as a temporary weir, pending the completion of a more elaborate, permanent device. Due to difficulties in installation, the latter was discontinued and the temporary structure was therefore improved and made more nearly permanent. For supporting the screen face of the wings, nine-foot, steel, snow-fence posts were driven into the bottom; each was buttressed on the downstream side with an identical post. Four additional posts were driven as anchors for the box-type trap. Twenty-eight-inch by nine-foot sections of salvaged rock and gravel screening were wired to the upstream side of the steel posts. Placing them in pairs, one above the other, gave each wing a heighth of 56 inches. This screening was of a very heavy gauge wire (3/16-inch diameter) of roughly one-inch mesh, reinforced along one edge with angle iron, and therefore quite rigid. Using this coarse grid for support, hardware cloth of 1/2-inch mesh was laid against the upstream side of the heavy screening and wired to it. The wings were joined at the shore to a baffle of double sheet piling, driven into the softer bank; they were also secured at the

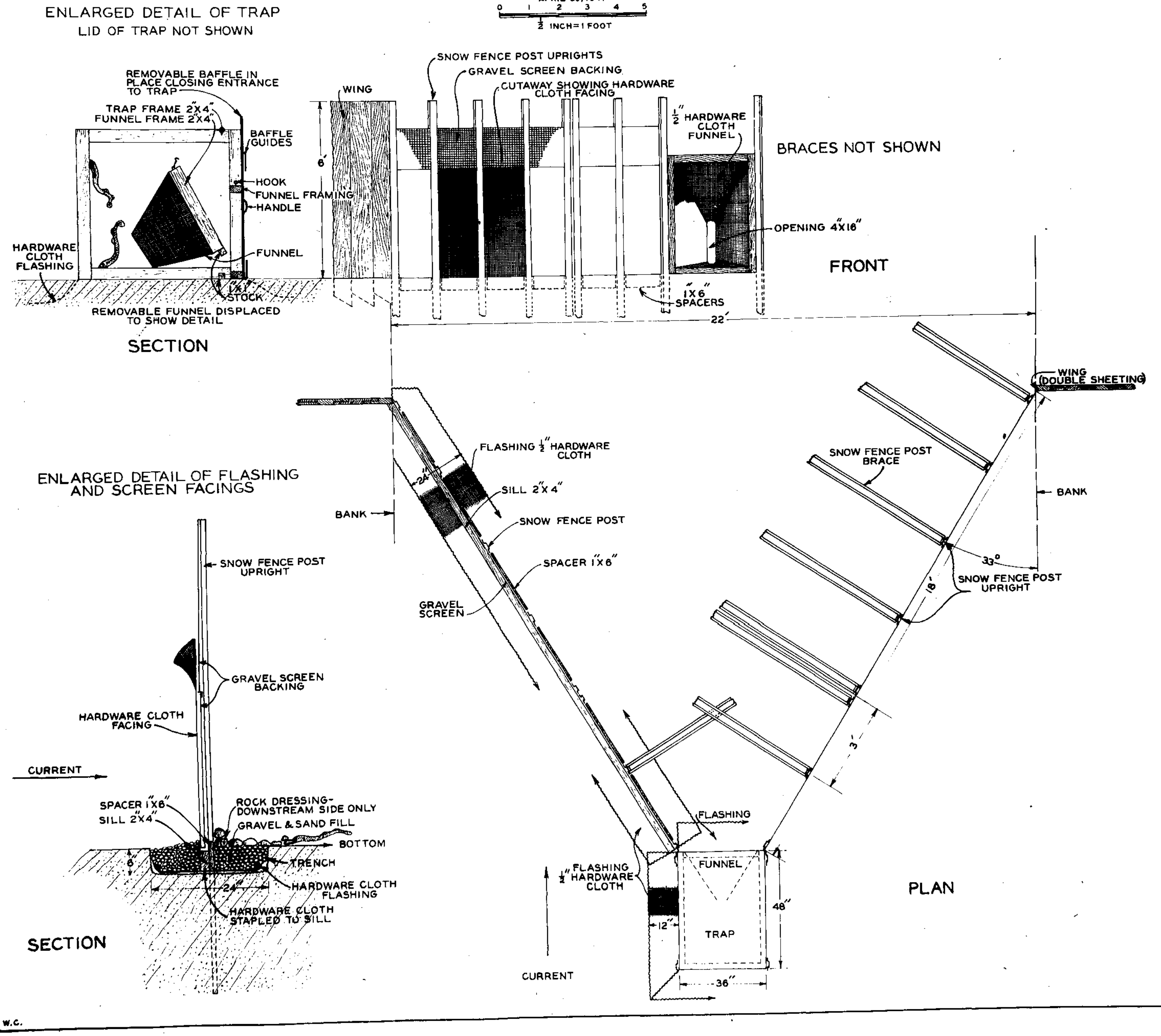
Figure 5. Carp Creek sea lamprey weir.

MICHIGAN DEPARTMENT OF CONSERVATION
INSTITUTE FOR FISHERIES RESEARCH

# SEA LAMPREY WEIR AND TRAP

CARP CREEK PRESQUE ISLE COUNTY

DIAGRAMATIC PLANS
V. C. APPLEGATE
APRIL 30, 1947



trap, on each side of its entrance. The greatest problem was anchoring the wings and trap to the stream bottom so that no undercutting would take place. It was impossible to drive sheet piling for this purpose since beneath a shallow layer of gravel the stream bed was composed of very hard clay. This is the condition that was instrumental in halting the construction of the permanent weir. To circumvent this, a trench two feet wide and six inches deep was dug (with a crowbar) astraddle the line of fence-post uprights. A strip of hardware cloth the length of the wing and 24 inches wide was nailed to a 2" by 4" sill of equal length and placed, hardware cloth down, in the trench, with the 2" by 4" braced against the upstream side of the uprights. The bottom edge of the lower gravel screen rested on this sill. Spacers of 1" by 6" stock were added on the downstream side, between the uprights, to prevent any buckling of the gravel screen backing (see detail, Figure 5). After the hardware cloth had been added, the trench was filled with heavy gravel and sand. A dressing of larger rocks was placed on the downstream side to prevent scouring.

The trap was a simple box-like frame (36" by 48" by 48") of 2" by 4" lumber covered with 1/4-inch mesh hardware cloth and built as a single movable unit. Its funnel, fabricated of hardware cloth and a 2" by 4" wood frame, was removable after insertion of a closing baffle on the front of the trap. This facilitated removing both lampreys and fish.

The original structure without the subsequent improvements was fabricated and installed in two working days by four men. Problems in construction other than the extreme discomfort of working in the water at temperatures of 38° F. to 40° F. were minimized by low water levels and the relatively small size of the stream. The sill and flashing of hardware cloth which was substituted for sheet piling proved very satisfactory and is strongly recommended for semi-permanent structures on those sites where the nature of the bottom prevents the driving of piling; it is inexpensive to fabricate and very easily installed.

It would be well to note again that the maximum mesh size for sea lamprey weirs and traps is one-half inch. Experiments conducted with 5/8-inch mesh screen indicated that some of the smallest lampreys can work their way through this. These statements apply to square-mesh screen. I am not too certain at the present date that weir screens constructed of vertical rods with a one-half inch spacing between them would be entirely lamprey-tight.

The basic requirements of an effective sea lamprey weir are that it be strong enough to withstand the impact of maximum flood waters and that it be high enough and wide enough to remain fish-tight under like conditions. The Carp Creek weir withstood severe flood conditions on three occasions. On May 31, 1947, the north wing partly buckled during a period of very high water due to improper bracing. This wing was completely removed and rebuilt on May 31 and June 1.

The weir in its final form was essentially lamprey-tight. We discovered early that a sea lamprey will find and make use of the smallest, and perhaps only, aperture in a large barrier. Consequently, we continually checked all possible loci of escapement with our hands as part of the routine visits to the weir. On May 9, May 11, May 14, May 29 and July 1, the creek was patrolled from Carp Lake to the weir. On all but the latter date, no trace of sea lampreys was found. On July 1, I found five nests about three-quarters of a mile above the weir. Eggs were found in two nests and promptly destroyed. The other three nests had not been spawned in although they had evidently been completed for several weeks. I suspect that this escapement, which probably did not exceed ten individuals, occurred during the period May 31 to June 1 while the north wing of the weir was being repaired.

Maintenance of such a weir and trap present numerous problems. Under normal conditions the screens must be cleaned with wire brushes at least three times during a 24 hour period or the resultant damming action of the clogged screen is very severe. During high water, more frequent visits for cleaning must be made. At least during the time of the sucker runs, the trap must be emptied of fish and lampreys at least three times a day. During the smelt and sucker runs there is the inevitable damage to be repaired resulting from overzealous fishermen using the structure to augment their catches. This amounted to a considerable item in 1947 when we repaired the trap and funnel no less than four times after sucker spearers attempted to impale fish in the trap by spearing through the funnel.

The Carp Creek sea lamprey weir functioned very satisfactorily and efficiently for experimental purposes; I consider that better than 99 percent of the sea lamprey run was captured. The structure was simple to fabricate and install and the cost of materials was nominal since primarily salvage materials were used. For these reasons, it is planned to re-use this structure in its final, refined form in future years in Carp Creek. Small changes may be made such as the addition of a white-painted floor in the trap to make it easier to see fish and facilitate their removal, especially at night. All of the weir except the steel upright posts and the sills and flashing was removed from the creek on August 1 and August 4 and stored pending reinstallation in 1948.

Records were kept during the construction and operation of the weir of all costs incurred. Operational costs are of the greatest interest since they provide a measure of the expense of operating one sea lamprey weir for one season on a small stream under typical conditions. The cost of the weir itself provides no index of the cost of a typical sea lamprey weir since it was constructed primarily of salvage materials and since it is highly unlikely that it could be reproduced in another stream at the same cost.

Expenditures in man-hours and money for the construction, maintenance and operation of the weir were as follows:

| Item | Material and Man-hours | | Cost |
|---|---|---|---|
| Trap | 52' rough fir, 2" by 4", at $130/M. . . . . | $ | 7.00 |
| | 80 sq. ft. 1/4" mesh h'ware cloth (salvage) | | ... |
| | Lock, hasp, hinges, nails, etc. . . . . . . | | 1.50 |
| Wings | 24 steel snow-fence posts (borrowed from Mich. State Highway Dept.). . . . . . . . . . | | ... |
| | 8 steel, rock and gravel screens (salvage). | | ... |
| | 44' by 4' by 1/2" mesh hardware cloth . . . | | 22.44 |
| | 40' rough fir, 2" by 4", at $130/M. . . . . | | 3.34 |
| | 100' rough fir, 1" by 6", at $130/M . . . . | | 6.50 |
| | Minor hardware, wire, etc. (salvage). . . . | | ... |
| Trap and Wings | Fabrication and installation-- 35 man-hours. . . . . . . . . . . . . . . . . . | $ | 33.42[2] |
| | Total cost of construction. . . . . . . . . . | $ | 74.20 |
| Operation | Apr. 21-30, 8 man-hours per day-- 80 man-hours. . . . . . . . . . . . . . . . . | | 96.00 |
| | May 1-12, 8 man-hours per day-- 96 man-hours. . . . . . . . . . . . . . . . . | | 102.24 |
| | May 13-22, 7 man-hours per day-- 70 man-hours. . . . . . . . . . . . . . . . . | | 71.70 |

---

[2] Wages have been computed on the basis of hours worked in varying amounts by four individuals whose hourly rates varied from $.78 to $1.26 per hour.

| | | |
|---|---|---|
| Repair | May 22, improvements on south wing--5 man-hours. . . . . . . . . . . . . . . . . . . . | $ 5.48 |
| | May 25, improvements on north wing--8 man-hours. . . . . . . . . . . . . . . . . . . . | 8.76 |
| | May 31-June 1, rebuild north wing--40 man-hours . . . . . . . . . . . . . . . . . . . . | 43.80 |
| | June 2-4, rebuild bank abutments and rebrace weir--41 man-hours . . . . . . . . . . | 39.84 |
| Operation | May 23-30 and June 1-4, 7 man-hours per day--84 man-hours. . . . . . . . . . . . . . . . | 85.84 |
| | June 5-23, 4 man-hours per day--76 man-hours . . . . . . . . . . . . . . . . . . . . | 76.95 |
| | June 23-30, 2.5 man-hours per day--20 man-hours . . . . . . . . . . . . . . . . . . . . | 18.60 |
| | July 1-20, 1.5 man-hours per day--30 man-hours . . . . . . . . . . . . . . . . . . . . | 37.80 |
| Removal | Aug. 1, dismantle, remove and store south wing--5 man-hours. . . . . . . . . . . . | 6.30 |
| | Aug. 4, dismantle, remove and store north wing--2.5 man-hours. . . . . . . . . . . | 3.15 |
| Transportation | Computed at $.03/mile[3] . . . . . . . . . . . . . . | 90.72 |
| | Total cost of operation and maintenance. . . | $ 687.18 |
| | Grand Total. . . . . . . . . . . . . . . . . . . . | $ 761.38 |

The foregoing operational costs indicate the specific expense of one project among several carried on simultaneously. If the weir had been the sole project carried on, the presence of two men would still have been required and operational costs would have amounted to $1,321.00.

---

[3] Maintenance and fuel costs only; depreciation not included.

Figure 6. Carp Creek weir, May 5, 1947. Note damming action of weir screen prior to cleaning. This screen had been cleaned six hours earlier.

Figure 7. Carp Creek weir, May 5, 1947. View from above.

Figure 8. Carp Creek weir at low water stage. July 1, 1947.

The sea lamprey run

(1) Collection of data:--Normally, the weir-trap was inspected and the fish and sea lampreys removed three times each day. We attempted to make these visits as close as possible to 8:00 A. M., 5:00 P. M. and midnight each day. All specimens removed at each of these times were recorded as separate collections. Of the entire sea lamprey run, all but 17 specimens were examined for sex, length, weight and stage of maturity. More detailed dissections were made of 328 specimens. All individuals of other species taken in the trap were examined for evidence of sea lamprey attacks and these data recorded.

A maximum-minimum thermometer was maintained in the creek just above the weir from April 16 to June 30. Readings were made daily during the morning visit and the water temperature at this time was noted with a pocket thermometer in order to verify records on the fixed thermometer. On June 30, the maximum-minimum thermometer was found to have been broken by some inquisitive visitor and thereafter, only readings at the time of the visit were recorded. Frequent records were made of the surface water temperatures at the mouth of the creek and in Hammond Bay itself. There was some difficulty in finding a proper location for a water gauge but after several false starts, accurate readings were obtained for most of the period of weir operations. Water gauge readings are in inches and fractions and represent absolute depth in midstream just below the weir. Daily records of wind and other weather conditions were made and these data supplemented with similar records maintained by Mr. G. W. Hansen, 40 Mile Point Light Station, Lake Huron.

Since virtually all sea lamprey migratory activity in Carp Creek occurred during the hours of darkness, the data was arranged so that all individuals entering the trap during one night were tabulated as a unit. Thus the catches subsequently designated for any given day (which are listed at the time of the morning visit) represent the migration into the trap since the morning visit of the preceding day (approximately 23 clock hours since the trap would be closed about an hour each day while the fish were being removed). Maximum, minimum and mean water temperatures recorded for any given date likewise reflect conditions which existed during the preceding 24 hours.

(2) Time limits and extent of the run:--The earliest migrants observed at Carp Creek were four individuals seen by the writer between 11:00 and 12:00 P. M. on the night of April 14. These sea lampreys were spotted with the aid of a jack-light about 100 feet offshore on the gravel "fan" which extends from the mouth of Carp Creek into Hammond Bay (Figure 9). During the time they were observed, they made no effort to move up into the creek mouth but clung persistently to the same rock until deliberately frightened by the observers. When frightened, they darted off across, or with, the current and dropped into the deeper waters of the bay. At the time of these observations, the water temperature on the "fan" was 39° F. and the air temperature was 32° F. Flow ice was still present in the bay.

During the period April 15 to April 19, repeated trips were made to the gravel "fan" at all times of the day and night by the writer, Mr. Robert Frank (formerly with the Fish Division, Department of Conservation), and Mr. Edward Karsten of Ocqueoc, Michigan. On April 15, about 11:00 P. M., a male sea lamprey 19.3 inches long and a female 16.7 inches long were seen and captured by spearing. Three others were seen later in the night. On the following night, about midnight, two females, 15.3 and 17.2 inches long were likewise taken. Again, at least two more were

Figure 9. Observer standing on the "fan" off the mouth of Carp Creek where sea lampreys were first observed on April 14, 1947.

seen in the following hours. On both nights, the water temperature remained at 40° F. during the hours of observation--the air temperature varied from 24° F. to 32° F. A total of six sea lampreys were observed under similar circumstances on the succeeding three nights.

From these observations, made at all hours of the day and night during this period, we gained the impression that the sea lampreys observed were making no effort to enter the Carp Creek proper at that time. None were ever observed during the daylight hours. About two hours after full darkness they seemed to appear suddenly on the central and outward portions of the "fan" where they apparently remained until dawn. They were never in evidence in the estuary or lower creek proper at the times inspections were made on the "fan." I presume from this that they dropped back into the bay with the coming of daylight.

Unfortunately, we cannot fix the exact date when the actual upstream migration began. The weir and trap were put in operation on April 21 and by the following morning (April 22) one specimen had entered the trap. During the period April 15 to 18, water in the creek proper was one degree or more colder than that in the bay. This was due primarily to melting snow run-off in the watershed. On April 19, 20 and 21 it rose in temperature above that of the bay for a few hours each afternoon. I believe that these temperature differences between the creek and the bay were responsible for the behavior of the lampreys noted on the "fan" in so far as it slowed or inhibited their entrance into the creek proper. No appreciable number of lampreys entered the trap until April 25 when the mean temperature of the creek water had risen six degrees above that in the bay (Tables 1 and 2, Figure 10). In view of these facts I believe that

Table 1. Daily minimum, maximum and mean water temperatures and water gauge readings for Carp Creek with air temperatures and wind and weather records for the locality: April 15-July 20, 1947.[1]

| Date 1947 | Time | Water temperature (Degrees F.) Minimum | Mean | Maximum | At visit | Water gauge[2] | Air temperature Time | Degree F. | Wind[3] Strength | Direction and shift | Weather |
|---|---|---|---|---|---|---|---|---|---|---|---|
| April 15 | 1700 | ... | ... | ... | ... | 11.50 | ... | ... | Light | NW | ... |
| 16 | 0900 | 38 | 38.5 | 39 | 38 | 13.00 | 1000 | 36 | " | " | ... |
| 17 | 0930 | 38 | 38.5 | 39 | 39 | 15.50 | 1000 | 40 | " | NW to W | ... |
| 18 | 0930 | 37 | 38.0 | 39 | 39 | 17.25 | 1000 | 41 | " | W to SW | Overcast |
| 19 | 0900 | 37 | 38.0 | 39 | 39 | ... | ... | ... | " | W | Clear |
| | 1600 | 38 | 41.0 | 44 | 42 | 18.25 | 1600 | 40 | " | W | ... |
| 20 | 1600 | 37 | 40.5 | 44 | 44 | 19.25 | 1700 | 45 | Strong | NE | Clear |
| 21 | 0900 | 36 | 39.0 | 42 | 41 | 19.50 | 0920 | 38 | " | NE to E | Overcast |
| 22 | 0900 | 40 | 40.5 | 41 | 41 | 20.50 | 0830 | 41 | Moderate | E to SE | " |
| 23 | 0830 | 40 | 40.0 | 40 | 40 | 18.00 | 0900 | 46 | Light | SE | Rain |
| 24 | 0930 | 39 | 40.5 | 42 | 42 | ... | 0900 | 50 | " | W | Clear |
| | 1600 | 42 | 45.5 | 52 | 52 | 18.00 | ... | ... | " | W | ... |
| 25 | 1630 | 45 | 48.5 | 52 | 52 | ... | 0900 | 42 | " | W | Overcast |
| 26 | 0900 | 44 | 48.0 | 52 | 45 | ... | 0900 | 42 | Moderate | NE to NW | Heavy rain |
| 27 | 1615 | 45 | 46.0 | 47 | 47 | ... | ... | ... | Strong | WNW | Clear, cold |
| 28 | 1600 | 44 | 46.5 | 49 | 49 | ... | 1600 | 60 | Moderate | SW | Clear, warmer |
| 29 | 0900 | 48 | 48.0 | 48 | 48 | ... | 0930 | 68 | Light | SW | Overcast |
| 30 | 0900 | 48 | 51.0 | 54 | 54 | ... | 0845 | 52 | Moderate | ENE | Rain, cold |
| May 1 | 0900 | 47 | 47.5 | 48 | 48 | ... | 0930 | 52 | Strong | ENE | Overcast, cold |
| 2 | 0930 | 45 | 46.0 | 47 | 45 | ... | ... | ... | Light | NE to E | Heavy rain |
| 3 | 0900 | 42 | 43.0 | 44 | 44 | ... | 0930 | 54 | Light | E to S | Overcast, cool |
| 4 | 0930 | 44 | 47.0 | 50 | 50 | ... | 0930 | 64 | " | E to S | Overcast, warmer |
| 5 | 0930 | 46 | 47.0 | 48 | 48 | ... | 0830 | 54 | " | W | Light rain |
| 6 | 0930 | 48 | 50.0 | 52 | 48 | ... | 1100 | 44 | Strong | NW | Snowflurries |
| 7 | 1030 | 46 | 49.0 | 52 | 46 | ... | 1145 | 44 | " | NW to NE | Overcast |
| 8 | 1030 | 38 | 46.0 | 54 | 40 | ... | 1130 | 30 | " | NE | Partly overcast |
| 9 | 1030 | 38 | 39.5 | 41 | 40 | 19.50 | 1045 | 41 | Moderate | SW | " " |
| 10 | 0930 | 41 | 44.5 | 48 | 44 | 18.00 | 1230 | 60 | Light | SW | " " |
| 11 | 1000 | 50 | 51.5 | 53 | 50 | 17.00 | 0815 | 50 | " | SW to S | " " |
| 12 | 0930 | 48 | 50.0 | 52 | 52 | 16.00 | 0845 | 67 | " | SW | Overcast, warm |
| 13 | 1000 | 49 | 51.0 | 53 | 52 | 16.00 | 0845 | 41 | " | ENE | Rain, cold |
| 14 | 0930 | 47 | 48.0 | 49 | 47 | 16.50 | 0900 | 49 | " | E | Clear, cold |
| 15 | 0930 | 48 | 50.0 | 52 | 52 | 16.50 | 0930 | 57 | " | E to W | Overcast, warmer |
| 16 | 1000 | 52 | 53.0 | 54 | 54 | 16.00 | 0930 | 58 | " | W | Partly overcast, warm |
| 17 | 1000 | 53 | 56.0 | 60 | 55 | 15.50 | 0945 | 65 | " | E | Overcast, warm |
| 18 | 1030 | 52 | 55.0 | 58 | 56 | 15.00 | 1000 | 63 | " | E | Clear, warm |
| 19 | 0915 | 59 | 60.5 | 62 | 61 | 14.75 | 0915 | 73 | " | SE | Overcast, very warm |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 16 | 1000 | 52 | 53.0 | 54 | 54 | 16.00 | 0930 | 58 | " | W | Partly overcast, warm |
| | 17 | 1000 | 53 | 56.0 | 60 | 55 | 15.50 | 0945 | 65 | " | E | Overcast, warm |
| | 18 | 1030 | 52 | 55.0 | 58 | 56 | 15.00 | 1000 | 63 | " | E | Clear, warm |
| | 19 | 0915 | 59 | 60.5 | 62 | 61 | 14.75 | 0915 | 73 | " | SE | Overcast, very warm |
| | 20 | 0930 | 54 | 59.0 | 64 | 56 | 15.50 | 0900 | 51 | " | E | Clear, cool |
| | 21 | 1000 | 54 | 59.0 | 64 | 54 | 15.00 | 0845 | 43 | Strong | E | Heavy, cold rain |
| | 22 | 1000 | 52 | 53.5 | 55 | 53 | 15.00 | 0915 | 50 | Moderate | E | Clear, cool |
| | 23 | 1030 | 54 | 54.5 | 55 | 55 | 15.50 | 0945 | 51 | Light | E | Overcast, cool |
| | 24 | 1030 | 53 | 55.0 | 57 | 56 | 15.50 | 0900 | 56 | " | E | Clear, warmer |
| | 25 | 1045 | 55 | 57.5 | 60 | 55 | 15.75 | 0930 | 55 | Moderate | E to SW | Rain |
| | 26 | 1045 | 54 | 56.0 | 58 | 56 | 16.75 | 1000 | 52 | Light | W | Rain squalls, cold |
| | 27 | 1100 | 50 | 53.0 | 56 | 50 | 16.50 | 0930 | 42 | " | E | Rain, cold |
| | 28 | 1030 | 47 | 48.5 | 50 | 47 | 16.75 | 1000 | 47 | " | ENE | Hail, rain, sleet |
| | 29 | 1130 | 46 | 47.0 | 48 | 46 | 19.00 | 1015 | 40 | Strong | SW | Rain, cold |
| | 30 | 1030 | 43 | 44.5 | 46 | 46 | 22.00 | 0915 | 50 | " | NW | Clear |
| | 31 | 0915 | 47 | 49.0 | 51 | 49 | 22.00 | 0915 | 53 | Light | W | Clear, warmer |
| June | 1 | 0945 | 52 | 54.0 | 56 | 56 | 21.50 | 0845 | 55 | Light | W | Partly overcast |
| | 2 | 1000 | 55 | 55.0 | 55 | 55 | 21.00 | 0945 | 47 | " | SE | Clear, warm |
| | 3 | 1030 | 55 | 56.5 | 58 | 56 | 18.00 | 0900 | 46 | " | E | Clear, cool |
| | 4 | 1045 | 57 | 58.5 | 60 | 58 | 16.50 | 0900 | 60 | " | E | Clear, warm |
| | 5 | 1030 | 57 | 57.5 | 58 | 58 | 16.00 | 0900 | 70 | " | SE | Clear, warmer |
| | 6 | 1030 | 58 | 60.0 | 62 | 61 | 16.00 | 1000 | 66 | " | E | Clear, warm |
| | 7 | 1100 | 62 | 66.0 | 70 | 62 | 15.50 | 0915 | 54 | " | SE | Overcast, cool |
| | 8 | 1100 | 62 | 64.5 | 67 | 62 | 14.75 | 0900 | 58 | " | E to W | Clear, warm |
| | 9 | 1000 | 63 | 66.0 | 69 | 65 | 14.00 | 1215 | 72 | " | ENE | " " |
| | 10 | 1030 | 68 | 70.0 | 72 | 72 | 13.75 | 0900 | 80 | " | SW to SE | Clear, hot |
| | 11 | 1000 | 68 | 72.0 | 76 | 68 | 13.25 | 1130 | 58 | " | W | Overcast, cool |
| | 12 | 1100 | 55 | 59.5 | 64 | 59 | 12.50 | 1015 | 56 | " | NW | Clear, cool |
| | 13 | 1100 | 59 | 60.5 | 62 | 59 | 12.50 | 1045 | 52 | " | E | Rain, cool |
| | 14 | 1045 | 54 | 56.5 | 59 | 57 | 13.25 | 1015 | 56 | " | E | Overcast, cool |
| | 15 | 1100 | 56 | 56.0 | 56 | 56 | 14.25 | 1115 | 53 | Moderate | E | Clear, warmer |
| | 16 | 1115 | 56 | 59.0 | 62 | 61 | 14.00 | 1030 | 56 | Light | NW | " " |
| | 17 | 1200 | 62 | 64.5 | 67 | 64 | 15.50 | 1145 | 59 | " | W to E | Clear, warm |
| | 18 | 1145 | 64 | 66.0 | 68 | 66 | 13.00 | 1145 | 62 | " | W | " " |
| | 19 | 1100 | 61 | 65.5 | 70 | 64 | 12.50 | 1030 | 64 | " | W | " " |
| | 20 | 1130 | 64 | 68.5 | 73 | 68 | 11.75 | 1115 | 68 | " | SE | " " |
| | 21 | 1015 | 64 | 69.0 | 74 | 66 | 11.25 | 0930 | 66 | " | E | " " |
| | 22 | 1045 | 63 | 68.0 | 73 | 66 | 10.50 | 1145 | 74 | " | E | " " |
| | 23 | 1100 | 65 | 68.0 | 71 | 68 | 10.25 | 1015 | 78 | " | SE | " " |
| | 24 | 1030 | 66 | 70.0 | 74 | 66 | 10.00 | 0930 | 62 | " | SE | Rain, warm |
| | 25 | 1445 | 66 | 70.0 | 74 | 74 | 10.00 | 1400 | 74 | " | SE | Clear |
| | 26 | 0945 | 68 | 71.0 | 74 | 68 | 9.50 | 0900 | 64 | " | SE | Clear |
| | 27 | 1000 | 71 | 72.5 | 74 | 71 | 9.25 | 0915 | 78 | " | E | Rain squalls |
| | 28 | 1045 | 70 | 72.5 | 75 | 70 | 10.00 | 0930 | 74 | " | E | Clear |
| | 29 | 0945 | 72 | 73.0 | 74 | 72 | 10.00 | 0930 | 70 | Moderate | E | Light rain |
| | 30 | 1030 | Max.-min. thermometer broken | | | 65 | 10.50 | 0945 | 66 | Light | W | Clear, cooler |
| July | 1 | 0930 | ... | ... | ... | 67 | 10.50 | 0900 | 56 | Light | W to NW | Overcast, cold |
| | 2 | 1030 | ... | ... | ... | 64 | 10.00 | 1100 | 70 | " | NW | Clear, cool |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 1045 | 54 | 56.5 | 59 | 57 | 13.25 | 1015 | 56 | " | E | Overcast, cool |
| | 15 | 1100 | 56 | 56.0 | 56 | 56 | 14.25 | 1115 | 53 | Moderate | E | Clear, warmer |
| | 16 | 1115 | 56 | 59.0 | 62 | 61 | 14.00 | 1030 | 56 | Light | NW | " " |
| | 17 | 1200 | 62 | 64.5 | 67 | 64 | 15.50 | 1145 | 59 | " | W to E | Clear, warm |
| | 18 | 1145 | 64 | 66.0 | 68 | 66 | 13.00 | 1145 | 62 | " | W | " " |
| | 19 | 1100 | 61 | 65.5 | 70 | 64 | 12.50 | 1030 | 64 | " | W | " " |
| | 20 | 1130 | 64 | 68.5 | 73 | 68 | 11.75 | 1115 | 68 | " | SE | " " |
| | 21 | 1015 | 64 | 69.0 | 74 | 66 | 11.25 | 0930 | 66 | " | E | " " |
| | 22 | 1045 | 63 | 68.0 | 73 | 66 | 10.50 | 1145 | 74 | " | E | " " |
| | 23 | 1100 | 65 | 68.0 | 71 | 68 | 10.25 | 1015 | 78 | " | SE | " " |
| | 24 | 1030 | 66 | 70.0 | 74 | 66 | 10.00 | 0930 | 62 | " | SE | Rain, warm |
| | 25 | 1445 | 66 | 70.0 | 74 | 74 | 10.00 | 1400 | 74 | " | SE | Clear |
| | 26 | 0945 | 68 | 71.0 | 74 | 68 | 9.50 | 0900 | 64 | " | SE | Clear |
| | 27 | 1000 | 71 | 72.5 | 74 | 71 | 9.25 | 0915 | 78 | " | E | Rain squalls |
| | 28 | 1045 | 70 | 72.5 | 75 | 70 | 10.00 | 0930 | 74 | " | E | Clear |
| | 29 | 0945 | 72 | 73.0 | 74 | 72 | 10.00 | 0930 | 70 | Moderate | E | Light rain |
| | 30 | 1030 | Max.-min. | thermometer | broken | 65 | 10.50 | 0945 | 66 | Light | W | Clear, cooler |
| July | 1 | 0930 | ... | ... | ... | 67 | 10.50 | 0900 | 56 | Light | W to NW | Overcast, cold |
| | 2 | 1030 | ... | ... | ... | 64 | 10.00 | 1100 | 70 | " | NW | Clear, cool |
| | 3 | 1000 | ... | ... | ... | 65 | 9.75 | 1030 | 74 | " | W | Clear, warmer |
| | 4 | 1100 | ... | ... | ... | 70 | 9.25 | 1000 | 76 | " | W to SE | Clear, hot |
| | 5 | 1000 | ... | ... | ... | 70 | 9.00 | 0930 | 68 | " | E | Rain squalls |
| | 6 | 0915 | ... | ... | ... | 67 | 9.00 | 0945 | 62 | " | E | Clear |
| | 7 | 0945 | ... | ... | ... | 66 | 8.75 | 1030 | 70 | Light | NW | Clear |
| | 8 | 1215 | ... | ... | ... | 72 | 8.25 | 0930 | 70 | " | NW | " |
| | 9 | 0945 | ... | ... | ... | 68 | 8.25 | 1000 | 72 | " | NW | " |
| | 10 | 1030 | ... | ... | ... | 70 | 7.25 | 1000 | 72 | Moderate | ESE | " |
| | 11 | 1200 | ... | ... | ... | 72 | 7.25 | 1100 | 74 | Light | E to NW | " |
| | 12 | 1000 | ... | ... | ... | 66 | 6.25 | 1015 | 70 | " | NW | Overcast |
| | 13 | 1630 | ... | ... | ... | 73 | 5.50 | 1330 | 82 | " | NE | Clear, hot |
| | 14 | ... | ... | ... | ... | ... | ... | ... | ... | " | E | Overcast, rain |
| | 15 | 1030 | ... | ... | ... | 69 | 5.75 | 1145 | 70 | " | E | Rain, clearing |
| | 16 | 0930 | ... | ... | ... | 66 | 5.75 | 1000 | 72 | " | ESE | Clear, hot |
| | 17 | 1000 | ... | ... | ... | 68 | 5.75 | 1145 | 82 | " | E to S | " " |
| | 18 | 1030 | ... | ... | ... | 70 | 5.50 | 1100 | 74 | Moderate | WNW | Clear, cool |
| | 19 | 0930 | ... | ... | ... | 63 | 5.50 | 0845 | 59 | Light | NW | " " |
| | 20 | 1800 | ... | ... | ... | 62 | 5.50 | 1200 | 71 | " | NW | Rain |

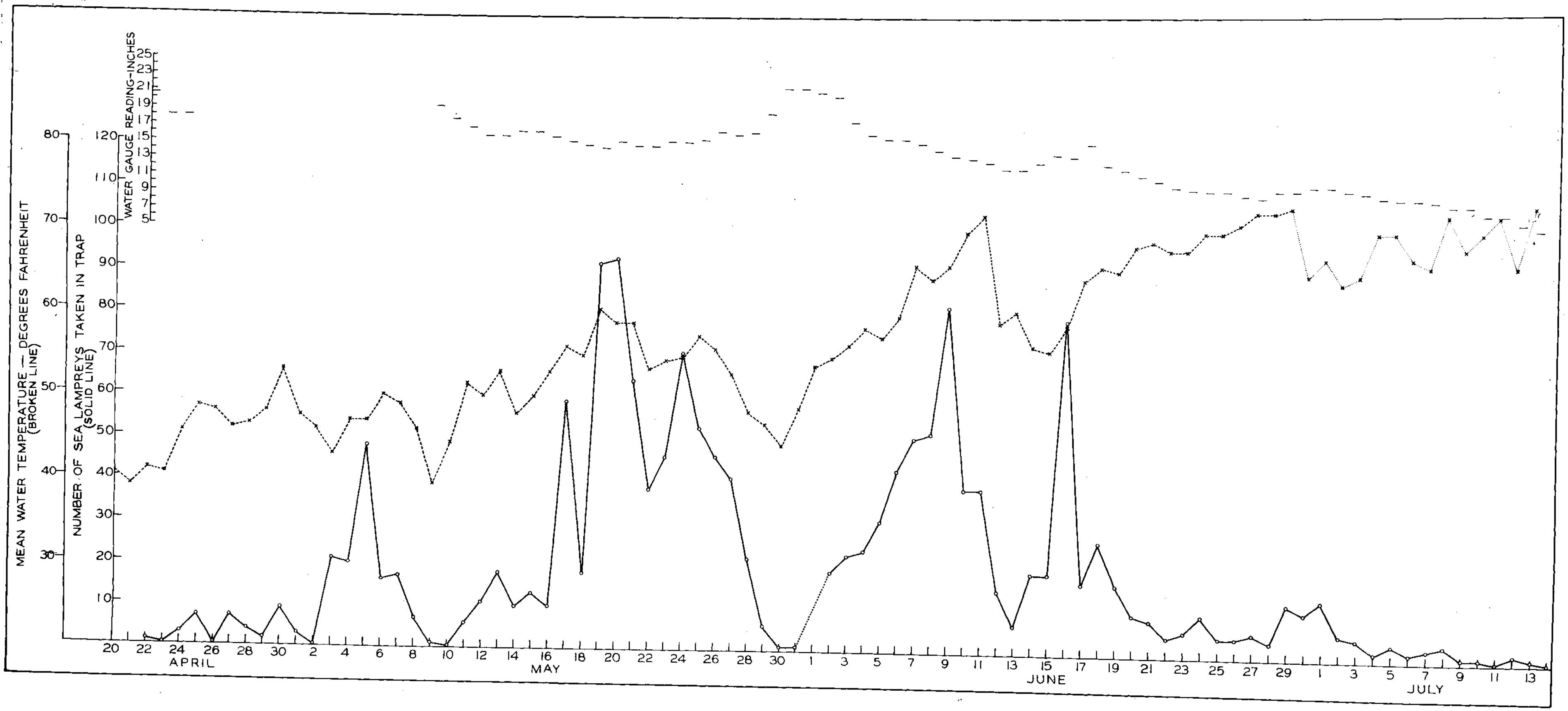
1/ Water temperatures taken at station just above weir.
2/ Water gauge readings are in inches and represent absolute depth in midstream just below weir.
3/ Wind records supplemented by records of Mr. G. W. Hanson, U.S.C.G., 40 Mile Point Light Station, Lake Huron.

Table 2. Water temperatures in Hammond Bay and in the mouth of Carp Creek: April 25-June 27, 1947.

| Date 1947 | Mouth of Carp Creek[1] Time | Mouth of Carp Creek[1] Water temperature (Degrees F.) | Hammond Bay[2] Time | Hammond Bay[2] Water temperature (Degrees F.) |
|---|---|---|---|---|
| April 25 | ... | ... | 1600 | 42.5 |
| May 5 | 1100 | 48.0 | 1115 | 48.0 |
| May 14 | 1200 | 48.0 | 1130 | 48.0 |
| May 19 | 1130 | 63.0 | 1135 | 54.0 |
| May 22 | 1015 | 53.0 | 1020 | 52.0 |
| May 28 | 1700 | 50.0 | 1705 | 49.0 |
| May 30 | 1100 | 46.0 | 1110 | 48.0 |
| June 4 | 1615 | 59.0 | 1630 | 51.0 |
| June 11 | 1120 | 68.0 | 1130 | 52.0 |
| June 19 | 1100 | 66.0 | 1050 | 62.0 |
| June 27 | 1030 | 72.0 | 1035 | 60.0 |

1/ Temperature station where creek water enters zone of wave action.
2/ Temperatures taken six inches below surface outside the zone of wave action. Stations variable but usually 300 to 500 feet north or south of creek mouth and always beyond the possible influence of the discharge from Carp Creek.

Figure 10. Number of sea lampreys taken each day in the Carp Creek weir between April 22 and July 13, 1947, and the mean water temperature and water gauge readings for this period.



MEAN WATER TEMPERATURE — DEGREES FAHRENHEIT (BROKEN LINE)
NUMBER OF SEA LAMPREYS TAKEN IN TRAP (SOLID LINE)
WATER GAUGE READING-INCHES
APRIL
MAY
JUNE
JULY

the upstream migration of the sea lampreys entering Carp Creek began not earlier than April 19 and obviously not later than April 21.

From April 23 to May 2 upstream migrants entered the trap sporadically, the daily catch varying from none to seven individuals (Table 2 and Figure 10). The bulk of the migration as reflected in the trap catches occurred between May 2 and June 21. Of 1,617 individuals taken during the entire operation of the weir, 1,471 or 91.0 percent of the total captures were taken during this 50-day period. There was no single peak of greatest migratory activity. Instead, during the period May 3 to June 21, four pronounced peaks occurred, of which those on May 20 and June 9 are the most significant (Figure 10). On May 20, 93 sea lampreys and on June 9, 82 sea lampreys were removed from the trap. These two peaks were separated by a sharp decline in migratory activity which reached a minimum between May 29 and May 31 when the run virtually ceased. This decline was apparently induced by a severe drop in water temperatures resulting from sleet, hail and cold rain storms which began on May 26 and lasted for four days. Had this unseasonably cold weather not arrived with its resultant effect upon the creek water temperatures, I believe a single major influx of upstream migrants would have occurred between May 15 and June 7.

From June 22 on, a small and generally declining number of sea lampreys entered the trap each day until July 13 when the last migrant, a male, was taken. The weir and trap were inspected regularly until August 1 but no additional sea lampreys were captured.

(3) <u>Factors affecting the run</u>:--Field observations and an examination of the data collected indicate a very close relationship

between water temperature and the amount of sea lamprey migratory activity. Figure 10 was prepared primarily to show the relationship between the numbers of lampreys taken in the trap and the water temperature of the creek. Mean daily water temperatures during the period of weir operation varied from 39.0° F. to 73.0° F. Due to the small size of the creek and the extremely shallow character of its source, Carp Lake, these temperatures fluctuated considerably, reflecting closely even moderate changes in the weather. Between April 21 and June 18, virtually every consistent rise and fall in water temperatures was accompanied by an increase or decrease in the number of lampreys taken in the trap. However, the response in migratory activity was not always proportional to the amount of change in water temperature which suggests that some other environmental factor or factors may have some influence upon the run.

From April 21 until May 15, water temperatures were predominantly below 50° F. and the run during that period was, on the average, light. It is interesting to note that at mean temperature levels of 41° F. or lower, virtually no migratory activity occurred (April 21 to 23 and May 9). On May 16 the mean daily water temperature rose above 50° F. and, except for the period May 28 to 31, remained well above that temperature for the balance of the run. Concurrently, the greatest migratory activity began. The most pronounced interruption in the run occurred during the period May 28 to 31 when the mean water temperatures fell to a low of 44.5° F. These data agree with the observations of Shetter (1948?) for the 1945 sea lamprey run in the Ocqueoc River for which he noted that the greatest migratory activity occurred at water temperatures of 51° F. or higher.

It should be noted that the erratic character of the sea lamprey run in Carp Creek is probably peculiar to most small sea lamprey spawning streams where temperatures respond rapidly to climatic changes. Data presented by Shetter for the Ocqueoc River run in 1945 and that collected by the writer in 1947 for the same stream, indicate that in a larger stream with more stable temperatures, the sea lamprey run has a correspondingly more continuous character.

Certain inexplicable declines in the number of migrants entering the trap were not always preceded or accompanied by a proportionately rapid drop in water temperature or occurred on a slightly rising or stable temperature. I believe that this is related to the effect of certain onshore winds upon the water discharged from the creek into Hammond Bay. Carp Creek flows almost due east into Hammond Bay. We observed on numerous occasions that moderate to strong NE to SE winds tended to deflect the entire discharge from the creek into the zone of wave action along the Hammond Bay shore. The creek water was always identifiable until thoroughly diffused into that of the bay by its distinctive brown color and usually higher temperatures. On such occasions we could ordinarily wade to a point beyond the band of deflected creek water and seldom be standing at a depth greater than two feet.

I presume that sexually mature sea lampreys when seeking a tributary stream in which to spawn are attracted into that stream, possibly among other things, by a strong positive rheotropic response and/or a reaction to the higher temperature of the creek's discharge. If either or both of these responses exist, then conditions which deflect the creek's discharge into a narrow, shallow band in the zone of wave action would materially reduce the chances of a sea lamprey finding that stream as it moves along the lake shoreline. Erratic declines in migratory activity that are not satisfactorily explained by water temperature variations occurred on April 26 and 28, May 4, 6, 16, 18, and 22, and June 13 and 17 (Figure 10). In almost every case these can be associated with periods of easterly, onshore winds.

I do not believe that comparable onshore winds would have any appreciable effect upon larger streams such as the Ocqueoc River. It would take a gale of storm proportions to deflect similarly the discharge from such a stream under most conditions.

No correlation exists between stream volume as reflected by depth gauge readings and the sea lamprey run except in so far as rapidly rising water levels (resulting from cold rains or melting snow) were generally accompanied by declining water temperatures (Figure 10).

Observations on turbidity and routine oxygen and carbon dioxide determinations of the creek water showed no significant relationship of these properties to the run. It would seem that the amount of turbidity and the chemical quality of the water have little or no relation to the incidence or magnitude of Great Lakes sea lamprey runs. For example, observations on the Manistique River and at the paper mill on that river revealed that sea lampreys entered channels in the estuary which carried a very heavy suspension of woodpulp waste. Furthermore, upon reaching the paper mill on the river, large numbers of them entered a pipe discharging the combined hot pond and plant sewage wastes and traversed this pipe to reach a small seepage channel above the mill. (This latter condition can no longer occur due to alterations in the level of the waste pipe made early in 1947).

(4) Time of migration during the day:--It has been previously observed, that the greatest upstream movement of sea lampreys occurs during the hours of darkness. Of 1,521 sea lampreys taken in Carp Creek between April 24 and June 21, 1,492 or 98.1 percent entered the trap between 6:00 P. M. and 8:00 A. M. the following day. Only 29 or 1.9 percent were taken during the hours of full daylight. Of those migrating between 6:00 P. M. and 8:00 A. M., 578 or 38.0 percent entered the trap between 6:00 and 12:00 P. M. while 914 or 60.1 percent were taken between that latter hour and 8:00 A. M. This agrees generally with Shetter's data on the Ocqueoc River for which he noted that 55 percent of the run occurred between the hours of midnight and 6:00 A. M.

A slight, and probably not significant, difference was displayed in the time of migration of the two sexes. Of 941 males taken between the aforementioned dates, 19 or 1.0 percent entered the trap during full daylight (prior to 6:00 P. M.), 339 or 36.0 percent between 6:00 and 12:00 P. M., and 583 or 63.0 percent between midnight and 8:00 A. M. Of 580 females, 10 or 1.7 percent entered the trap prior to 6:00 P. M., 239 or 41.2 percent between 6:00 and 12:00 P. M., and 331 or 57.1 percent between midnight and 8:00 A. M. The small difference displayed might be interpreted to mean that the females generally begin their upstream movement each night at an earlier hour than do the males.

Significant changes did occur in the daily time of migration during the course of the run. Until May 29, no sea lampreys entered the trap except during the hours of full darkness. Furthermore, during this same period, the bulk of the upstream movement occurred between the hours of midnight and 8:00 A. M. Following this date, sea lampreys began to appear in the trap during the daylight hours and an increasing number entered during the earlier hours of the evening. If we break down the data for the period April 24 to June 21 into two arbitrary periods we find that the following occurred: Of 898 sea lampreys taken in the trap between April 24 and May 31, only 1 or 0.1 percent entered during the hours of full daylight (prior to 6:00 P. M.), 265 or 29.5 percent between 6:00 and 12:00 P. M., and 632 or 70.4 percent between the latter hour and 8:00 A. M. Between June 1 and June 21, 623 sea lampreys were trapped. Of these, 28 or 4.5 percent moved into the trap during daylight hours (prior to 6:00 P. M.), 313 or 50.2 percent entered between 6:00 and 12:00 P. M., and 282 or 45.3 percent entered between midnight and 8:00 A. M.

Field observations during 1947 revealed that at the beginning of the spawning run sea lampreys display a very strong negative response to light--which becomes less and less pronounced among later arrivals as the season progresses. These data from the Carp Creek weir confirm these observations. They do not agree closely with the observations of Shetter (1948?) for the Ocqueoc River run where he found a somewhat greater proportion of migrants moving during the hours of daylight. In view of the generally negative response of upstream migrants to light, I believe the differences in our data may be attributed to the very shallow and more exposed character of Carp Creek in its course upstream between the bay and the weir.

(5) <u>Length, weight and sex ratio</u>:--Of the 1,617 sea lampreys taken in the Carp Creek weir, length, weight and sex data were obtained from 1,600 specimens. Of these 1,600 sea lampreys, 997 or 62.3 percent

were males and 603 or 37.7 percent were females. This is a ratio of 165 males:100 females.

Male sea lampreys varied from 13.0 to 22.4 inches in total length (330 to 569 mm.) and from 59 grams (2.1 ounces) to 400 grams (14.1 ounces) in weight. The average total length of 997 males was 17.4 inches (442 mm.) and the average weight was 181.6 grams (6.4 ounces).

Female sea lampreys varied from 12.0 to 22.6 inches in total length (305 to 575 mm.) and from 61 grams (2.1 ounces) to 436 grams (15.4 ounces) in weight. The average total length of 603 females was 17.4 inches (442 mm.) and the average weight was 186.6 grams (6.6 ounces).

No gross sexual dimorphism in length is evident in these figures.

Table 3 has been prepared primarily to show the relative average length (and weight) of males and females and the sex ratio from day to day throughout the course of the run. Cumulative averages by 5-day periods are also presented. The picturesque spawning run characteristics ascribed to this species wherein the males predominate among early migrants and females among the late ones (with the peak of the run about evenly divided) are only vaguely evident in the Carp Creek run. The cumulative 5-day totals of migrants entering the trap display a one and one-half to one ratio between males and females quite generally throughout the entire season. The only suggestion of the aforementioned phenomena occurred between May 1 and 10 when the ratio of males to females was about 2:1. At the termination of the run, between July 1 and 13, the males suddenly began to outnumber the females by a ratio of almost 3:1.

The largest specimens of both sexes were taken at the beginning of the run and for both males and females, the average total length

Table 3. Number and average length and weight by sexes and total sea lampreys taken in the Carp Creek weir by dates and by cumulative periods.

| Date 1947 | Males: Number taken | Males: Average length in inches | Males: Average length in milli-meters | Males: Average weight in grams | Females: Number taken | Females: Average length in inches | Females: Average length in milli-meters | Females: Average weight in grams | Number taken with no data recorded | Total ♂♂ and ♀♀ taken |
|---|---|---|---|---|---|---|---|---|---|---|
| April 22 | 0 | ... | ... | ... | 0 | ... | ... | ... | 1 | 1 |
| 23 | 0 | ... | ... | ... | 0 | ... | ... | ... | 0 | 0 |
| 24 | 1 | 17.6 | 447 | 202 | 1 | 18.5 | 470 | 285 | 1 | 3 |
| 25 | 3 | 17.6 | 447 | 182 | 4 | 18.1 | 460 | 165 | 0 | 7 |
| April 22-25 | 4 | 17.6 | 447 | 187 | 5 | 18.2 | 462 | 189 | 2 | 11 |
| April 26 | 0 | ... | ... | ... | 0 | ... | ... | ... | 0 | 0 |
| 27 | 3 | 17.3 | 439 | 160 | 4 | 17.7 | 450 | 191 | 0 | 7 |
| 28 | 2 | 17.3 | 439 | 171 | 2 | 17.5 | 445 | 184 | 0 | 4 |
| 29 | 0 | ... | ... | ... | 2 | 17.5 | 445 | 168 | 0 | 2 |
| 30 | 6 | 17.1 | 434 | 175 | 3 | 17.0 | 432 | 173 | 0 | 9 |
| April 26-30 | 11 | 17.2 | 437 | 170 | 11 | 17.4 | 442 | 180 | 0 | 22 |
| May 1 | 2 | 17.7 | 450 | 195 | 1 | 17.3 | 439 | 155 | 0 | 3 |
| 2 | 0 | ... | ... | ... | 0 | ... | ... | ... | 0 | 0 |
| 3 | 15 | 18.0 | 457 | 178 | 6 | 18.5 | 470 | 206 | 0 | 21 |
| 4 | 12 | 17.6 | 447 | 179 | 8 | 18.2 | 462 | 187 | 0 | 20 |
| 5 | 36 | 18.1 | 460 | 194 | 12 | 18.5 | 470 | 208 | 0 | 48 |
| May 1-5 | 65 | 17.9 | 455 | 187 | 27 | 18.3 | 465 | 199 | 0 | 92 |
| May 6 | 12 | 17.4 | 442 | 153 | 4 | 17.7 | 450 | 172 | 0 | 16 |
| 7 | 12 | 17.6 | 447 | 163 | 5 | 17.8 | 452 | 179 | 0 | 17 |
| 8 | 5 | 17.4 | 442 | 158 | 2 | 18.5 | 470 | 215 | 0 | 7 |
| 9 | 1 | 20.3 | 516 | 239 | 0 | ... | ... | ... | 0 | 1 |
| 10 | 0 | ... | ... | ... | 0 | ... | ... | ... | 0 | 0 |
| May 6-10 | 30 | 17.6 | 447 | 161 | 11 | 17.9 | 455 | 183 | 0 | 41 |
| May 11 | 6 | 18.6 | 472 | 226 | 0 | ... | ... | ... | 0 | 6 |
| 12 | 5 | 17.3 | 439 | 181 | 6 | 17.8 | 452 | 194 | 0 | 11 |
| 13 | 11 | 16.9 | 429 | 180 | 7 | 16.9 | 429 | 189 | 0 | 18 |
| 14 | 7 | 18.2 | 462 | 191 | 3 | 18.3 | 465 | 208 | 0 | 10 |
| 15 | 6 | 17.6 | 447 | 179 | 5 | 16.2 | 411 | 133 | 2 | 13 |
| May 11-15 | 35 | 17.6 | 447 | 190 | 21 | 17.2 | 437 | 180 | 2 | 58 |
| May 16 | 2 | 16.3 | 414 | 121 | 5 | 16.9 | 429 | 183 | 3 | 10 |

2

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 7 | [illegible] | [illegible] | 191 | [illegible] | [illegible] | [illegible] | 200 | [illegible] | [illegible] |
| 15 | 6 | 17.6 | 447 | 179 | 5 | 16.2 | 411 | 133 | 2 | 13 |
| May 11-15 | 35 | 17.6 | 447 | 190 | 21 | 17.2 | 437 | 180 | 2 | 58 |
| May 16 | 2 | 16.3 | 414 | 121 | 5 | 16.9 | 429 | 183 | 3 | 10 |
| 17 | 33 | 17.6 | 447 | 186 | 26 | 18.0 | 457 | 210 | 0 | 59 |
| 18 | 9 | 17.8 | 452 | 175 | 9 | 17.0 | 432 | 181 | 0 | 18 |
| 19 | 55 | 17.7 | 450 | 192 | 37 | 18.1 | 460 | 211 | 0 | 92 |
| 20 | 57 | 17.6 | 447 | 185 | 31 | 18.1 | 460 | 198 | 5 | 93 |
| May 15-20 | 156 | 17.6 | 447 | 186 | 108 | 17.9 | 455 | 203 | 8 | 272 |
| May 21 | 38 | 17.6 | 447 | 190 | 26 | 17.8 | 452 | 208 | 0 | 64 |
| 22 | 28 | 17.5 | 445 | 173 | 10 | 17.6 | 447 | 193 | 0 | 38 |
| 23 | 32 | 17.8 | 452 | 184 | 14 | 17.5 | 445 | 177 | 0 | 46 |
| 24 | 40 | 17.7 | 450 | 188 | 26 | 17.0 | 432 | 177 | 5 | 71 |
| 25 | 40 | 17.5 | 445 | 179 | 13 | 17.4 | 442 | 185 | 0 | 53 |
| May 21-25 | 178 | 17.6 | 447 | 183 | 89 | 17.5 | 445 | 189 | 5 | 272 |
| May 26 | 33 | 18.0 | 457 | 197 | 13 | 17.6 | 447 | 182 | 0 | 46 |
| 27 | 30 | 17.3 | 439 | 177 | 11 | 17.3 | 439 | 181 | 0 | 41 |
| 28 | 12 | 17.6 | 447 | 168 | 10 | 18.5 | 470 | 196 | 0 | 22 |
| 29 | 4 | 18.9 | 480 | 206 | 2 | 17.0 | 432 | 172 | 0 | 6 |
| 30 | 0 | ... | ... | ... | 1 | 17.6 | 447 | 198 | 0 | 1 |
| May 26-30 | 79 | 17.7 | 450 | 186 | 37 | 17.7 | 450 | 186 | 0 | 116 |
| May 31 | 1 | 18.6 | 472 | 240 | 0 | ... | ... | ... | 0 | 1 |
| June 1 | | | | (Weir inoperative) | | | | | | ... |
| 2 | 12 | 17.2 | 437 | 173 | 7 | 18.0 | 457 | 198 | 0 | 19 |
| 3 | 11 | 17.4 | 442 | 182 | 12 | 17.3 | 439 | 197 | 0 | 23 |
| 4 | 15 | 16.6 | 422 | 171 | 9 | 16.9 | 429 | 177 | 0 | 24 |
| 5 | 18 | 17.7 | 450 | 178 | 13 | 18.0 | 457 | 210 | 0 | 31 |
| May 31-June 5 | 57 | 17.3 | 439 | 177 | 41 | 17.6 | 447 | 197 | 0 | 98 |
| June 6 | 27 | 17.5 | 445 | 195 | 16 | 17.2 | 437 | 189 | 0 | 43 |
| 7 | 27 | 16.9 | 429 | 176 | 24 | 17.5 | 445 | 193 | 0 | 51 |
| 8 | 31 | 16.7 | 424 | 172 | 21 | 17.1 | 434 | 178 | 0 | 52 |
| 9 | 43 | 17.2 | 437 | 183 | 39 | 17.0 | 432 | 178 | 0 | 82 |
| 10 | 28 | 17.5 | 445 | 200 | 11 | 17.4 | 442 | 186 | 0 | 39 |
| June 6-10 | 156 | 17.2 | 437 | 185 | 111 | 17.2 | 437 | 184 | 0 | 267 |
| June 11 | 22 | 17.0 | 432 | 188 | 17 | 16.9 | 429 | 191 | 0 | 39 |
| 12 | 9 | 17.7 | 450 | 195 | 6 | 17.3 | 439 | 188 | 0 | 15 |
| 13 | 6 | 18.3 | 465 | 215 | 1 | 16.0 | 406 | 150 | 0 | 7 |
| 14 | 12 | 16.8 | 427 | 153 | 7 | 16.8 | 427 | 147 | 0 | 19 |
| 15 | 9 | 17.0 | 432 | 162 | 10 | 16.9 | 429 | 160 | 0 | 19 |
| June 11-15 | 58 | 17.2 | 437 | 180 | 41 | 16.9 | 429 | 172 | 0 | 99 |
| June 16 | 47 | 16.9 | 429 | 175 | 32 | 16.9 | 429 | 172 | 0 | 79 |
| 17 | 11 | 17.1 | 434 | 159 | 6 | 16.9 | 429 | 171 | 0 | 17 |

3

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 9 | 17.0 | 432 | 162 | 10 | 16.9 | 429 | 166 | 0 | 19 |
| June 11-15 | 58 | 17.2 | 437 | 180 | 41 | 16.9 | 429 | 172 | 0 | 99 |
| June 16 | 47 | 16.9 | 429 | 175 | 32 | 16.9 | 429 | 172 | 0 | 79 |
| 17 | 11 | 17.1 | 434 | 159 | 6 | 16.9 | 429 | 171 | 0 | 17 |
| 18 | 12 | 16.5 | 419 | 155 | 15 | 16.3 | 414 | 157 | 0 | 27 |
| 19 | 11 | 16.4 | 417 | 167 | 6 | 15.9 | 404 | 158 | 0 | 17 |
| 20 | 7 | 17.3 | 439 | 190 | 3 | 17.4 | 442 | 195 | 0 | 10 |
| June 16-20 | 88 | 16.8 | 427 | 171 | 62 | 16.8 | 427 | 168 | 0 | 150 |
| June 21 | 4 | 17.7 | 450 | 201 | 5 | 17.6 | 447 | 188 | 0 | 9 |
| 22 | 3 | 16.8 | 427 | 168 | 2 | 16.2 | 411 | 154 | 0 | 5 |
| 23 | 4 | 17.6 | 447 | 196 | 2 | 18.3 | 465 | 209 | 0 | 6 |
| 24 | 8 | 17.7 | 450 | 188 | 2 | 16.4 | 417 | 202 | 0 | 10 |
| 25 | 3 | 17.3 | 439 | 175 | 2 | 16.6 | 422 | 148 | 0 | 5 |
| June 21-25 | 22 | 17.5 | 445 | 187 | 13 | 17.1 | 434 | 182 | 0 | 35 |
| June 26 | 1 | 18.9 | 480 | 264 | 4 | 16.6 | 422 | 166 | 0 | 5 |
| 27 | 4 | 16.5 | 419 | 148 | 2 | 15.3 | 389 | 115 | 0 | 6 |
| 28 | 4 | 17.1 | 434 | 150 | 0 | ... | ... | ... | 0 | 4 |
| 29 | 8 | 16.8 | 427 | 147 | 5 | 16.2 | 411 | 163 | 0 | 13 |
| 30 | 8 | 17.3 | 439 | 181 | 3 | 17.0 | 432 | 148 | 0 | 11 |
| June 26-30 | 25 | 17.0 | 432 | 163 | 14 | 16.4 | 417 | 154 | 0 | 39 |
| July 1 | 12 | 17.5 | 445 | 181 | 2 | 16.1 | 409 | 153 | 0 | 14 |
| 2 | 4 | 17.2 | 437 | 177 | 2 | 17.3 | 439 | 179 | 0 | 6 |
| 3 | 3 | 16.2 | 412 | 164 | 2 | 18.0 | 457 | 259 | 0 | 5 |
| 4 | 0 | ... | ... | ... | 2 | 15.3 | 389 | 116 | 0 | 2 |
| 5 | 3 | 16.0 | 406 | 143 | 1 | 14.8 | 376 | 118 | 0 | 4 |
| July 1-5 | 22 | 17.1 | 434 | 173 | 9 | 16.4 | 417 | 170 | 0 | 31 |
| July 6 | 1 | 15.6 | 396 | 142 | 1 | 15.6 | 396 | 142 | 0 | 2 |
| 7 | 3 | 16.7 | 424 | 151 | 0 | ... | ... | ... | 0 | 3 |
| 8 | 2 | 17.2 | 437 | 170 | 2 | 19.2 | 488 | 255 | 0 | 4 |
| 9 | 1 | 18.9 | 480 | 260 | 0 | ... | ... | ... | 0 | 1 |
| 10 | 1 | 16.8 | 427 | 196 | 0 | ... | ... | ... | 0 | 1 |
| July 6-10 | 8 | 17.0 | 432 | 174 | 3 | 17.9 | 455 | 217 | 0 | 11 |
| July 11 | 0 | ... | ... | ... | 0 | ... | ... | ... | 0 | 0 |
| 12 | 2 | 17.8 | 452 | 205 | 0 | ... | ... | ... | 0 | 2 |
| 13 | 1 | 17.0 | 432 | ... | 0 | ... | ... | ... | 0 | 1 |
| | | (No sea lampreys entered the trap after July 13) | | | | | | | | |
| July 11-13 | 3 | 17.5 | 445 | (2)205 | 0 | ... | ... | ... | 0 | 3 |
| Totals and Grand Averages | 997 | 17.4 | 442 | 181.6 | 603 | 17.4 | 442 | 186.6 | 17 | 1,617 |

gradually decreased almost regularly during the course of the run. This was more pronounced among the females than among the males. Periodic averages of the total lengths of females taken during the first half of the run varied from 17.4 to 18.3 inches (Table 3). Thereafter, these averages declined to a low of 16.4 inches toward the end of the run. Comparable averages of total length among the males were generally more consistent. The dominant periodic average of total length of males during the first half of the run was 17.6 inches. This declined, as among the females, in the latter half of the season to values ranging very close to 17.0 inches. This decline in size may be attributed to an earlier attainment of sexual maturity among larger specimens than among the smaller ones.

## Other species of fishes taken in the weir and trap

(1) Kinds and numbers:--In addition to the sea lampreys taken in the Carp Creek weir, 9,585 individuals of 18 other species of fish and one other species of lamprey were taken as they migrated upstream (Tables 4 and 5). The species of fish taken were as follows (total number taken appears after each species' name): White sucker (*Catostomus c. commersonnii*), 3,548; Northern redhorse suckers (*Moxostoma aureolum*), 152; Rainbow trout (*Salmo gairdnerii*), 17; Brown trout (*Salmo trutta fario*), 1; Brook trout (*Salvelinus f. fontinalis*), 1; Smelt (*Osmerus m. mordax*), 538; Lake chubs (*Couesius plumbeus*), 4,147; Rock bass (*Ambloplites r. rupestris*), 104; Northern pike (*Esox lucius*), 5; Black bullheads (*Ameiurus m. melas*), 89; Common shiners (*Notropis cornutus frontalis*), 138; Great Lakes longnose dace (*Rhinichthys c. cataractae*), 804; Finescale dace (*Pfrille neogaea*), 29; Creek chubs (*Semotilus a. atromaculatus*), 1; Mudminnows (*Umbra limi*), 1;

Table 4. Upstream and downstream migration of white suckers and redhorse suckers taken in the Carp Creek weir: April 25-July 11, 1947.

| Date 1947 | Mean water temperature (Degrees F.) | Upstream migration: White suckers | Upstream migration: Redhorse suckers | Upstream migration: Number bearing lamprey scars[1] | Downstream migration: White suckers and redhorse suckers[2] |
|---|---|---|---|---|---|
| April 25 | 48.5 | 1 | 3 | ... | ... |
| 26 | 48.0 | 2 | 1 | ... | ... |
| 27 | 46.0 | ... | 1 | ... | ... |
| 28 | 46.5 | ... | ... | ... | ... |
| 29 | 48.0 | 5 | ... | ... | ... |
| 30 | 51.0 | ... | ... | ... | ... |
| May 1 | 47.5 | 2 | ... | ... | ... |
| 2 | 46.0 | 4 | ... | ... | ... |
| 3 | 43.0 | ... | ... | ... | ... |
| 4 | 47.0 | ... | ... | ... | ... |
| 5 | 47.0 | 1 | ... | ... | ... |
| 6 | 50.0 | ... | ... | ... | ... |
| 7 | 49.0 | 3 | ... | ... | ... |
| 8 | 46.0 | ... | ... | ... | ... |
| 9 | 39.5 | ... | ... | ... | ... |
| 10 | 44.5 | ... | ... | ... | ... |
| 11 | 51.5 | ... | ... | ... | ... |
| 12 | 50.0 | ... | ... | ... | ... |
| 13 | 51.0 | 10 | ... | ... | ... |
| 14 | 48.0 | 1 | ... | 1 | ... |
| 15 | 50.0 | 5 | ... | ... | ... |
| 16 | 53.0 | 51 | 47 | 3 | ... |
| 17 | 56.0 | 62 | 55 | 5 | ... |
| 18 | 55.0 | 73 | 4 | 2 | ... |
| 19 | 60.5 | 119 | 11 | 5 | ... |
| 20 | 59.0 | 37 | ... | 1 | ... |
| 21 | 59.0 | 52 | ... | 3 | ... |
| 22 | 53.5 | 75 | 6 | 5 | ... |
| 23 | 54.5 | 159 | 4 | 10 | ... |
| 24 | 55.0 | 170 | 2 | 8 | ... |
| 25 | 57.5 | 206 | 2 | 12 | ... |
| 26 | 56.0 | 70 | ... | 6 | ... |
| 27 | 53.0 | 127 | 1 | 2 | ... |
| 28 | 48.5 | 138 | 8 | 5 | ... |
| 29 | 47.0 | 37 | 3 | 8 | ... |
| 30 | 44.5 | 15 | ... | ... | ... |
| 31 | 49.0 | (Weir inoperative) | | | |
| June 1 | 54.0 | 9 | ... | 2 | ... |
| 2 | 55.0 | 166 | 2 | 15 | ... |
| 3 | 56.5 | 184 | ... | 14 | ... |
| 4 | 58.5 | 110 | 2 | 9 | ... |
| 5 | 57.5 | 217 | ... | 20 | ... |
| 6 | 60.0 | 251 | ... | 29 | ... |
| 7 | 66.0 | 250 | ... | 22 | ... |
| 8 | 64.5 | 222 | ... | 15 | ... |
| 9 | 66.0 | 214 | ... | 18 | ... |
| 10 | 70.0 | 82 | ... | 10 | 30 |
| 11 | 72.0 | 16 | ... | 2 | 141 |
| 12 | 59.5 | 20 | ... | ... | 472 |
| 13 | 60.5 | 38 | ... | 1 | 668 |
| 14 | 56.5 | 2 | ... | ... | 440[3] |
| 15 | 56.0 | 44 | ... | 10 | 297 |
| 16 | 59.0 | 32 | ... | 2 | 244 |
| 17 | 64.5 | 26 | ... | 1 | 276 |
| 18 | 66.0 | 1 | ... | 1 | 216 |
| 19 | 65.5 | 5 | ... | ... | 137 |
| 20 | 68.5 | 6 | ... | ... | 47 |
| 21 | 69.0 | ... | ... | ... | 94 |
| 22 | 68.0 | 16 | ... | 2 | 26 |
| 23 | 68.0 | 12 | ... | ... | 6 |
| 24 | 70.0 | 3 | ... | ... | 25 |
| 25 | 70.0 | ... | ... | ... | 11 |
| 26 | 71.0 | ... | ... | ... | 4 |
| 27 | 72.5 | 1 | ... | ... | 4 |
| 28 | 72.5 | 2 | ... | 1 | 2 |
| 29 | 73.0 | 6 | ... | 1 | 3 |
| 30 | (65)[5] | 12 | ... | 1 | 1 |
| July 1 | (67) | 31 | ... | ... | ... |
| 2 | (64) | 27 | ... | 2 | 1 |
| 3 | (65) | 49 | ... | 3 | 2 |
| 4 | (70) | 34 | ... | ... | 8 |
| 5 | (70) | 12 | ... | ... | 6 |
| 6 | (67) | 17 | ... | 2 | 10 |
| 7 | (66) | 4 | ... | 1 | 12 |
| 8 | (72) | 2 | ... | ... | 9 |
| 9 | (68) | ... | ... | ... | 5 |
| 10 | (70) | ... | ... | ... | 1 |
| 11 | (72) | ... | ... | ... | ... |
| Totals | | 3,548 | 152 | 257[4] | 3,198 |

1/ Fish bearing one or more recent or fresh lamprey scars. Maximum number of scars found on one fish was three.
2/ Species not differentiated in records of downstream transfer.
3/ Total number not exact. Transfer made by Conservation Officer H. Burris who kept only fairly accurate count.
4/ Of total upstream transfers, 7.0 percent bore recent or fresh lamprey scars.
5/ Maximum-minimum thermometer broken. Temperatures at morning visit between 0900 and 1000.

Table 5. Numbers and kinds of fish other than sea lampreys, white suckers and redhorse suckers taken in the Carp Creek weir: April 25-July 15, 1947. (Upstream migrants)

| Date 1947 | | Mean water temperature (Degrees F.) | Rainbow trout | Smelt | Lake chubs | Common shiners | Rock bass | Great Lakes long-nose dace | Black bullheads | Miscellaneous species (with total length in inches) |
|---|---|---|---|---|---|---|---|---|---|---|
| April | 25 | 48.5 | 3 | 153 | 5 | 3 | ... | ... | ... | 1 Northern pike; 17.7 |
| | 26 | 48.0 | 1 | 228 | 2 | ... | ... | ... | ... | ... |
| | 27 | 46.0 | 2 | 49 | 5 | 1 | ... | ... | ... | ... |
| | 28 | 46.5 | ... | 28 | 4 | 1 | ... | ... | ... | ... |
| | 29 | 48.0 | ... | 10 | 14 | ... | ... | ... | ... | 1 Northern pike; 23.9 |
| | 30 | 51.0 | 1 | 3 | 89 | ... | 2 | ... | ... | 1 Northern pike; 17.5 |
| May | 1 | 47.5 | ... | 3 | 7 | ... | ... | ... | ... | 2 Northern pike; 19.6, 24.2 |
| | 2 | 46.0 | 1 | 1 | 5 | 3 | ... | ... | ... | ... |
| | 3 | 43.0 | 1 | ... | ... | ... | ... | ... | ... | ... |
| | 4 | 47.0 | ... | 15 | 3 | ... | ... | ... | ... | ... |
| | 5 | 47.0 | ... | 4 | 4 | ... | ... | ... | ... | ... |
| | 6 | 50.0 | ... | ... | 1 | ... | ... | ... | ... | ... |
| | 7 | 49.0 | ... | ... | 1 | 1 | ... | ... | ... | 1 Mudminnow |
| | 8 | 46.0 | 1 | ... | 2 | ... | ... | ... | ... | ... |
| | 9 | 39.5 | ... | ... | ... | ... | ... | ... | ... | ... |
| | 10 | 44.5 | ... | ... | 55 | ... | ... | 28 | ... | ... |
| | 11 | 51.5 | ... | 26 | 394 | 2 | ... | 130 | ... | ... |
| | 12 | 50.0 | ... | 7 | 446 | 2 | 1 | 14 | 1 | 1 Horny-head chub |
| | 13 | 51.0 | ... | ... | 295 | 4 | ... | 7 | 1 | 2 Horny-head chubs |
| | 14 | 48.0 | ... | ... | 111 | 2 | 1 | 6 | ... | 5 Fine-scale dace |
| | 15 | 50.0 | ... | ... | 215 | 2 | ... | 15 | ... | 1 " " " |
| | 16 | 53.0 | ... | 6 | 336 | 4 | 1 | 40 | 1 | 3 " " " |
| | 17 | 56.0 | ... | 4 | 240 | ... | ... | 11 | 1 | 7 " " " |
| | 18 | 55.0 | ... | ... | 136 | 3 | ... | 2 | 6 | 1 " " " |
| | 19 | 60.5 | ... | ... | 40 | ... | 2 | 12 | 5 | ... |
| | 20 | 59.0 | ... | ... | 76 | 6 | 1 | 77 | 5 | 12 Fine-scale dace |
| | 21 | 59.0 | ... | ... | 268 | 12 | 2 | 17 | 3 | {1 Brown trout; 5.8 |
| | 22 | 53.5 | ... | ... | 111 | 13 | 1 | 4 | 1 | 1 Horned dace; 7.6 |
| | 23 | 54.5 | ... | ... | 160 | 12 | 1 | 101 | ... | 1 Muddler} |
| | 24 | 55.0 | ... | ... | 127 | 5 | 4 | 33 | 2 | 1 Silver lamprey |
| | 25 | 57.5 | 1 | ... | 171 | 2 | 1 | 76 | ... | 1 Johnny darter |
| | 26 | 56.0 | ... | ... | 153 | ... | 1 | 65 | 1 | 1 Brook trout; 6.0 |
| | 27 | 53.0 | ... | ... | 86 | 1 | ... | 4 | ... | 1 Horny-head chub; 7.0 |
| | 28 | 48.5 | ... | 1 | 64 | 1 | ... | 6 | ... | 1 Creek chub |
| | 29 | 47.0 | ... | ... | 20 | 1 | ... | ... | ... | ... |
| | 30 | 44.5 | ... | ... | ... | ... | ... | ... | ... | ... |
| | 31 | 49.0 | (Weir inoperative) | | | | | | | |
| June | 1 | 54.0 | ... | ... | 9 | ... | 2 | 1 | ... | ... |
| | 2 | 55.0 | ... | ... | 113 | 2 | 2 | 6 | 2 | ... |
| | 3 | 56.5 | ... | ... | 195 | 8 | 1 | 26 | 3 | ... |
| | 4 | 58.5 | ... | ... | 73 | 1 | 5 | 5 | 3 | ... |
| | 5 | 57.5 | ... | ... | 34 | 3 | 3 | 48 | 1 | 1 Silver lamprey; 10.5 |
| | 6 | 60.0 | ... | ... | 10 | ... | 2 | 23 | 9 | ... |
| | 7 | 66.0 | 1 | ... | 8 | 3 | ... | 8 | 1 | ... |
| | 8 | 64.5 | ... | ... | 16 | 3 | 5 | 17 | ... | ... |
| | 9 | 66.0 | ... | ... | 2 | ... | 4 | 7 | 2 | ... |
| | 10 | 70.0 | ... | ... | 7 | 2 | 1 | 2 | 7 | ... |
| | 11 | 72.0 | ... | ... | 4 | ... | 16 | 5 | 5 | ... |
| | 12 | 59.5 | 2 | ... | 2 | ... | ... | ... | 2 | ... |
| | 13 | 60.5 | 1 | ... | 4 | 1 | 2 | 2 | 1 | ... |
| | 14 | 56.5 | 1 | ... | 10 | 4 | ... | ... | ... | ... |
| | 15 | 56.0 | ... | ... | 6 | ... | 6 | 1 | 1 | ... |
| | 16 | 59.0 | ... | ... | 1 | ... | ... | 1 | ... | ... |
| | 17 | 64.5 | 1 | ... | 5 | 4 | 6 | 3 | 5 | ... |
| | 18 | 66.0 | ... | ... | 2 | 8 | 9 | 1 | 3 | ... |
| | 19 | 65.5 | ... | ... | ... | ... | 6 | ... | ... | ... |
| | 20 | 68.5 | ... | ... | ... | 1 | 3 | ... | 2 | ... |
| | 21 | 69.0 | ... | ... | ... | ... | 2 | ... | 2 | ... |
| | 22 | 68.0 | ... | ... | ... | ... | 1 | ... | 2 | ... |
| | 23 | 68.0 | ... | ... | ... | ... | 1 | ... | 1 | ... |
| | 24 | 70.0 | ... | ... | ... | ... | 1 | ... | ... | ... |
| | 25 | 70.0 | ... | ... | ... | ... | 2 | ... | ... | ... |
| | 26 | 71.0 | ... | ... | ... | ... | ... | ... | ... | ... |
| | 27 | 72.5 | ... | ... | ... | 1 | ... | ... | ... | ... |
| | 28 | 72.5 | ... | ... | ... | ... | ... | ... | ... | ... |
| | 29 | 73.0 | ... | ... | ... | 6 | ... | ... | 1 | ... |
| | 30 | (65)[1] | ... | ... | ... | ... | ... | ... | 1 | 1 Johnny darter |
| July | 1 | (67) | ... | ... | ... | ... | 1 | ... | ... | ... |
| | 2 | (64) | ... | ... | ... | ... | ... | ... | 1 | 1 Snapping turtle |
| | 3 | (65) | ... | ... | ... | 6 | 1 | ... | ... | ... |
| | 4 | (70) | ... | ... | ... | 1 | ... | ... | 1 | 1 Snapping turtle |
| | 5 | (70) | ... | ... | ... | ... | 2 | ... | 2 | ... |
| | 6 | (67) | ... | ... | ... | ... | 1 | ... | ... | ... |
| | 7 | (66) | ... | ... | ... | ... | ... | ... | 2 | ... |
| | 8 | (72) | ... | ... | ... | ... | 1 | ... | ... | ... |
| | 9 | (68) | ... | ... | ... | 3 | ... | ... | 1 | ... |
| | 10 | (70) | ... | ... | ... | ... | ... | ... | ... | ... |
| | 11 | (72) | ... | ... | ... | ... | ... | ... | 1 | 1 Painted turtle |
| | 12 | ... | ... | ... | ... | ... | ... | ... | ... | 1 Water snake |
| | 13 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | 14 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | 15 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Totals | | | 17 | 538 | 4,147 | 138 | 104 | 804 | 89 | |

[1] Maximum-minimum thermometer broken. Temperatures at morning visit between 0900 and 1000.

Hornyhead chub (Nocomis biguttatus), 5; Muddler (Cottus sp.), 1; Johnny darters (Boleosoma nigrum), 2. The other species of lamprey taken consisted of two specimens of the silver lamprey (Ichthyomyzon unicuspis).

Two snapping turtles (Chelydra serpentina), one painted turtle (Chrysemys picta), and one water snake (Natrix s. sipedon) also entered the trap.

(2) Length, weight and age:--Samples for length, weight and, in some instances, age data were collected for those species entering the trap most frequently. These data are summarized as follows:

| Species | Date of collection (1947) | Number of specimens | Total length in inches | | |
|---|---|---|---|---|---|
| | | | Minimum | Average | Maximum |
| White suckers | May 26-June 12 | 102 | 12.2 | 15.8 | 19.9 |
| Lake chubs | May 26 | 50 | 4.1 | 5.1 | 6.3 |
| Smelt | Apr. 25 | 50 | 5.5 | 6.9 | 9.7 |
| Smelt | May 11 | 26 | 5.7 | 7.0 | 8.1 |
| Rainbow trout | Apr. 25-May 25 | 11 | 9.3 | 14.9 | 23.5 |
| Rainbow trout | June 7-17 | 6 | 5.0 | 5.9 | 6.5 |
| Rock bass | Apr. 30-July 10 | 73 | 2.5 | 5.3 | 8.0 |
| Great Lakes longnose dace | May 11 | 30 | 2.9 | 3.6 | 4.5 |
| Black bullheads | May 13-July 11 | 58 | 3.0 | 6.5 | 10.0 |

Scale samples obtained from 18 rock bass taken between June 11 and 15 were aged and the data for these was as follows:

| Age group | Number of specimens | Total length in inches | | | Average weight in grams |
|---|---|---|---|---|---|
| | | Minimum | Average | Maximum | |
| II* | 2 | 3.6 | 4.3 | 4.9 | 29.5 |
| III* | 14 | 4.7 | 6.0 | 6.8 | 109.0 |
| IV* | 2 | 7.4 | 7.5 | 7.5 | 155.5 |

One female rainbow trout 17.9 inches in total length (taken on May 26) was in age group III*. Another female, 34.5 inches long (taken on May 12) was in age group IV*. This latter fish was a downstream migrant and was spent when taken.

(3) Times of migration:--White suckers entered the trap sporadically and in small numbers until May 15 (the last day of the open season for spearing this species). The greatest upstream migration occurred between May 16 and June 9. Thereafter, they entered the trap in small numbers until July 8. Like the sea lamprey, their peak activity apparently occurs at temperature levels of 50° F. or higher (Table 4). Of 152 Northern redhorse suckers, 117 or 77 percent were taken during the 4-day period May 16 to 19. White and redhorse suckers were the only species for which complete downstream migration records were kept. The peak period of downstream migration for spent white and redhorse suckers was from June 11 to June 19 (Table 4). Of 3,548 white and 152 redhorse suckers (total 3,700) transferred upstream, 3,198 returned to the weir and were transferred downstream. The bulk of the difference, 502 suckers, was harvested by two supervised spearing parties which took place during the closed season.

The peak of the runs of three species, the northern pike, the smelt, and the rainbow trout were apparently past prior to the first day of operation of the weir (April 21). Field observations and incomplete data from the weir indicated that the peak of the smelt run occurred between April 18 and April 27.

Lake chubs attained the peak of their migration between May 11 and June 3. Like the sea lampreys and the suckers, their peak run was erratic in character, probably as a result of wide fluctuations in the water temperature (Table 5). The greatest upstream movement of Great Lakes longnose dace occurred between May 12 and June 8. Their peak run likewise fluctuated widely with temperature variations.

Common shiners, rock bass and black bullheads entered the trap in small numbers throughout most of the period of weir operation. The number taken, however, was insufficient to reveal any peak periods of migratory activity.

(4) Species and numbers bearing lamprey scars:--All suckers, trout, northern pike, rock bass and bullheads taken in the trap were examined for lamprey scars. Of the 3,700 white and redhorse suckers transferred upstream, 257 or 7.0 percent of the run bore one or more relatively fresh or recent scars (Table 4). Occasional fish had two scars and two instances of three scars on one fish were noted. On May 2, a rainbow trout, 26.0 inches in total length, was confiscated from a sucker spearer who had taken it in the estuary of the creek. This fish bore a fresh lamprey scar 2 1/4 inches in diameter and nearly 1/4 inch deep. A 24.5-inch female rainbow trout which came downstream on May 12 bore two recent lamprey scars and one which was

nearly healed. A third rainbow trout, 17.9 inches long, taken in the trap on May 26 had an old, healed-over scar. One northern pike, 19.6 inches long, taken on May 1 had two fresh lamprey scars. No bullheads or rock bass bore any evidence of lamprey attacks.

Few, if any, of the aforementioned fish bore scars so fresh and raw that one could suspect that they had been inflicted while the fish was traveling the short distance from the mouth of the creek to the weir. This opinion is based on the comparative examination of these fish and that of a series of scarred whitefish and "chubs" taken in Lake Huron, on some of which the lampreys were still attached when the nets were lifted. On the latter, the scars had a bright red, raw appearance which was seldom approached in freshness of appearance in the specimens taken in the trap.

Furthermore, only one instance of recent feeding was found among the sea lampreys taken in the trap (the digestive tracts of nearly all sea lampreys taken in the trap were opened). On May 1, a female sea lamprey, 17.3 inches long was taken from the trap in which the intestine was partially distended with blood. This specimen was in a retarded state of sexual maturity as evidenced by the condition of its liver and the under-development of the gonad.

It is concluded from these data that the fish entering Carp Creek which bore scars were attacked by lampreys sometime prior to their entrance into the stream. This point is made since the concentration of so many fish and lampreys moving in the narrow confines of the creek might lead the casual observer to believe that the incidence of attacks noted was directly related to coincident spawning runs of predator and prey.

## III. Ocqueoc River investigations

The sea lamprey run in the Ocqueoc River during 1947 was not impeded by any weir, trap or other man-made structure. For this reason, it was used in that year as an area for the study of the migratory and spawning habits and spawning requirements of the sea lamprey. In addition to these observations, a series of samples of the sea lamprey run were obtained to augment the materials collected at Carp Creek. Since the data for both streams are combined or drawn upon in subsequent analyses presented, a brief description of the river, methods and places of collection, and data on the sea lamprey run are presented herewith. Further details of the physical characteristics of the Ocqueoc River watershed will be presented in the section on spawning habits and spawning requirements of the species. A description of the sea lamprey runs entering this river in 1944 and 1945 has been presented by Shetter (1948? and I.F.R. Rept. 1015).

### The Ocqueoc River

This river is by far the largest stream entering Hammond Bay. It flows in a northerly direction from its headwaters to Ocqueoc Lake and from there, almost due east into the bay. Its watershed flows through, or drains, the better part of six townships. Its depth in the spring months varies from about 8 inches in the riffle areas to 9.5 feet in its deeper pools. The river varies from 24 to 60 feet in width during the same season. Through the upper third of its course where it flows through a chain of lakes, the current is predominantly sluggish and the bottom silted. The balance of the stream, flowing first through pastured land and woodlot and then through a wooded valley, is characterized by swifter currents and bottom types of rock, rubble, gravel and sand.

In 1947, sea lampreys spawned in varying concentrations throughout the entire lower two-thirds of the river. The farthest point upstream at which spawning occurred was 16.5 miles above the mouth (T. 34 N., R. 4 E., Sect. 19). It is estimated (on the basis of nest counts and specimen samples obtained) that between 10,000 and 11,000 sea lampreys entered the Ocqueoc River in 1947. Of four permanent tributaries of the Ocqueoc River, a small number of sea lampreys entered two, and spawned. These were the Little Ocqueoc River and Silver Creek. The remainder, Indian Creek and the Orchard Lake Outlet (tributary to Ocqueoc Lake) did not contain subsidiary r uns.

## Methods, places and times of sampling and collection of other data

Sea lampreys in the Ocqueoc watershed tended to concentrate at two points during their upstream migration. The first concentration occurred in Ocqueoc Lake, 2 1/4 miles above the mouth of the river. This phenomena was accidently discovered on May 29, 1947, when netting operations were begun to determine if any predation upon resident game fish occurred while the sea lampreys were passing through the lake. On that date, an 18.2-inch male sea lamprey in an advanced state of sexual maturity was taken in the 25-foot length of 1 1/2-inch stretch measure netting in a 125-foot experimental gill net (set in the north end of the lake). Thereafter, gill nets set in the northern half of the lake always yielded one or more sea lampreys in the 1 1/2-inch mesh portion of the nets. The greatest catch was on June 19 when 16 sea lampreys were taken in a 125-foot, 1 1/2-inch stretch measure gill net. This was a 20-hour set. This concentration in Ocqueoc Lake was evidently due to the inability of the run moving into the lake to find immediately the inlet of the Ocqueoc River. Ocqueoc Lake is long, narrow and irregular in outline; its outlet where the sea lampreys migrate into the lake is at the extreme northern end of the lake and its inlet enters on its southernmost extension. Captures in the gill nets were made at all depths from 2 to 18 feet. Furthermore, specimens taken were traveling in all possible directions which would seem to indicate that they were searching more or less aimlessly for the inlet of the Ocqueoc River. On several occasions during the second week in June, sea lampreys were seen from the bank moving along the shoals in a direction opposite to that which would lead them to the inlet of the river.

Altogether, 69 sea lampreys in advanced stages of sexual maturity were collected by this method (Table 6). They varied in total length from 14.3 to 20.5 inches and presumably indicate the size range most efficiently trapped by this method. Actually, the sea lamprey does not become "gilled" in the net but is trapped by its own natural reactions. Swimming normally with their buccal funnel closed, their immediate reaction to any restriction, such as forcing their head into the mesh of the net, is to open the funnel. The net then catches them between the branchial "basket" and the opened funnel. Subsequent "tailing" through innumerable meshes of the net eliminates any chance of escape (Figure 11).

It has been suggested that netting operations be attempted in the Great Lakes proper to obtain specimens of sexually immature adults and to test the possibility of a fishery for these individuals. Although this method of capture was practical and productive in Ocqueoc Lake where the concentration of individuals was abnormally high in a small body of water, I believe it would be of little or no value in the Great Lakes where the sexually immature adult populations are undoubtedly greatly dispersed.

Table 6. Number and average length and weight by sexes and total sea lampreys taken in the Ocqueoc watershed.

| Date 1947 | Location in watershed | Nature of specimens | Males: Number taken | Males: Average length in inches | Males: Average length in milli-meters | Males: Average weight in grams | Females: Number taken | Females: Average length in inches | Females: Average length in milli-meters | Females: Average weight in grams | Total ♂♂ and ♀♀ taken |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May 14 | Below Lower Falls | Migrants | 3 | 16.8 | 427 | 159 | 3 | 19.1 | 485 | 258 | 6 |
| 17 | " " " | " | 3 | 17.8 | 452 | 218 | 2 | 17.3 | 439 | 202 | 5 |
| 26 | " " " | " | ... | ... | ... | ... | 1 | (18.3) | (465) | (238) | 1 |
| May 29-June 1 | Ocqueoc Lake | " | 4 | 17.5 | 445 | 168 | ... | ... | ... | ... | 4 |
| June 4 | Below Lower Falls | Dead - unspawned | 1 | (16.3) | (414) | (118) | ... | .... | ... | ... | 1 |
| 6 | " " " | Migrants | 9 | 15.4 | 391 | 187 | 1 | (15.7) | (399) | (134) | 10 |
| June 7-10 | Ocqueoc Lake | " | 6 | 16.6 | 422 | 174 | 2 | 18.7 | 475 | 241 | 8 |
| 12 | Below Lower Falls | " | 37 | 16.2 | 412 | 151 | 44 | 16.8 | 427 | 177 | 81 |
| 14 | " " " | " | 17 | 17.0 | 432 | 149 | 18 | 16.3 | 414 | 149 | 35 |
| June 14-16 | Ocqueoc Lake | " | 5 | 15.7 | 399 | 117 | 6 | 16.3 | 414 | 133 | 11 |
| 16 | Lower Falls | " | 114 | 16.1 | 409 | 152 | 97 | 16.2 | 412 | 158 | 211 |
| 17 | " " | " | 40 | 15.7 | 399 | 136 | 39 | 16.2 | 412 | 153 | 79 |
| June 18-19 | Ocqueoc Lake | " | 13 | 15.7 | 399 | 128 | 14 | 16.5 | 419 | 149 | 27 |
| 20 | Lower & Upper Falls | " | 23 | 16.7 | 424 | 180 | 23 | 17.1 | 434 | 200 | 46 |
| 20 | Lower River | Spawning or spent | 11 | 15.6 | 396 | 180 | 4 | 17.4 | 442 | 240 | 15 |
| June 20-21 | Ocqueoc Lake | Migrants | 4 | 17.2 | 437 | 181 | 1 | (20.5) | (521) | (270) | 5 |
| 21 | Lower Falls | " | 19 | 16.7 | 424 | 181 | 14 | 16.4 | 417 | 165 | 33 |
| 21 | Lower River | Spawning or spent | 14 | 16.0 | 406 | 182 | 16 | 15.4 | 391 | 161 | 30 |
| 22 | Lower Falls | Migrants | 2 | 15.7 | 399 | 134 | 2 | 17.9 | 455 | 192 | 4 |
| 24 | Lower River | Spawning or spent | 1 | (16.6) | (422) | (208) | 4 | 14.0 | 356 | 124 | 5 |
| 24 | " " | Dead or dying | 11 | 16.0 | 406 | 169 | 5 | 13.5 | 343 | 92 | 16 |
| June 25-26 | Ocqueoc Lake | Migrants | 5 | 16.3 | 414 | 154 | 5 | 15.4 | 391 | 127 | 10 |
| 27 | Lower River | Spawning or spent | 6 | 16.1 | 409 | 195 | ... | ... | ... | ... | 6 |
| 28 | " " | Dead or dying | 4 | 16.5 | 419 | 202 | 5 | 14.5 | 368 | 129 | 9 |
| 29 | " " | Spawning or spent | 11 | 16.2 | 412 | 198 | 6 | 15.2 | 386 | 152 | 17 |
| July 12-13 | Ocqueoc Lake | Migrants | 1 | (14.7) | (373) | (103) | 2 | 15.7 | 399 | 129 | 3 |
| 15 | " " | " | ... | ... | ... | ... | 1 | (16.0) | (406) | (106) | 1 |
| Grand totals and averages | | | 364 | 16.2 | 412 | 154 [1] | 315 | 16.3 | 414 | 165 [2] | 679 |

[1] Average based on migrant specimens only. Fifty-eight spawning, spent, dying or dead males not included.
[2] Average based on migrant specimens only. Forty spawning, spent, dying or dead females not included.

Figure 11. Sea lampreys captured in a gill net in Ocqueoc Lake, June 25, 1947.

The second, and most visible, concentration of migrating sea lampreys in the Ocqueoc River occurs at a series of three falls located about one-third of the way upstream (T. 35 N., R. 3 E., Sect. 22). Two natural falls, 4.5 and 6.0 feet high respectively, and the spillway of an old mill dam form obstructions below which, the upstream migrants tend to "pile-up" while seeking the most favorable route over the obstacles. Periodic collections were made at the lower and upper natural falls. These were made with scap-nets or by capturing the lampreys by hand in the white water on the face, or at the base, of the falls. A total of 511 sea lampreys were collected in this manner (Table 6).

In addition to the 580 unspawned, upstream migrants collected in Ocqueoc Lake and at the falls in the river, 99 spawning, spent and dying or dead sea lampreys were collected on the various spawning grounds in the river (Table 6).

Water temperature and water gauge readings were recorded for the Ocqueoc River at a station situated 100 feet below the outlet of Ocqueoc Lake. As in the Carp Creek, a maximum-minimum thermometer was maintained and minimum, mean and maximum water temperatures were recorded for the period April 15 to August 4, 1947 (Table 7).

## The sea lamprey run

(1) Time limits and extent of the run:--Data collected for the Ocqueoc River run was concerned almost entirely with the arrival, extent of activity and disappearance of the lampreys on their spawning grounds. Conclusions as to the time limits and peaks of migratory activity, as they might be measured by a weir and trap near the river's mouth, are based entirely on field observations and a consideration of migratory activity at the Ocqueoc falls, 8.8 miles upstream from the mouth of the river.

Table 7. Daily minimum, maximum and mean water temperatures and water gauge readings for the Ocqueoc River with air temperatures for the locality: April 15-August 4, 1947.[1]

| Date 1947 | Time | Water temperature (Degrees F.) Minimum | Mean | Maximum | At visit | Air temperature (Degrees F.) | Water gauge (in inches)[2] |
|---|---|---|---|---|---|---|---|
| April 15 | 1630 | ... | ... | ... | ... | ... | 41.50 |
| 16 | 1000 | ... | ... | ... | 38 | 36 | ... |
| | 1600 | 38 | 38.0 | 38 | 38 | 47 | 37.50 |
| 17 | 1000 | 38 | 38.5 | 39 | 38 | 40 | ... |
| | 1600 | 38 | 38.0 | 38 | 38 | 41 | 33.25 |
| 18 | 1000 | 37 | 38.0 | 39 | 39 | 41 | ... |
| | 1600 | 39 | 39.0 | 39 | 39 | 40 | 30.00 |
| 19 | 0945 | 38 | 38.5 | 39 | 39 | ... | ... |
| | 1600 | 38 | 38.5 | 39 | 39 | 40 | 27.00 |
| 20 | 1700 | 39 | 39.5 | 40 | 40 | 45 | 25.00 |
| 21 | 0920 | 39 | 39.5 | 40 | 40 | 38 | ... |
| | 1600 | 40 | 40.0 | 40 | 40 | 39 | 23.00 |
| 22 | 0830 | 40 | 40.0 | 40 | 40 | 41 | ... |
| | 1600 | 40 | 40.5 | 41 | 41 | 42 | 21.50 |
| 23 | 0900 | 40 | 41.0 | 42 | 41 | 46 | ... |
| | 1600 | 40 | 40.5 | 41 | 41 | 58 | 21.00 |
| 24 | 0900 | 40 | 40.5 | 41 | 41 | 50 | ... |
| | 1600 | 41 | 41.5 | 42 | 41 | 54 | 24.50 |
| 25 | 0900 | 40 | 40.5 | 41 | 40 | 42 | ... |
| | 1600 | 42 | 43.0 | 44 | 44 | 51 | 25.00 |
| 26 | 0900 | 41 | 42.5 | 44 | 44 | 42 | ... |
| | 1600 | 44 | 45.0 | 46 | 46 | 46 | 24.00 |
| 27 | 1600 | 43 | 44.5 | 46 | 46 | ... | 24.75 |
| 28 | 1600 | 44 | 45.5 | 47 | 47 | 60 | 23.50 |
| 29 | 0930 | 46 | 46.5 | 47 | 47 | 68 | 22.00 |
| | 1630 | 47 | 48.0 | 49 | 49 | 66 | 21.75 |
| 30 | 0845 | 47 | 48.5 | 50 | 48 | 52 | ... |
| | 1600 | ... | ... | ... | ... | ... | 23.75 |
| May 1 | 0930 | 47 | 48.0 | 49 | 49 | 52 | 26.00 |
| 2 | 1000 | 47 | 48.0 | 49 | 48 | ... | ... |
| | 1600 | ... | ... | ... | ... | ... | 28.50 |
| 3 | 0930 | 47 | 48.0 | 49 | 47 | 54 | ... |
| | 1600 | ... | ... | ... | ... | ... | 38.00 |
| 4 | 0930 | 46 | 46.5 | 47 | 47 | 64 | 38.50 |
| 5 | 0830 | 46 | 46.5 | 47 | 47 | 54 | 43.00 |
| 6 | 1100 | 45 | 46.5 | 48 | 48 | 44 | 40.00 |
| 7 | 1145 | 46 | 49.0 | 52 | 48 | 44 | 34.00 |
| 8 | 1130 | 38 | 45.0 | 52 | 48 | 30 | 29.00 |
| 9 | 1045 | 42 | 45.0 | 48 | 46 | 41 | 25.50 |
| 10 | 1230 | 42 | 45.0 | 48 | 48 | 60 | 22.00 |
| 11 | 0815 | 45 | 46.5 | 48 | 47 | 50 | 20.50 |
| 12 | 0845 | 46 | 47.5 | 49 | 49 | 67 | 18.00 |
| 13 | 0845 | 48 | 49.5 | 51 | 50 | 41 | 18.00 |
| 14 | 0900 | 49 | 51.0 | 53 | 50 | 49 | 20.00 |
| 15 | 0930 | 48 | 49.5 | 51 | 51 | 57 | 18.50 |
| 16 | 0930 | 49 | 50.5 | 52 | 51 | 58 | 17.00 |
| 17 | 0945 | 49 | 51.0 | 53 | 53 | 65 | 15.75 |
| 18 | 1000 | 52 | 53.0 | 54 | 54 | 63 | 14.50 |
| 19 | 0915 | 52 | 55.0 | 58 | 57 | 73 | 13.00 |
| 20 | 0900 | 53 | 56.0 | 59 | 55 | 51 | 13.50 |
| 21 | 0845 | 53 | 56.0 | 59 | 56 | 43 | 13.25 |
| 22 | 0915 | 55 | 56.5 | 58 | 56 | 50 | 16.00 |
| 23 | 0945 | 55 | 56.5 | 58 | 56 | 51 | 16.00 |
| 24 | 0900 | 54 | 55.5 | 57 | 56 | 56 | 15.25 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 11 | 0815 | 45 | 46.5 | 48 | 47 | [illegible] | [illegible] |
| | 12 | 0845 | 46 | 47.5 | 49 | 49 | 67 | 18.00 |
| | 13 | 0845 | 48 | 49.5 | 51 | 50 | 41 | 18.00 |
| | 14 | 0900 | 49 | 51.0 | 53 | 50 | 49 | 20.00 |
| | 15 | 0930 | 48 | 49.5 | 51 | 51 | 57 | 18.50 |
| | 16 | 0930 | 49 | 50.5 | 52 | 51 | 58 | 17.00 |
| | 17 | 0945 | 49 | 51.0 | 53 | 53 | 65 | 15.75 |
| | 18 | 1000 | 52 | 53.0 | 54 | 54 | 63 | 14.50 |
| | 19 | 0915 | 52 | 55.0 | 58 | 57 | 73 | 13.00 |
| | 20 | 0900 | 53 | 56.0 | 59 | 55 | 51 | 13.50 |
| | 21 | 0845 | 53 | 56.0 | 59 | 56 | 43 | 13.25 |
| | 22 | 0915 | 55 | 56.5 | 58 | 56 | 50 | 16.00 |
| | 23 | 0945 | 55 | 56.5 | 58 | 56 | 51 | 16.00 |
| | 24 | 0900 | 54 | 55.5 | 57 | 56 | 56 | 15.25 |
| | 25 | 0930 | 54 | 56.0 | 58 | 56 | 55 | 14.50 |
| | 26 | 1000 | 55 | 56.5 | 58 | 56 | 52 | 16.50 |
| | 27 | 0930 | 54 | 56.0 | 58 | 54 | 42 | 17.00 |
| | 28 | 1000 | 53 | 54.5 | 55 | 53 | 47 | 17.00 |
| | 29 | 1015 | 50 | 52.0 | 54 | 50 | 40 | 18.00 |
| | 30 | 0915 | 49 | 50.5 | 51 | 49 | 50 | 23.50 |
| | 31 | 0915 | 49 | 51.0 | 53 | 49 | 53 | 21.75 |
| June | 1 | 0845 | 49 | 50.5 | 52 | 51 | 55 | 18.75 |
| | 2 | 0945 | 50 | 51.5 | 53 | 52 | 47 | 16.00 |
| | 3 | 0900 | 50 | 51.5 | 53 | 50 | 46 | 14.00 |
| | 4 | 0900 | 52 | 54.5 | 57 | 55 | 60 | 12.25 |
| | 5 | 0900 | 54 | 56.0 | 58 | 56 | 70 | 11.25 |
| | 6 | 1000 | 56 | 58.0 | 60 | 57 | 66 | 10.50 |
| | 7 | 0915 | 57 | 59.5 | 62 | 59 | 54 | 9.75 |
| | 8 | 0900 | 57 | 59.5 | 62 | 62 | 58 | 9.25 |
| | 9 | 1215 | 60 | 62.0 | 64 | 64 | 72 | 8.25 |
| | 10 | 0900 | 61 | 64.0 | 67 | 66 | 80 | 8.00 |
| | 11 | 1130 | 65 | 68.5 | 72 | 68 | 58 | 8.00 |
| | 12 | 1015 | 64 | 66.0 | 68 | 66 | 56 | 7.25 |
| | 13 | 1045 | 64 | 66.0 | 68 | 64 | 52 | 6.50 |
| | 14 | 1015 | 61 | 62.5 | 64 | 63 | 56 | 8.25 |
| | 15 | 1115 | 61 | 62.0 | 63 | 60 | 53 | 8.00 |
| | 16 | 1030 | 61 | 61.0 | 61 | 60 | 56 | 9.00 |
| | 17 | 1145 | 58 | 60.0 | 62 | 62 | 59 | 8.00 |
| | 18 | 1145 | 60 | 62.0 | 64 | 62 | 62 | 7.25 |
| | 19 | 1030 | 60 | 62.0 | 64 | 64 | 64 | 6.50 |
| | 20 | 1115 | 62 | 65.0 | 68 | 66 | 68 | 6.00 |
| | 21 | 0930 | 62 | 65.0 | 68 | 65 | 66 | 5.25 |
| | 22 | 1145 | 65 | 67.5 | 70 | 69 | 74 | 5.00 |
| | 23 | 1015 | 67 | 69.0 | 71 | 69 | 78 | 4.75 |
| | 24 | 0930 | 67 | 69.0 | 71 | 67 | 62 | 4.00 |
| | 25 | 1400 | 65 | 68.0 | 71 | 70 | 74 | 4.50 |
| | 26 | 0900 | 68 | 70.0 | 72 | 68 | 64 | 4.00 |
| | 27 | 0915 | 64 | 68.5 | 73 | 72 | 78 | 3.00 |
| | 28 | 0930 | 72 | 73.0 | 74 | 72 | 74 | 4.75 |
| | 29 | 0930 | 70 | 72.5 | 75 | 72 | 70 | 5.00 |
| | 30 | 0945 | 68 | 70.5 | 73 | 70 | 66 | 4.50 |
| July | 1 | 0900 | 68 | 69.5 | 71 | 68 | 56 | 4.50 |
| | 2 | 1100 | 66 | 68.5 | 71 | 70 | 70 | 4.00 |
| | 3 | 1030 | 67 | 69.5 | 72 | 68 | 74 | 3.25 |
| | 4 | 1000 | 68 | 71.0 | 74 | 70 | 76 | 2.75 |
| | 5 | 0930 | 70 | 72.0 | 74 | 72 | 68 | 2.50 |
| | 6 | 0945 | 68 | 70.0 | 72 | 69 | 62 | 8.00 |
| | 7 | 1030 | 66 | 68.0 | 70 | 68 | 70 | 9.00 |
| | 8 | 0930 | 66 | 68.0 | 70 | 67 | 70 | 7.75 |
| | 9 | 1000 | 68 | 69.0 | 70 | 70 | 72 | 6.00 |
| | 10 | 1000 | 68 | 71.0 | 74 | 72 | 72 | 4.75 |
| | 11 | 1100 | 69 | 71.0 | 73 | 72 | 74 | 4.00 |
| | 12 | 1015 | 69 | 71.5 | 74 | 73 | 70 | 3.50 |
| | 13 | 1330 | 71 | 73.5 | 76 | 76 | 82 | 3.25 |
| | 14 | ... | ... | ... | ... | ... | ... | ... |
| | 15 | 1145 | 70 | 73.5 | 77 | 70 | 70 | 4.50 |
| | 16 | 1000 | 69 | 71.0 | 73 | 70 | 72 | 4.50 |
| | 17 | 1145 | 70 | 73.0 | 76 | 75 | 82 | 4.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 4 | 0900 | 52 | 54.5 | 57 | 55 | 60 | 12.25 |
| | 5 | 0900 | 54 | 56.0 | 58 | 56 | 70 | 11.25 |
| | 6 | 1000 | 56 | 58.0 | 60 | 57 | 66 | 10.50 |
| | 7 | 0915 | 57 | 59.5 | 62 | 59 | 54 | 9.75 |
| | 8 | 0900 | 57 | 59.5 | 62 | 62 | 58 | 9.25 |
| | 9 | 1215 | 60 | 62.0 | 64 | 64 | 72 | 8.25 |
| | 10 | 0900 | 61 | 64.0 | 67 | 66 | 80 | 8.00 |
| | 11 | 1130 | 65 | 68.5 | 72 | 68 | 58 | 8.00 |
| | 12 | 1015 | 64 | 66.0 | 68 | 66 | 56 | 7.25 |
| | 13 | 1045 | 64 | 66.0 | 68 | 64 | 52 | 6.50 |
| | 14 | 1015 | 61 | 62.5 | 64 | 63 | 56 | 8.25 |
| | 15 | 1115 | 61 | 62.0 | 63 | 60 | 53 | 8.00 |
| | 16 | 1030 | 61 | 61.0 | 61 | 60 | 56 | 9.00 |
| | 17 | 1145 | 58 | 60.0 | 62 | 62 | 59 | 8.00 |
| | 18 | 1145 | 60 | 62.0 | 64 | 62 | 62 | 7.25 |
| | 19 | 1030 | 60 | 62.0 | 64 | 64 | 64 | 6.50 |
| | 20 | 1115 | 62 | 65.0 | 68 | 66 | 68 | 6.00 |
| | 21 | 0930 | 62 | 65.0 | 68 | 65 | 66 | 5.25 |
| | 22 | 1145 | 65 | 67.5 | 70 | 69 | 74 | 5.00 |
| | 23 | 1015 | 67 | 69.0 | 71 | 69 | 78 | 4.75 |
| | 24 | 0930 | 67 | 69.0 | 71 | 67 | 62 | 4.00 |
| | 25 | 1400 | 65 | 68.0 | 71 | 70 | 74 | 4.50 |
| | 26 | 0900 | 68 | 70.0 | 72 | 68 | 64 | 4.00 |
| | 27 | 0915 | 64 | 68.5 | 73 | 72 | 78 | 3.00 |
| | 28 | 0930 | 72 | 73.0 | 74 | 72 | 74 | 4.75 |
| | 29 | 0930 | 70 | 72.5 | 75 | 72 | 70 | 5.00 |
| | 30 | 0945 | 68 | 70.5 | 73 | 70 | 66 | 4.50 |
| July | 1 | 0900 | 68 | 69.5 | 71 | 68 | 56 | 4.50 |
| | 2 | 1100 | 66 | 68.5 | 71 | 70 | 70 | 4.00 |
| | 3 | 1030 | 67 | 69.5 | 72 | 68 | 74 | 3.25 |
| | 4 | 1000 | 68 | 71.0 | 74 | 70 | 76 | 2.75 |
| | 5 | 0930 | 70 | 72.0 | 74 | 72 | 68 | 2.50 |
| | 6 | 0945 | 68 | 70.0 | 72 | 69 | 62 | 8.00 |
| | 7 | 1030 | 66 | 68.0 | 70 | 68 | 70 | 9.00 |
| | 8 | 0930 | 66 | 68.0 | 70 | 67 | 70 | 7.75 |
| | 9 | 1000 | 68 | 69.0 | 70 | 70 | 72 | 6.00 |
| | 10 | 1000 | 68 | 71.0 | 74 | 72 | 72 | 4.75 |
| | 11 | 1100 | 69 | 71.0 | 73 | 72 | 74 | 4.00 |
| | 12 | 1015 | 69 | 71.5 | 74 | 73 | 70 | 3.50 |
| | 13 | 1330 | 71 | 73.5 | 76 | 76 | 82 | 3.25 |
| | 14 | ... | ... | ... | ... | ... | ... | ... |
| | 15 | 1145 | 70 | 73.5 | 77 | 70 | 70 | 4.50 |
| | 16 | 1000 | 69 | 71.0 | 73 | 70 | 72 | 4.50 |
| | 17 | 1145 | 70 | 73.0 | 76 | 75 | 82 | 4.00 |
| | 18 | 1100 | 72 | 75.0 | 78 | 76 | 74 | 3.75 |
| | 19 | 0845 | 69 | 73.0 | 77 | 69 | 59 | 3.50 |
| | 20 | 1200 | 68 | 70.5 | 73 | 71 | 71 | 3.25 |
| | 30 | 1530 | 66[3] | 72.5 | 79[3] | 77 | 84 | 3.50 |
| August | 4 | 0930 | ... | ... | ... | ... | ... | 1.75 |

[1] Readings taken at station 100 feet below the outlet of Ocqueoc Lake.
[2] Depth in midstream directly opposite water gauge was approximately 24 inches greater than gauge readings listed.
[3] Minimum and maximum water temperatures for period July 21 to July 30 inclusive.

It was reported to me by Mr. Enos Brege of Ocqueoc, Michigan, that on or about April 10, 1947, he saw "several" sea lampreys off the mouth of the Ocqueoc River while he was prospecting for the beginning of the smelt run. Data presented by Shetter (1948?) for the 1945 sea lamprey run show daily trap catches of no or solitary sea lampreys for the period April 22 (first day of trap operations) to April 28, during which time, the average daily water temperature varied from 42° F. to 44° F. In 1947, mean daily water temperatures in the Ocqueoc River remained below 40° F. until April 21 (Table 7). After consideration of these data and that presented in this report for Carp Creek for the period April 14 to 21, I believe that little or no upstream migration occurred until on or about April 20, 1947.

The greatest concentrations of sea lampreys at and on the Ocqueoc falls were present during the period June 4 to 17. Water temperatures at the falls during this period varied from 56° F. to 64° F. (all recordings made between 10:00 and 12:00 P. M.). The individuals composing this peak concentration obviously required some time to make the journey upstream (and through Ocqueoc Lake) from the mouth of the river. Since the mean daily water temperatures (in the lower river) rose and remained above 50° F. on May 16 (Table 7), I presume that the peak migration into the river began on that date and continued until about June 10.

The last spawning migrants observed in the entire river were a pair of sea lampreys which, on July 19 and 20, built a nest and spawned in the lower river about 350 feet below the outlet of Ocqueoc Lake. It was impossible to ascertain whether these spawners had come up the river from Hammond Bay or had dropped down from Ocqueoc Lake where they may have been unsuccessful in locating the inlet of the Ocqueoc River. No spawning sea lampreys could be found in the upper river during the second week in

July. Since individuals could still be taken in Ocqueoc Lake by means of gill nets as late as July 15 (Table 6), I consider the lake as the most probable source. Netting operations undertaken in the lake on August 1 and August 31 to September 1 did not yield any additional sea lampreys.

(2) Length, weight and sex ratio of samples:--Of 679 sea lampreys collected in the Ocqueoc River, 364 or 53.6 percent were males and 315 or 46.4 percent were females. This is a ratio of 116 males:100 females.

The average total length of 364 males was 16.2 inches (412 mm.). They ranged in length from 12.5 to 19.4 inches (318 to 493 mm.). The average weight of 306 unspawned, migrant males was 154 grams (5.4 ounces) and they varied from 73 to 300 grams (2.6 to 10.6 ounces).

The average total length of 315 females was 16.3 inches (414 mm.) and they ranged in length from 12.0 to 21.1 inches (305 to 536 mm.). The average weight of 275 unspawned, migrant females was 165 grams (5.8 ounces) and they varied from 70 to 316 grams (2.5 to 11.2 ounces).

Both ranges and averages of length and weight values for the Ocqueoc River run are appreciably lower than those given for the complete run taken in the Carp Creek. I do not believe that any such real difference exists in the length and weight composition of the two runs. An analysis of the sampling procedure as undertaken in the Ocqueoc River suggests that it was selective in favor of the smaller specimens. During the latter part of the spawning season, there was a visible decline in the size of males and females on the spawning grounds. The very smallest specimens seen and collected during 1947 were found on the upper Ocqueoc River spawning grounds during the last week in June and the first three days of July. These field observations agree with the data presented for Carp Creek wherein it was demonstrated that the average size of the upstream migrants declined during the latter half of the run. Our collections in the Ocqueoc River were made primarily at the Ocqueoc falls, during and after the peak concentrations of migrants there. Furthermore, collections on the spawning grounds were made almost entirely in the latter half of the period of spawning activity. For these reasons, I conclude that the data on the range and average of size for the Ocqueoc River run was influenced by the period during which collections were made.

The primary collecting technique used, capture by hand, also favored the smaller specimens. It is obviously easier to grasp and hold a 14-inch sea lamprey than one which is 18 or 20 inches long.

The validity of the more equal sex ratio displayed in the Ocqueoc River samples cannot be determined since data on the sex composition of the entire run and any differential migration by sexes is lacking.

## IV. Biological characteristics of spawning runs

### A. Length composition of spawning runs

In order to demonstrate the length composition of sea lampreys in spawning runs, a tabulation of length-frequencies for the 1,600 sea lampreys taken in the Carp Creek and the 679 specimens collected in the Ocqueoc watershed is presented in Table 8.

Male sea lampreys entering Carp Creek varied from 13.0 to 22.4 inches (330 to 569 mm.) and averaged 17.4 inches (442 mm.) with a standard deviation of ± 1.52 inches (38 mm.). Female sea lampreys varied from 12.0 to 22.6 inches (305 to 574 mm.) and averaged 17.4 inches with a standard deviation of ± 1.60 (41 mm.). The sexes combined average 17.4 inches with a standard deviation of ± 1.55 inches (39 mm.). These data for the Carp Creek sea lampreys are presented pictorially by histograms in Figure 12.

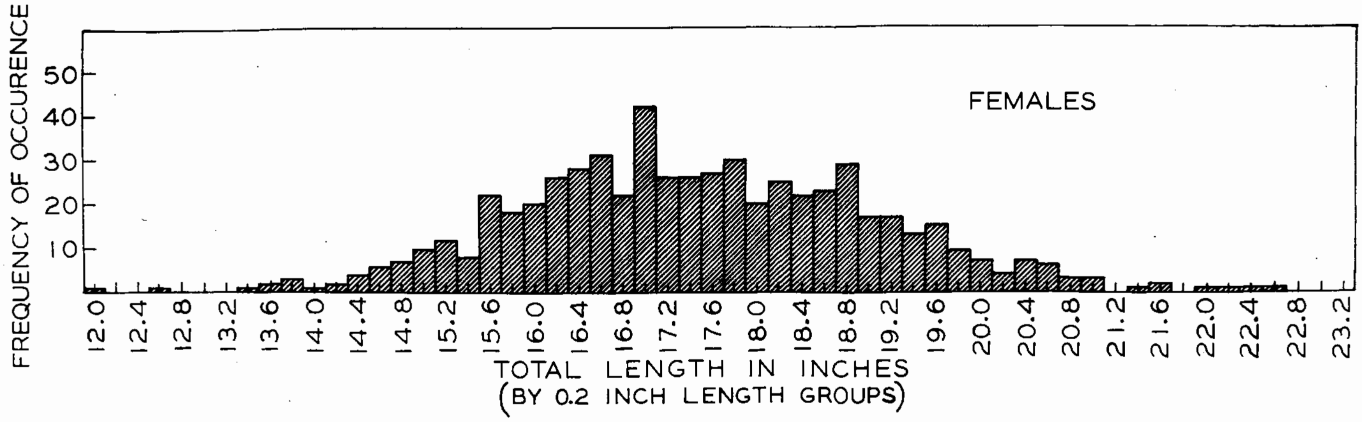
Table 8. Length-frequency table for sea lampreys collected in Carp Creek, Ocqueoc River and Ocqueoc Lake, Presque Isle County, in 1947.

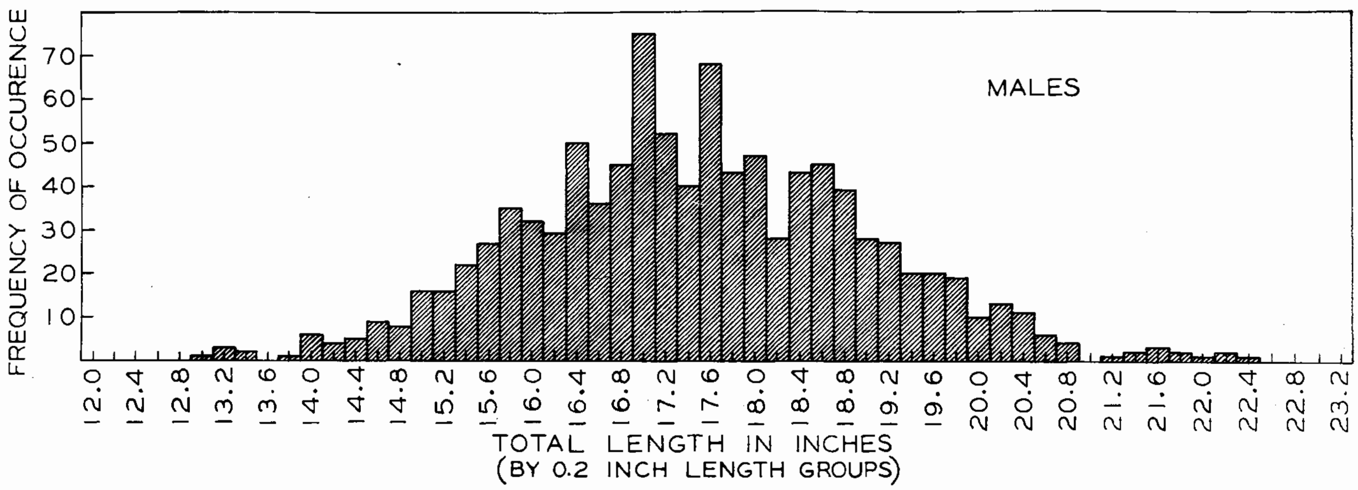
| Size to nearest 0.1 inch | Carp Creek | | | Ocqueoc River and Ocqueoc Lake | | |
|---|---|---|---|---|---|---|
| | Males | Females | Sexes combined | Males | Females | Sexes combined |
| 12.0 | ... | 1 | 1 | ... | 1 | 1 |
| .1 | ... | ... | ... | ... | ... | ... |
| .2 | ... | ... | ... | ... | ... | ... |
| .3 | ... | ... | ... | ... | ... | ... |
| .4 | ... | ... | ... | ... | ... | ... |
| .5 | ... | ... | ... | 1 | ... | 1 |
| .6 | ... | 1 | 1 | ... | 1 | 1 |
| .7 | ... | ... | ... | ... | ... | ... |
| .8 | ... | ... | ... | ... | ... | ... |
| .9 | ... | ... | ... | ... | 1 | 1 |
| 13.0 | 1 | ... | 1 | ... | 1 | 1 |
| .1 | 2 | ... | 2 | 2 | 2 | 4 |
| .2 | 1 | ... | 1 | 1 | 4 | 5 |
| .3 | ... | ... | ... | 1 | ... | 1 |
| .4 | 2 | 1 | 3 | ... | 1 | 1 |
| .5 | ... | ... | ... | 1 | 1 | 2 |
| .6 | ... | 2 | 2 | 1 | ... | 1 |
| .7 | ... | 2 | 2 | 3 | 2 | 5 |
| .8 | 1 | 1 | 2 | 2 | ... | 2 |
| .9 | 4 | ... | 4 | 1 | 1 | 2 |
| 14.0 | 2 | 1 | 3 | 2 | 1 | 3 |
| .1 | 2 | ... | 2 | 2 | 2 | 4 |
| .2 | 2 | 2 | 4 | 7 | 2 | 9 |
| .3 | 2 | 1 | 3 | 5 | 4 | 9 |
| .4 | 3 | 3 | 6 | 7 | 5 | 12 |
| .5 | 2 | 1 | 3 | 5 | 4 | 9 |
| .6 | 7 | 5 | 12 | 7 | 3 | 10 |
| .7 | 4 | 6 | 10 | 6 | 9 | 15 |
| .8 | 4 | 1 | 5 | 7 | 9 | 16 |
| .9 | 6 | 4 | 10 | 7 | 2 | 9 |
| 15.0 | 10 | 6 | 16 | 9 | 6 | 15 |
| .1 | 7 | 10 | 17 | 9 | 9 | 18 |
| .2 | 9 | 2 | 11 | 10 | 9 | 19 |
| .3 | 8 | 6 | 14 | 12 | 7 | 19 |
| .4 | 14 | 2 | 16 | 4 | 5 | 9 |
| .5 | 11 | 17 | 28 | 15 | 10 | 25 |
| .6 | 16 | 5 | 21 | 6 | 10 | 16 |
| .7 | 12 | 5 | 17 | 8 | 8 | 16 |
| .8 | 23 | 13 | 36 | 13 | 4 | 17 |
| .9 | 15 | 9 | 24 | 10 | 16 | 26 |
| 16.0 | 17 | 11 | 28 | 11 | 10 | 21 |
| .1 | 14 | 9 | 23 | 7 | 5 | 12 |
| .2 | 15 | 17 | 32 | 14 | 5 | 19 |
| .3 | 34 | 14 | 48 | 7 | 9 | 16 |
| .4 | 16 | 14 | 30 | 12 | 8 | 20 |
| .5 | 16 | 20 | 36 | 12 | 9 | 21 |
| .6 | 20 | 11 | 31 | 9 | 6 | 15 |
| .7 | 21 | 11 | 32 | 9 | 4 | 13 |
| .8 | 24 | 11 | 35 | 10 | 12 | 22 |
| .9 | 38 | 20 | 58 | 9 | 4 | 13 |
| 17.0 | 37 | 22 | 59 | 4 | 6 | 10 |
| .1 | 22 | 9 | 31 | 10 | 6 | 16 |
| .2 | 30 | 17 | 47 | 10 | 9 | 19 |
| [illegible] | [illegible] | [illegible] | [illegible] | 9 | 11 | 20 |

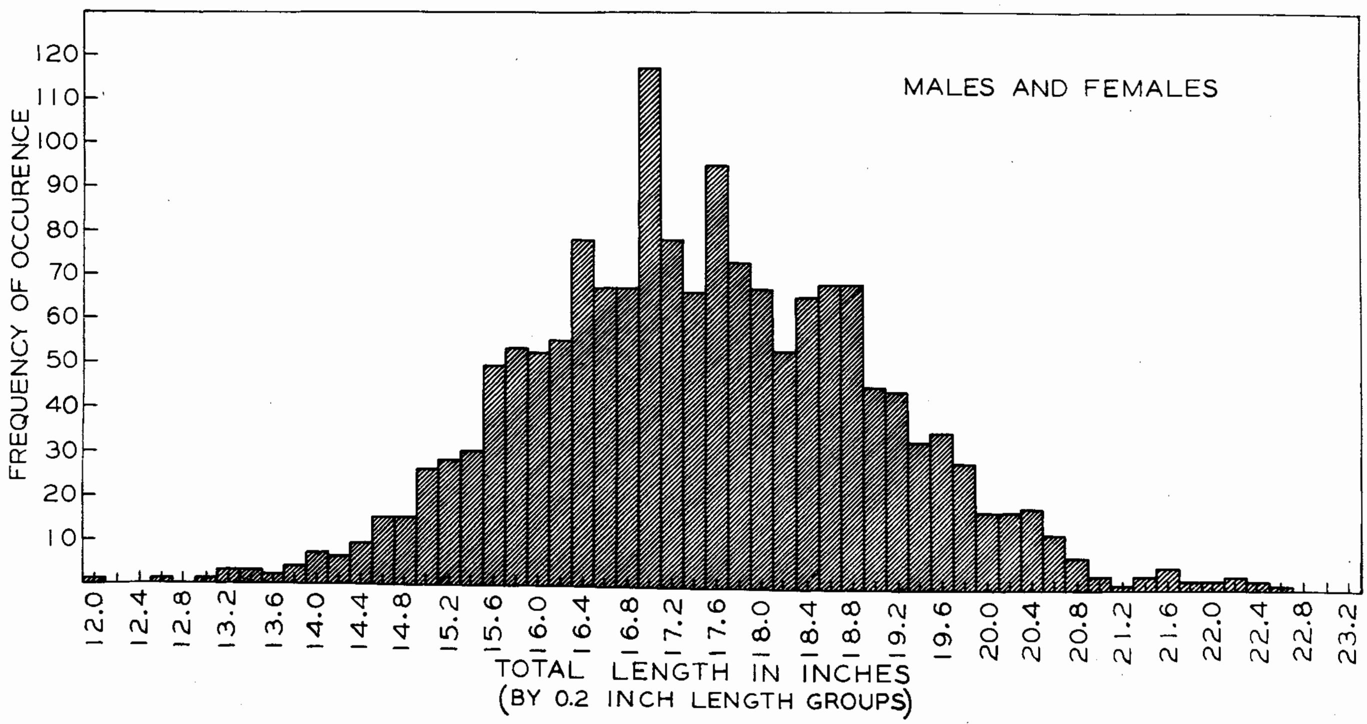
| | | | | | | |
|---|---|---|---|---|---|---|
| .9 | 15 | 9 | 24 | 10 | 10 | 20 |
| 16.0 | 17 | 11 | 28 | 11 | 10 | 21 |
| .1 | 14 | 9 | 23 | 7 | 5 | 12 |
| .2 | 15 | 17 | 32 | 14 | 5 | 19 |
| .3 | 34 | 14 | 48 | 7 | 9 | 16 |
| .4 | 16 | 14 | 30 | 12 | 8 | 20 |
| .5 | 16 | 20 | 36 | 12 | 9 | 21 |
| .6 | 20 | 11 | 31 | 9 | 6 | 15 |
| .7 | 21 | 11 | 32 | 9 | 4 | 13 |
| .8 | 24 | 11 | 35 | 10 | 12 | 22 |
| .9 | 38 | 20 | 58 | 9 | 4 | 13 |
| 17.0 | 37 | 22 | 59 | 4 | 6 | 10 |
| .1 | 22 | 9 | 31 | 10 | 6 | 16 |
| .2 | 30 | 17 | 47 | 10 | 9 | 19 |
| .3 | 16 | 16 | 32 | 9 | 11 | 20 |
| .4 | 24 | 10 | 34 | 6 | 3 | 9 |
| .5 | 40 | 14 | 54 | 4 | 4 | 8 |
| .6 | 28 | 13 | 41 | 1 | 5 | 6 |
| .7 | 21 | 17 | 38 | 9 | 7 | 16 |
| .8 | 22 | 13 | 35 | 7 | 3 | 10 |
| .9 | 19 | 5 | 24 | 7 | 4 | 11 |
| 18.0 | 28 | 15 | 43 | 2 | 4 | 6 |
| .1 | 15 | 9 | 24 | 2 | 4 | 6 |
| .2 | 13 | 16 | 29 | 8 | 3 | 11 |
| .3 | 18 | 12 | 30 | 5 | 4 | 9 |
| .4 | 25 | 10 | 35 | 1 | 2 | 3 |
| .5 | 23 | 11 | 34 | 2 | 4 | 6 |
| .6 | 22 | 12 | 34 | 1 | ... | 1 |
| .7 | 19 | 13 | 32 | 3 | 3 | 6 |
| .8 | 20 | 16 | 36 | 1 | 1 | 2 |
| .9 | 16 | 5 | 21 | 2 | 3 | 5 |
| 19.0 | 12 | 12 | 24 | 4 | 3 | 7 |
| .1 | 13 | 7 | 20 | 1 | 1 | 2 |
| .2 | 14 | 10 | 24 | ... | 2 | 2 |
| .3 | 13 | 3 | 16 | ... | 3 | 3 |
| .4 | 7 | 10 | 17 | 1 | 1 | 2 |
| .5 | 8 | 4 | 12 | ... | 1 | 1 |
| .6 | 12 | 11 | 23 | ... | ... | ... |
| .7 | 7 | 4 | 11 | ... | 3 | 3 |
| .8 | 12 | 5 | 17 | ... | ... | ... |
| .9 | 4 | 5 | 9 | ... | 1 | 1 |
| 20.0 | 6 | 2 | 8 | ... | ... | ... |
| .1 | 8 | 2 | 10 | ... | ... | ... |
| .2 | 5 | 2 | 7 | ... | ... | ... |
| .3 | 7 | 5 | 12 | ... | ... | ... |
| .4 | 4 | 2 | 6 | ... | ... | ... |
| .5 | 3 | 5 | 8 | ... | 1 | 1 |
| .6 | 3 | 1 | 4 | ... | ... | ... |
| .7 | 2 | 2 | 4 | ... | ... | ... |
| .8 | 2 | 1 | 3 | ... | ... | ... |
| .9 | ... | 1 | 1 | ... | ... | ... |
| 21.0 | ... | 2 | 2 | ... | ... | ... |
| .1 | 1 | ... | 1 | ... | 1 | 1 |
| .2 | ... | ... | ... | ... | ... | ... |
| .3 | 1 | ... | 1 | ... | ... | ... |
| .4 | 1 | 1 | 2 | ... | ... | ... |
| .5 | 2 | ... | 2 | ... | ... | ... |
| .6 | 1 | 2 | 3 | ... | ... | ... |
| .7 | 1 | ... | 1 | ... | ... | ... |
| .8 | 1 | ... | 1 | ... | ... | ... |
| .9 | 1 | ... | 1 | ... | ... | ... |
| 22.0 | ... | 1 | 1 | ... | ... | ... |
| .1 | 2 | 1 | 3 | ... | ... | ... |
| .2 | ... | ... | ... | ... | ... | ... |
| .3 | ... | 1 | 1 | ... | ... | ... |
| .4 | 1 | ... | 1 | ... | ... | ... |
| .5 | ... | ... | ... | ... | ... | ... |
| .6 | ... | 1 | 1 | ... | ... | ... |
| .7 | ... | ... | ... | ... | ... | ... |
| .8 | ... | ... | ... | ... | ... | ... |

| | | | | | | |
|---|---|---|---|---|---|---|
| .7 | 2 | 2 | 4 | ... | ... | ... |
| .8 | 2 | 1 | 3 | ... | ... | ... |
| .9 | ... | 1 | 1 | ... | ... | ... |
| 21.0 | ... | 2 | 2 | ... | ... | ... |
| .1 | 1 | ... | 1 | ... | 1 | 1 |
| .2 | ... | ... | ... | ... | ... | ... |
| .3 | 1 | ... | 1 | ... | ... | ... |
| .4 | 1 | 1 | 2 | ... | ... | ... |
| .5 | 2 | ... | 2 | ... | ... | ... |
| .6 | 1 | 2 | 3 | ... | ... | ... |
| .7 | 1 | ... | 1 | ... | ... | ... |
| .8 | 1 | ... | 1 | ... | ... | ... |
| .9 | 1 | ... | 1 | ... | ... | ... |
| 22.0 | ... | 1 | 1 | ... | ... | ... |
| .1 | 2 | 1 | 3 | ... | ... | ... |
| .2 | ... | ... | ... | ... | ... | ... |
| .3 | ... | 1 | 1 | ... | ... | ... |
| .4 | 1 | ... | 1 | ... | ... | ... |
| .5 | ... | ... | ... | ... | ... | ... |
| .6 | ... | 1 | 1 | ... | ... | ... |
| .7 | ... | ... | ... | ... | ... | ... |
| .8 | ... | ... | ... | ... | ... | ... |
| .9 | ... | ... | ... | ... | ... | ... |
| 23.0 | ... | ... | ... | ... | ... | ... |
| Totals | 997 | 603 | 1,600 | 364 | 315 | 679 |
| Mean length | 17.4 | 17.4 | 17.4 | 16.2 | 16.3 | ... |
| Standard deviation | ± 1.52 | ± 1.60 | ± 1.55 | ... | ... | ... |

Figure 12. Length-frequency diagrams for migratory sea lampreys taken in Carp Creek, Presque Isle County, in 1947.


FEMALES
FREQUENCY OF OCCURENCE
10 20 30 40 50
12.0 12.4 12.8 13.2 13.6 14.0 14.4 14.8 15.2 15.6 16.0 16.4 16.8 17.2 17.6 18.0 18.4 18.8 19.2 19.6 20.0 20.4 20.8 21.2 21.6 22.0 22.4 22.8 23.2
TOTAL LENGTH IN INCHES
(BY 0.2 INCH LENGTH GROUPS)


MALES
FREQUENCY OF OCCURENCE
10 20 30 40 50 60 70
12.0 12.4 12.8 13.2 13.6 14.0 14.4 14.8 15.2 15.6 16.0 16.4 16.8 17.2 17.6 18.0 18.4 18.8 19.2 19.6 20.0 20.4 20.8 21.2 21.6 22.0 22.4 22.8 23.2
TOTAL LENGTH IN INCHES
(BY 0.2 INCH LENGTH GROUPS)


MALES AND FEMALES
FREQUENCY OF OCCURENCE
10 20 30 40 50 60 70 80 90 100 110 120
12.0 12.4 12.8 13.2 13.6 14.0 14.4 14.8 15.2 15.6 16.0 16.4 16.8 17.2 17.6 18.0 18.4 18.8 19.2 19.6 20.0 20.4 20.8 21.2 21.6 22.0 22.4 22.8 23.2
TOTAL LENGTH IN INCHES
(BY 0.2 INCH LENGTH GROUPS)

An examination of tabular length-frequency data (Table 8) indicates a platykurtic distribution of lengths in the spawning population entering Carp Creek (i.e. the length-frequency distribution is somewhat flatter than a normal curve of distribution would be). The standard deviations of the sexes both separately and combined are high.

Possible interpretations of these data are ambiguous. Platykurtic distributions accompanied by high standard deviations reflect either high variability or some heterogeneity in the sample. In the case of a fish population such as these sea lampreys, this heterogeneity could be one of either age or origin. By heterogeneity of origin it is meant that the individuals composing this sea lamprey run may have come from widely separated localities of diverse characteristics in Lake Huron. Irregularities in the length composition of certain lake fish taken within the limits of Saginaw Bay alone have been attributed to this phenomenon according to Dr. Ralph Hile (verbal communication).

The determination of which of these characteristics is displayed in the Carp Creek data is of considerable importance in determining the biology of the species. For example, it would be of value to know if the sexually mature sea lampreys entering a stream to spawn are homogenous as to age or whether runs are composed of individuals of several age groups. Should the latter condition obtain, it would render any determination of length of the parasitic period based on collections of sexually immature individuals from the Great Lakes extremely difficult to make (as yet, no method has been devised to determine the age in years of adult sea lampreys).

Until additional data can be examined, we must consider that several possible interpretations of the data presented herein exist: (1) Either the spawning populations entering Carp Creek are characterized by a high morphological variability and are homogenous as to age and/or origin, or, (2) they are characterized by a lesser morphological variability (in length) and are heterogenous as to age and/or origin.

The length composition of the collections from the Ocqueoc watershed was not critically examined since the lampreys in it are a selected sample. Length-frequency data for the Ocqueoc River specimens are presented in Table 8 primarily to demonstrate the richer representation of smaller size groups (12 to 15 inches) as found in this, a much larger run, than in that for Carp Creek.

B. <u>Weight composition of spawning runs</u>

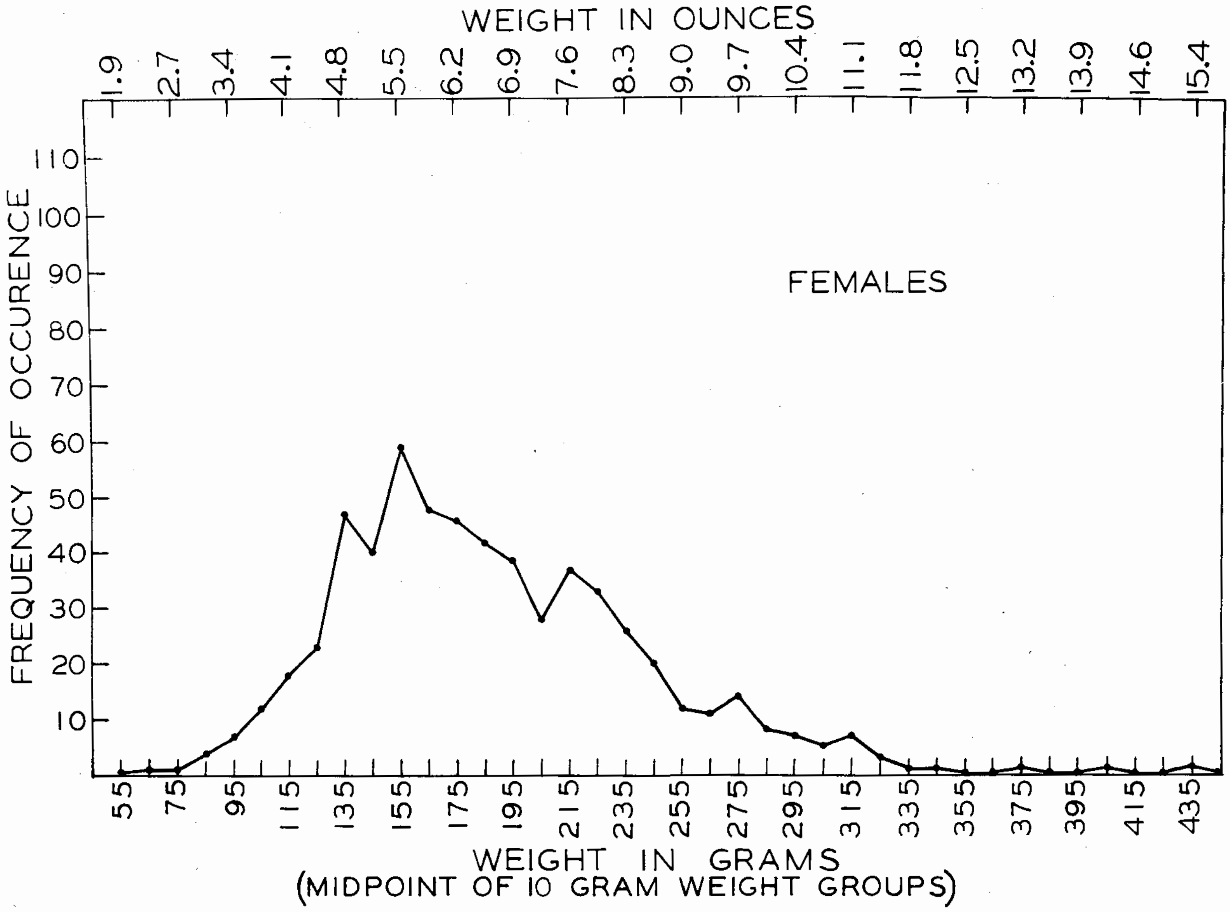
Weight-frequency data for 1,599 sea lampreys taken from Carp Creek are presented in Table 9. These data are presented separately for the males and the females. Male sea lampreys varied from 59 to 400 grams (2.1-14.1 ounces) and averaged 181.6 grams (6.4 ounces). Females varied in weight from 61 to 436 grams (2.1-15.4 ounces) and had a mean weight of 186.6 grams (6.6 ounces). Weight-frequency polygons for both males and females display a positive skewness (Figure 13). As a result, the modal weight values (i.e. most frequently encountered weights of migrating sea lampreys) for both sexes are appreciably lower than computed mean weights. The marked asymmetry of the weight-frequency distributions may again indicate some form of heterogeneity in the spawning run.

The actual total weight of all individuals comprising a run is surprisingly small. The total weight of the 1,617 sea lampreys taken in Carp Creek (which constituted 99 plus percent of the run) was 654 pounds. If we utilize the maximum estimate for the run entering the Ocqueoc River in 1947, 10,000 sea lampreys, and assign these migrants an average weight of 6.5 ounces for both sexes combined, we find that the total weight of the run in that river was very close to 4,062 pounds. These data indicate

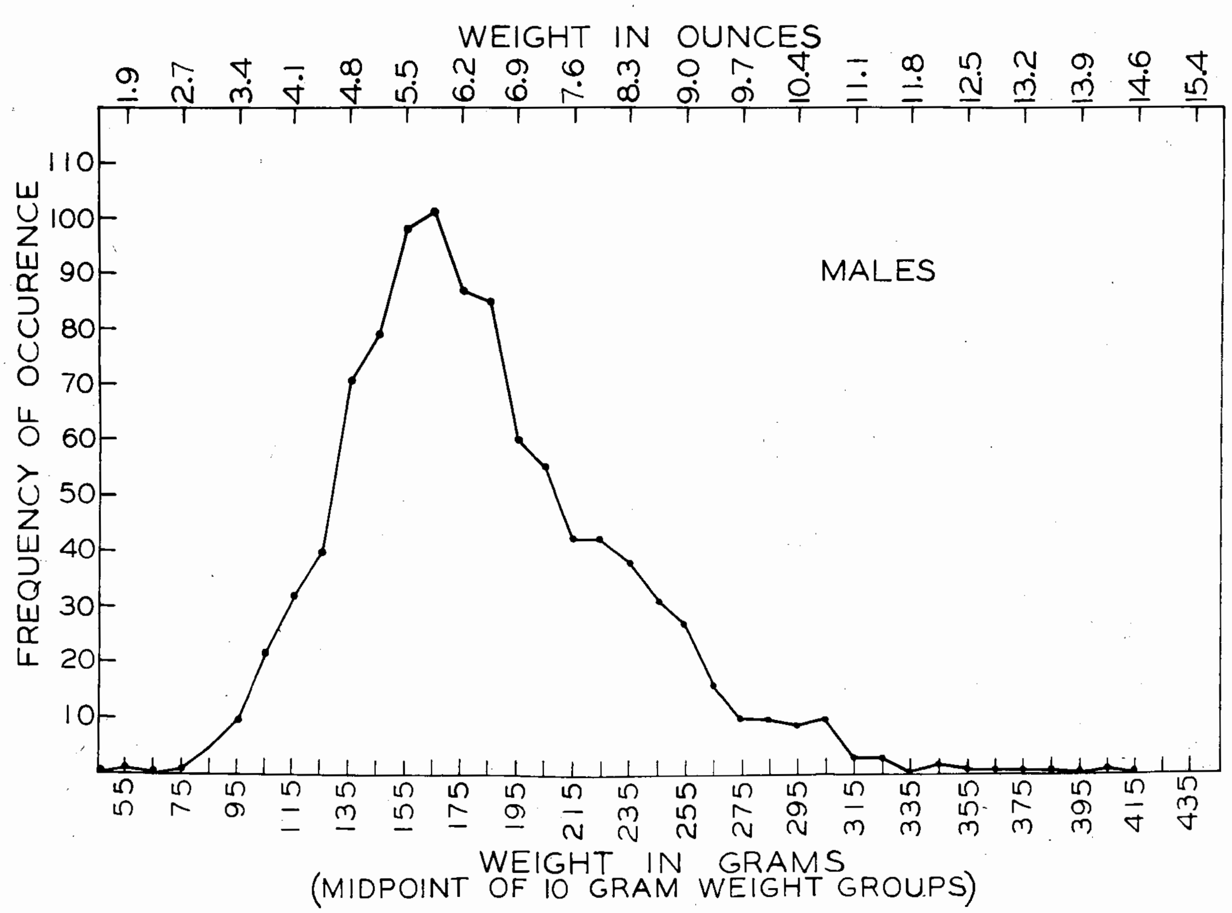
Table 9. Weight-frequency table for 1,599 sea lampreys collected in Carp Creek, Presque Isle County, in 1947.

| Weight group (10-gram interval) | Males | Females | Sexes combined |
|---|---|---|---|
| 50 - 59 | 1 | ... | 1 |
| 60 - 69 | ... | 1 | 1 |
| 70 - 79 | 1 | 1 | 2 |
| 80 - 89 | 5 | 4 | 9 |
| 90 - 99 | 10 | 7 | 17 |
| 100 - 109 | 22 | 12 | 34 |
| 110 - 119 | 32 | 18 | 50 |
| 120 - 129 | 40 | 23 | 63 |
| 130 - 139 | 71 | 47 | 118 |
| 140 - 149 | 79 | 40 | 119 |
| 150 - 159 | 98 | 59 | 157 |
| 160 - 169 | 101 | 48 | 149 |
| 170 - 179 | 87 | 46 | 133 |
| 180 - 189 | 85 | 42 | 127 |
| 190 - 199 | 60 | 39 | 99 |
| 200 - 209 | 55 | 28 | 83 |
| 210 - 219 | 42 | 37 | 79 |
| 220 - 229 | 42 | 33 | 75 |
| 230 - 239 | 38 | 26 | 64 |
| 240 - 249 | 31 | 20 | 51 |
| 250 - 259 | 27 | 12 | 39 |
| 260 - 269 | 16 | 11 | 27 |
| 270 - 279 | 10 | 14 | 24 |
| 280 - 289 | 10 | 8 | 18 |
| 290 - 299 | 9 | 7 | 16 |
| 300 - 309 | 10 | 5 | 15 |
| 310 - 319 | 3 | 7 | 10 |
| 320 - 329 | 3 | 3 | 6 |
| 330 - 339 | 1 | 1 | 2 |
| 340 - 349 | 2 | 1 | 3 |
| 350 - 359 | 1 | ... | 1 |
| 360 - 369 | 1 | ... | 1 |
| 370 - 379 | 1 | 1 | 2 |
| 380 - 389 | 1 | ... | 1 |
| 390 - 399 | ... | ... | ... |
| 400 - 409 | 1 | 1 | 2 |
| 410 - 419 | ... | ... | ... |
| 420 - 429 | ... | ... | ... |
| 430 - 439 | ... | 1 | 1 |
| Totals | 996 | 603 | 1,599 |

Figure 13. Weight-frequency diagrams for male and female sea lampreys taken in the Carp Creek weir and trap in 1947.



WEIGHT IN OUNCES
1.9
2.7
3.4
4.1
4.8
5.5
6.2
6.9
7.6
8.3
9.0
9.7
10.4
11.1
11.8
12.5
13.2
13.9
14.6
15.4
FREQUENCY OF OCCURENCE
FEMALES
WEIGHT IN GRAMS
(MIDPOINT OF 10 GRAM WEIGHT GROUPS)

WEIGHT IN OUNCES
FREQUENCY OF OCCURENCE
MALES
WEIGHT IN GRAMS
(MIDPOINT OF 10 GRAM WEIGHT GROUPS)

that even where large sea lamprey runs are present, the total poundages that might be removed for commercial purposes are not of encouraging proportions.

C. Relationship between length and weight in spawning runs.

Both length and weight data were obtained for 2,180 sea lampreys collected during 1947, 1,303 of which were males and 877 females. Of the total, 1,599 were taken in Carp Creek and 581 in the Ocqueoc River. Average weights by 0.2-inch length groups were computed separately for the males and females of each of the two runs. A comparison of corresponding sexes from both watersheds indicated no significant differences in the length-weight relationship. For this reason, the length and weight data for both runs were combined (Table 10), sexes separate. The empirically determined averages for the males and females were plotted separately upon graphs and curves were fitted to these points by inspection (Figs. 14 and 15).

In general, the weight of sea lampreys does not increase as rapidly with length as does the weight of many higher fishes (Beckman, 1948?). This is attributable to their more attenuate or snake-like body form; it is most evident in the male sea lampreys whose weight remains more or less directly proportionate to the length until a size of 19.5 to 20.0 inches is attained. Thereafter, weight increases rather rapidly with length (Fig. 14).

Among the females, weight increases more noticeably with length but the validity of this relationship is questionable due to the profound effect of the developing ovary upon the total weight of the female (Fig. 15).

The variation in weight at any given length is generally great and increases with increase in length. Occasionally, the heaviest specimen in a 0.2-inch length group exceeded twice the weight of the lightest

Table 10. Tentative length-weight relationship of migrating sea lampreys taken in Carp Creek and the Ocqueoc River, Presque Isle County, in 1947.

| Total length in inches (by 0.2-inch length groups) | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | Number of specimens | Average weight | | Number of specimens | Average weight | |
| | | Grams | Ounces | | Grams | Ounces |
| 12.0 | ... | ... | ... | 1 | 75 | |
| .2 | ... | ... | ... | ... | ... | |
| .4 | ... | ... | ... | ... | ... | |
| .6 | ... | ... | ... | 2 | 66 | |
| .8 | ... | ... | ... | ... | ... | |
| 13.0 | 1 | 85 | 3.0 | ... | ... | |
| .2 | 5 | 90 | 3.2 | 3 | 100 | |
| .4 | 2 | 78 | 2.8 | 1 | 81 | |
| .6 | 2 | 88 | 3.1 | 2 | 130 | |
| .8 | 6 | 100 | 3.5 | 5 | 98 | |
| 14.0 | 7 | 103 | 3.6 | 3 | 93 | |
| .2 | 12 | 99 | 3.3 | 5 | 123 | |
| .4 | 17 | 105 | 3.7 | 12 | 110 | |
| .6 | 18 | 121 | 4.3 | 11 | 114 | |
| .8 | 21 | 117 | 4.1 | 18 | 117 | |
| 15.0 | 28 | 124 | 4.4 | 18 | 128 | |
| .2 | 32 | 121 | 4.3 | 23 | 123 | |
| .4 | 34 | 137 | 4.8 | 19 | 128 | |
| .6 | 45 | 132 | 4.7 | 37 | 133 | |
| .8 | 55 | 139 | 4.9 | 30 | 137 | |
| 16.0 | 50 | 143 | 4.9 | 45 | 153 | |
| .2 | 47 | 145 | 5.1 | 36 | 150 | |
| .4 | 67 | 153 | 5.4 | 42 | 155 | |
| .6 | 50 | 162 | 5.7 | 46 | 157 | |
| .8 | 63 | 163 | 5.7 | 38 | 163 | |
| 17.0 | 83 | 162 | 5.7 | 52 | 173 | |
| .2 | 70 | 171 | 6.0 | 41 | 177 | |
| .4 | 52 | 174 | 6.1 | 38 | 181 | |
| .6 | 73 | 182 | 6.4 | 36 | 184 | |
| .8 | 55 | 191 | 6.7 | 39 | 191 | |
| 18.0 | 54 | 187 | 6.6 | 27 | 197 | |
| .2 | 37 | 198 | 7.0 | 31 | 209 | |
| .4 | 48 | 206 | 7.3 | 28 | 222 | |
| .6 | 48 | 219 | 7.7 | 27 | 225 | |
| .8 | 43 | 213 | 7.5 | 33 | 221 | |
| 19.0 | 34 | 226 | 8.0 | 23 | 229 | |
| .2 | 28 | 237 | 8.4 | 20 | 243 | |
| .4 | 21 | 240 | 8.4 | 17 | 263 | |
| .6 | 20 | 250 | 8.8 | 16 | 252 | |
| .8 | 19 | 252 | 8.9 | 12 | 264 | |
| 20.0 | 10 | 256 | 9.0 | 8 | 266 | |
| .2 | 13 | 271 | 9.6 | 4 | 266 | |
| .4 | 11 | 264 | 9.3 | 8 | 278 | |
| .6 | 6 | 277 | 9.8 | 7 | 274 | |
| .8 | 4 | 295 | 10.4 | 3 | 251 | |
| 21.0 | ... | ... | ... | 3 | 330 | |
| .2 | 1 | 284 | 10.0 | 1 | 316 | |
| .4 | 2 | 300 | 10.6 | ... | ... | |
| .6 | 3 | 350 | 12.3 | 2 | 361 | |
| .8 | 2 | 320 | 11.3 | ... | ... | |
| 22.0 | 1 | 400 | 14.1 | 1 | 374 | |
| .2 | 2 | 359 | 12.7 | 1 | 254 | |
| .4 | 1 | 385 | 13.6 | 1 | 318 | |
| .6 | ... | ... | ... | 1 | 436 | |
| .8 | ... | ... | ... | ... | ... | |
| 23.0 | ... | ... | ... | ... | ... | |
| Totals | 1,303 | ... | ... | 877 | ... | |

Figure 14. Length-weight relationship and range in weight at given lengths of male sea lampreys taken in Carp Creek and the Ocqueoc River.

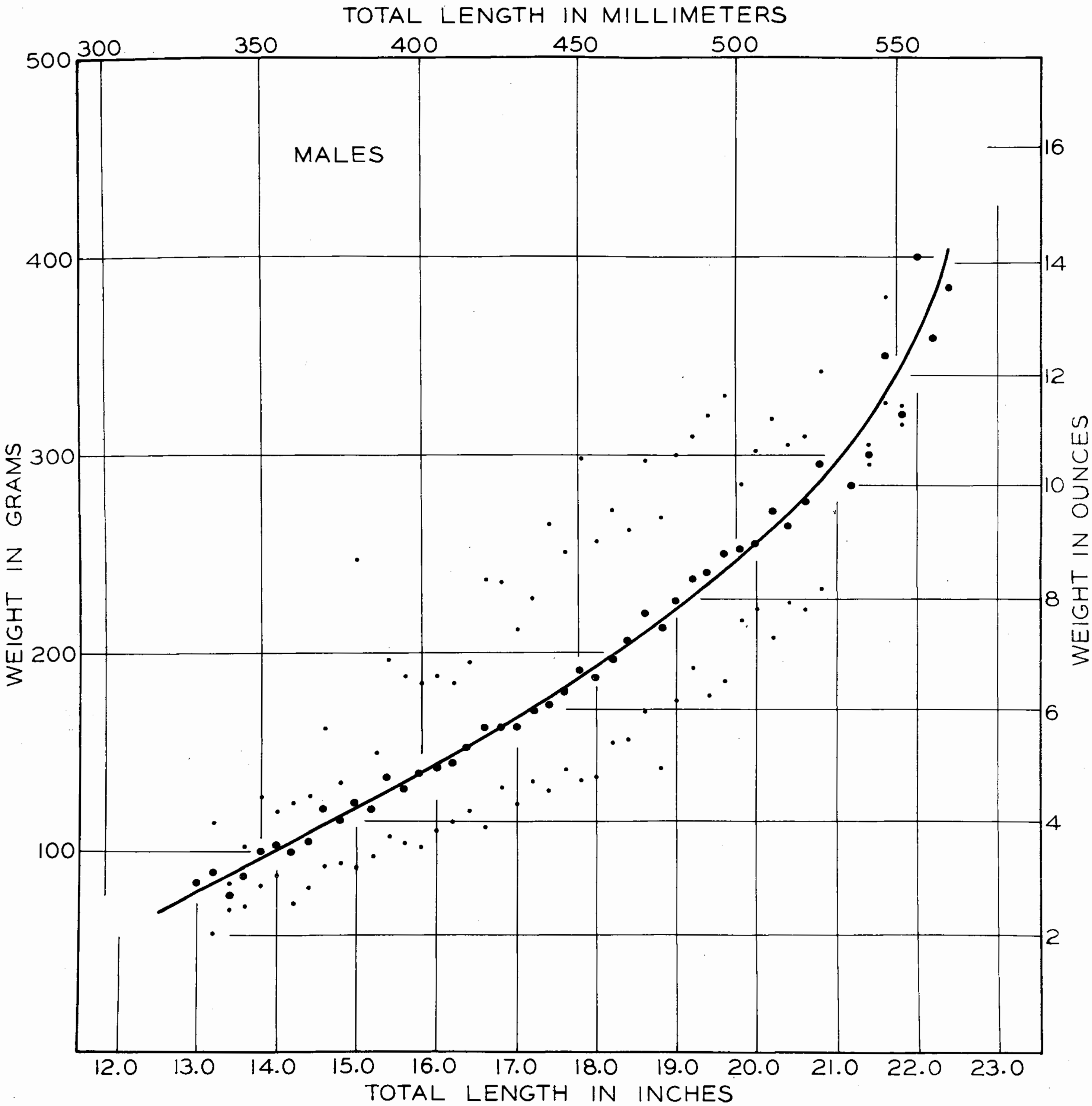
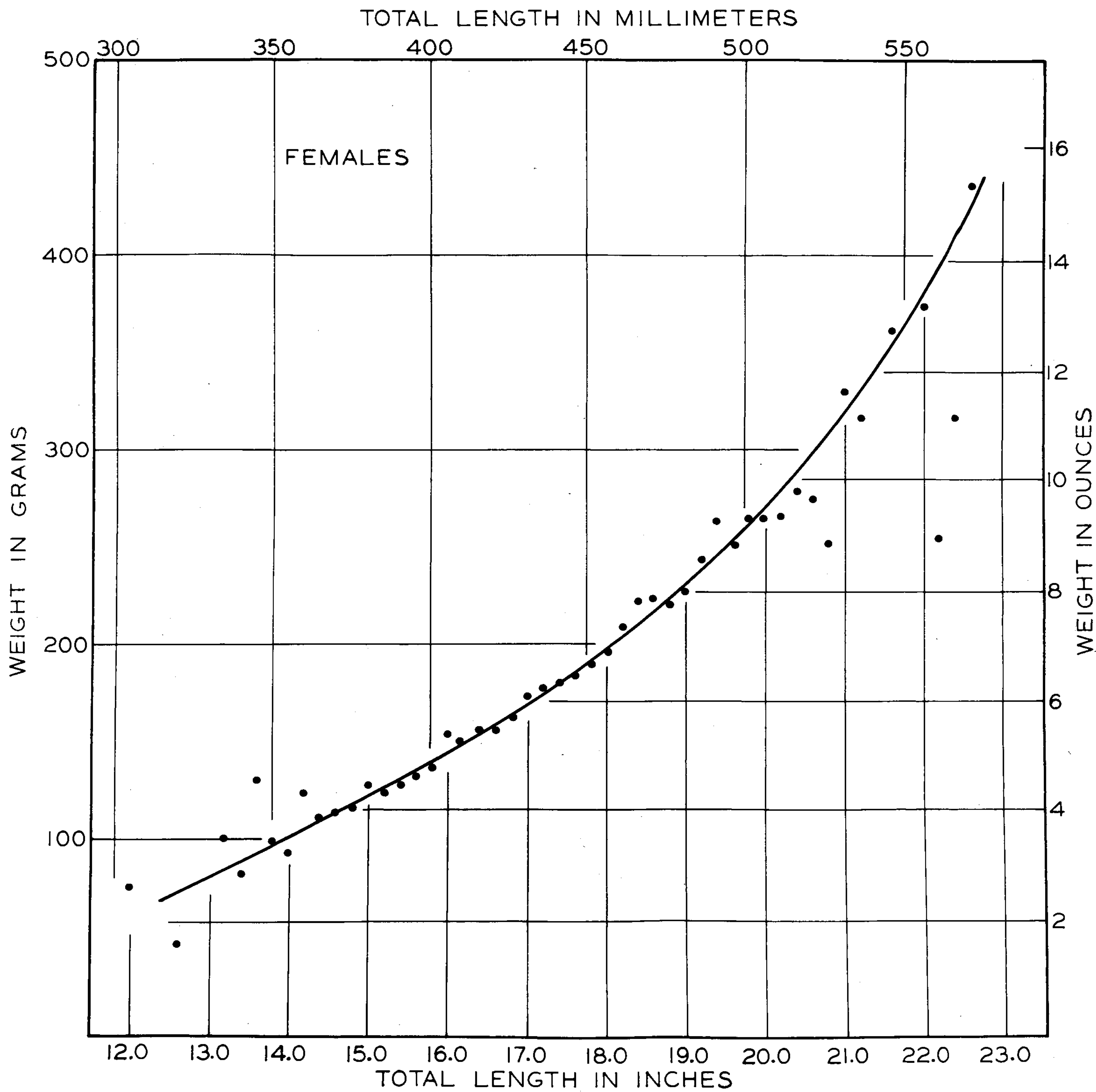

TOTAL LENGTH IN MILLIMETERS
300
350
400
450
500
550
MALES
WEIGHT IN GRAMS
500
400
300
200
100
WEIGHT IN OUNCES
16
14
12
10
8
6
4
2
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
TOTAL LENGTH IN INCHES

Figure 15. Length-weight relationship of female sea lampreys taken in Carp Creek and the Ocqueoc River.



TOTAL LENGTH IN MILLIMETERS
300
350
400
450
500
550
FEMALES
500
400
300
200
100
WEIGHT IN GRAMS
16
14
12
10
8
6
4
2
WEIGHT IN OUNCES
12.0
13.0
14.0
15.0
16.0
17.0
18.0
19.0
20.0
21.0
22.0
23.0
TOTAL LENGTH IN INCHES

specimen in the same group. This is illustrated in Figure 14 where the range in weight for each 0.2-inch length group of males has been plotted.

### D. Migratory habits and behavior.

Sea lampreys swim with a whip-like, undulatory motion which in its mechanics is identical with that of the eel (Anguilla) as described by Breder (1926) and termed by him: "anguilliform locomotion." It is very similar to the familiar movement of a snake traveling on the ground. During their upstream migration and presumably during all of the adult phase of their life cycle they are, on occasion, extremely rapid swimmers.

Sea lampreys swim normally with the oral disc closed giving the head a bullet-shaped conformity; an anteriorly cylindrical and posteriorly compressed body, covered with copious amounts of friction-reducing slime, adapt the species well to rapid locomotion. These characteristics may be particularly useful when the animal negotiates rapids and falls. When traversing areas of fast water, and when surmounting obstacles such as dams or natural falls, or when frightened, (presumably also when overtaking their prey) they are capable of amazing spurts of speed. However, these sudden spurts undoubtedly represent the terminal swimming velocity of the species and it seems unlikely that they could sustain such speeds for any appreciable distance.

When not taxed to their utmost by circumstances, the swimming habits (in migration) of the sea lamprey differ materially from those of other fishes. They seldom rest in midwater by maintaining their position and balance in the current through continual movement. Rather, when not deliberately moving upstream, changing position, or seeking their way around or over an obstacle, they cling by their mouths to a rock or log or any available solid object. This behavior was noted even under conditions of little or no current and among individuals resting in static water.

Related to their capacity for sudden bursts of speed is their ability to work their way over many natural falls and man-made dams of low or irregular construction. Surmounting such obstacles is not accomplished by spectacular leaps as among the salmon, but by throwing themselves upward and forward in short, wriggling thrusts and securing each gain by attaching themselves firmly in a new position by their oral disc. Each gain is followed by a seemingly long period of rest before another attempt to move further is begun. In this fashion, they progress slowly up and over the faces of falls, following crevices and fissures which offer the least resistance by current or vertical surface. Air chambers behind the falling water are traversed by the sea lampreys with no apparent difficulty. I have seen masses of them in such locations that were wet only by spray or occasional turbulent surges. Where falls and low dams offer vertical surfaces to be surmounted, it was noted that the sheer mass of migrating individuals "piling-up" at such a point occasionally forced the topmost individuals to a position where the barrier could be cleared in a single thrust. Mass action in these instances is thus helpful in ensuring that at least some individuals may gain the spawning grounds.

These latter observations were made in the falls of the Ocqueoc River and at several low dams on that river where it was possible to trace the routes of the lampreys over these obstructions by exploring the face of the falls by hand.

Observations at these locations and at several high dams, as those on the Cheboygan and Manistique rivers, indicate that sea lampreys can seldom "jump" vertically more than two feet although they have been occasionally observed leaping as much as four feet in a forward and slightly upward direction at the base of a natural falls. It is of interest to note that they can, and occasionally do, leap out of a 10 gallon milk can containing about 12 inches of water.

These and other behaviorisms are of some interest when trapping operations are considered. Sea lampreys observed arriving on the downstream side of the Carp Creek weir and trap did not "lead" immediately along the wings of the weir. In general, they tended to prod and explore both downstream and upstream along the barrier, seeking some small aperture through which to pass; eventually the trap entrance was discovered and entered. As a result of this searching behavior these lampreys had phenomenal success in finding and passing through the smallest of apertures in a weir face. When caught in a trap or held in live-crates, the same behavior was noted--an almost ceaseless searching for some means of escape. In 1947, I tested the ability of sea lampreys to find an opening large enough to permit their passage through a barrier screen. Eighteen migrating adults were placed in the lower of two compartments of a large live-crate that was situated in a moderate water current. The crate measured 3 by 3 by 6 feet and was made of 1/2-inch mesh hardware cloth on a light wooden frame. The depth of the water within the live-crate was approximately 20 inches. A small hole, one inch in diameter, was made in the center of the hardware cloth partition dividing the live-crate. Within four hours, all but two of the sea lampreys had found, and passed through, this hole into the upstream half of the box. For this reason, great care must be exercised in the construction and maintenance of both weirs and traps.

The physical characteristics of the lampreys and many of their natural behaviorisms make them extremely difficult to handle during trapping operations. All nets used for removing trapped specimens should have deep bags since the lampreys tend to jump and thrash violently when removed from the water. Unless considerable practice has been had, it is almost impossible to hold on to an adult sea lamprey with bare hands. When held out of the water they weave and twist violently and attempt to fasten by their mouths to the nearest solid object. Specimens which succeeded in attaching themselves to my hand or arm did nothing more than hold on--they never harmed me with either teeth or tongue. In handling live specimens, they are best grasped just behind the last gill opening in a finger lock between the middle finger and the index and fourth fingers. They may also be held by grasping them between the funnel and first gill opening between the thumb and forefinger.

Data relative to the differential migration of sexes during the spawning run and changes in its generally nocturnal nature have been presented in a preceding section.

The negative response of migrating sea lampreys to light is particularly marked during the first half of the run. In the Ocqueoc River watershed a period of six to eight weeks elapses between the entrance of the first migrants into the river and the beginning of spawning activity. Although towards the end of this period a great number of sea lampreys are present in the drainage, they are seldom if ever seen during the daylight hours. However, visits at night time to areas apparently devoid of sea lampreys during daylight reveal many migrants clinging to rocks or working their way upstream. The daylight hours are spent wedged between and under rocks, logs, brush tangles, hiding under overhanging banks or in the deeper pools. When prodded from these hiding places they dash blindly away with little regard for the direction taken. In several instances, disturbed specimens darted at right angles to the current with such force that they slithered several feet up onto a low, grassy bank or a mud flat. Generally, after traveling but a short distance, they sought to conceal themselves again by utilizing whatever cover was available. When disturbed at night by the observer shining an artificial light on them, the lampreys flee with apparent lack of direction, much as in the daytime. I have been unable to drive them ahead of me with a jacklight accompanied by splashing. The sea lampreys tend rather to scurry in all directions, mostly downstream and often between the legs of the drivers. Their fellow migrants, the suckers (Catostomus spp.), behave differently. They move from such disturbances in more or less of a growing school.

Prior to any spawning activity, migrant sea lampreys taken in streams are very tenacious of life, particularly in cool weather, and will survive much longer periods when held out of water than most other fishes will. Specimens retained in a milk can without water for six hours at about 35° F. on a spring night revived without apparent ill effects when placed in water again. The pumping action of the gill pouches is very persistent, and will last as long as 1 1/2 hours in specimens that have been "drawn" (gutted).

Both negative phototropism and vitality change with the advent of peak spawning activity. Migrants are more and more in evidence during daylight hours, particularly at obstructions to migration, and nest building and spawning activity becomes as great in the light as during the hours of darkness. Among those sea lampreys engaged in spawning, this is most probably due to the observed loss of vision which accompanies the physical degeneration taking place at this time. Most specimens observed nearing the completion of spawning were judged to be quite blind. The tendency of migrating sea lampreys to be more in evidence in daylight during the latter half of the run may be due to this ocular degeneration and/or to an urge to reach suitable grounds and commence spawning. Both or either may offset to some degree the displayed response to light of earlier migrants.

The great vitality noted in early migrants likewise disappears and late migrants bear little handling or removal from the water.

The question has often been raised as to whether or not sea lampreys feed during migration. I sought to answer this question by analyzing the contents of lamprey digestive tracts and by examining other fishes present in the same waters during a migration for lamprey scars. The dissection of migrants taken from both Carp Creek and the Ocqueoc River presents very strong evidence that feeding ceases with approaching sexual maturity and with upstream movement. Of 2,249 migrating sea lampreys examined in 1947 from Carp Creek and the Ocqueoc River, only one specimen showed any evidence of recent feeding.

Between May 29 and July 15, 1947, netting operations were undertaken in Ocqueoc Lake utilizing 125-foot experimental gill nets. Twenty-eight sets were made averaging 24 hours each. During the period of netting operations, migrant sea lampreys were concentrated in greater or lesser numbers in the lake while in passage to the upper reaches of the watershed. A total of 69 sea lampreys and 114 game, pan, and coarse fishes were taken as follows: 27 northern pike (average length: 21.7 inches, range: 13.0-32.3 inches); 41 rock bass (average length: 6.3 inches, range: 3.8-8.3 inches); 2 black bullheads (8.1 and 10.8 inches); 4 bluegills (average length: 4.0 inches); 28 yellow perch (average length: 5.7 inches); 2 largemouth bass (10.7 and 13.0 inches); 6 white suckers (average length: 13.3 inches, range: 9.0-17.8 inches); 2 walleye pike

(7.5 and 13.4 inches); and 2 pumpkinseed sunfish (average length: 3.5 inches).

Although the ratio of migrant sea lampreys to resident game fish taken in the nets was high, none of the fish bore any evidence of lamprey attacks except one 30.6-inch northern pike, taken on May 29, which had an old, healed scar. However, on May 24, 1947, a smallmouth bass about 14 inches in total length which bore a large, fresh lamprey scar was seen swimming in shoal water. Since smallmouth bass migrate into the Ocqueoc watershed from Lake Huron during this season and since many individuals of game species taken in the Carp Creek weir and trap bore lamprey scars, it is quite possible that this scarred fish may have been attacked at some earlier date while in Lake Huron.

One experimental gill net was set for a 36-hour period in Ocqueoc Lake on April 21, 1948. Seventeen northern pike (average: 19.7 inches, range: 13.7-33.9 inches); 2 rainbow trout (13.2 and 17.4 inches); 1 largemouth bass (11.0 inches); and 3 suckers (12.2, 12.2 and 12.9 inches) were taken. None had lamprey marks.

The data obtained from both netting operations and specimen dissections provide strong evidence that migrant sea lampreys seldom if ever attack and feed upon other fishes while in passage.

## E. Pathology, parasitism and predation.

### Pathology.

Of 5,135 sexually mature, migrant sea lampreys examined in 1947 and 1948, none displayed any macroscopic evidence of either bacterial or sporozoan induced infections, at least in so far as any such disease would exhibit itself by internal or external inflammations, ulcerous tissue, other obvious pathological conditions of the viscera, or by abnormal behavior.

In the samples examined, however, there were a very few individuals which displayed developmental or structural abnormalities such as those which ordinarily appear in any population of vertebrates. In the Carp Creek spawning run in 1947 (1,599 specimens examined), 3 sea lampreys (2 males, 17.1 and 18.4 inches in total length; 1 female, 14.7 inches in total length) had deformed caudal fins. A fourth specimen (male, 16.4 inches in total length) had a deformed second dorsal fin. One male sea lamprey was taken which was grotesquely short in body length in relation to its girth and other bodily development. This presumably was the result of some abnormality in the development of the notochord and musclature. The largest sea lamprey captured in 1947, a female, 22.6 inches in total length (weight: 436 grams) possessed a severely malformed ovary; the development of individual ova in this gonad was so retarded that the sex of the specimen could only be determined with the aid of a microscope. A similarly malformed and underdeveloped gonad was found in a male sea lamprey, 18.0 inches long (weight: 152 grams).

In the Carp Creek spawning run in 1948 (2,938 specimens examined), 2 sea lampreys (female, 15.0 inches, and male, 13.0 inches in total length) were taken which had deformed caudal fins. A male sea lamprey, 11.0 inches in total length, was captured whose body length was disproportionately short in relation to its other structural features. Two specimens were noted (females, 15.8 and 16.7 inches in total length) each with a small, healed perforation in the anterior body wall. In at least one of these cases the perforation opened into the body cavity. The origin of these anomalies is not clear; the position and nature of the perforations and the fact that they bore no resemblance to a former wound seems to exclude the possibility of having been originally inflicted by a spear.

It is concluded from these observations, that the migratory populations of sea lampreys examined were quite perfect physically and displayed no gross evidence of any maladjustment to their new habitat in the Lake Huron basin.

The condition of the sexually immature stocks in the Great Lakes proper is not known. Probably many unfit, metamorphosed individuals descend to the lakes and such lampreys may fall by the wayside before sexual maturity through the processes of natural selection. Presumably only the physically fit could attain sexual maturity and possess the vitality to complete the spawning migration.

These observations agree, in general, with those of Gage (1928) for the dwarf sea lamprey (lake lamprey) on its spawning grounds in inland New York waters. Among these he noted only occasional instances of abnormal structure or development.

## Parasitism.

During the 1948 spawning runs, a random sample of 100 migrating sea lampreys was carefully examined for the presence of internal parasites. This sample was collected between June 2 and 8, 1948, in the Ocqueoc River falls (69 specimens) and in Carp Creek (31 specimens). Fifty-six of the sea lampreys were males ranging from 12.6 to 18.9 inches in total length (average: 16.6 inches) and 44 were females ranging from 12.9 to 19.6 inches in total length (average: 16.4 inches).

Twenty sea lampreys (10 males and 10 females) or 20 percent of the total sample contained one or more individuals of several types of parasitic organisms within their digestive tracts. The most common of these were adults of the acanthocephalan Echinorhynchus coregoni[4] which occurred in 17 of the sea lampreys examined (9 males and 8 females). With the exception of one sea lamprey which contained three adult worms, all specimens examined had but one of these parasites in the digestive tract. This parasite has commonly been reported from whitefish and various other northern fishes.

Single, immature specimens of cestodes were found in the intestines of three sea lampreys; two of these tapeworms were identifiable--the third was not. Identified from the scolex only, one was found to be a larva of Trianophorus (crassus?)[5]. The adult of this tapeworm lives only in the northern pike, Esox lucius, where it matures, lays its eggs during the pike spawning season, and then dies. The eggs hatch into a ciliated coracidium which dies if not swallowed by the copepod, Cyclops bicuspidatus, within several days. In the copepod, it becomes a procercoid and after 10 days is ready to infest a corogonine fish; the procercoid is liberated by digestive juices when swallowed by such a fish. After liberation it burrows through the stomach wall, crosses the body cavity, and enters the flesh of the back. Here it becomes a plerocercoid and becomes enclosed in a cyst supplied by the host. The final host, the pike, becomes infected when eating an infected corogonine fish (Kennedy, 1948).

Larval cysts of Trianophorus crassus are found frequently, and occasionally in some abundance, in the flesh of the whitefish and tullibee (Cameron, 1945; Kennedy, 1948). It has been observed, that sea lampreys are now feeding extensively on whitefish in northern Lake Huron. Presumably, then, this larval tapeworm is traceable to this source. It is

---

[4] Identified by Dr. H. J. Van Cleave of the University of Illinois.
[5] Identified by Prof. A. E. Woodhead, Dept. of Zoology, University of Michigan.

considered doubtful if the plerocercoid larvae thus acquired by sea lampreys could ever become mature as the latter constitute an unnatural final host.

The other identifiable tapeworm was an immature specimen of Abothrium sp.[6] This parasite utilizes the crustacean, cyclops, as an intermediate host and any of several species of fish as a final host. Procercoid larvae can develop to maturity without another change in host. It is known to infect trout, coregonids and smelt (Plehn, 1924) and Burbot (Van Cleave and Mueller, 1934; Bangham, 1946). However, since the larvae are normally found imbedded in the intestinal wall of the above named hosts, the manner in which the sea lamprey carrying this parasite became infected is somewhat obscure.

Occasional sea lampreys were taken in 1947 and 1948 which had small tumor-like swellings in the wall of the intestine. Five such specimens were taken from Carp Creek in 1947 (1,599 sea lampreys examined) and 11 similarly afflicted specimens from the same stream in 1948 (2,938 sea lampreys examined). The majority of these swellings were examined and proved to be cysts. However, in each case the contents of the cysts were in a disintegrated condition and could not be identified. The circumstances suggest strongly that these cysts were those of nematode larvae which had died, according to A. E. Woodhead (verbal communication).

Although a large percentage of the total sample of sea lampreys contained internal parasites of one form or another, no single specimen contained enough parasites to constitute a severe or apparently harmful infection.

Occasional sea lampreys taken in the Carp Creek trap in 1948 had

---

[6] Identified by Prof. A. E. Woodhead, Dept. of Zoology, University of Michigan.

leeches attached to them. One of these, identical with the others observed, was identified as Piscicola milneri (Verrill, 1874)[7].

## Predation.

Since the beginning of the present investigation, occasional observations were made, or reports received, of predation upon migratory or spawning sea lampreys by fishes, birds and mammals. Perhaps the most interesting observations are those of predation by fishes. On June 27, 1947, a walleyed pike, 17.0 inches in total length, taken on a lure in Ocqueoc Lake, was found to have swallowed a mature, adult, female sea lamprey 14.5 inches long. At the time of capture, several inches of the sea lamprey's tail was still protruding from the pike's mouth. In the stomach, digestion of the victim had barely begun. Conservation Officer Charles Vanderstar of Naubinway, Michigan, reported that a 16-inch (sea) lamprey was removed from the stomach of a 7 1/2-pound (northern) pike taken from Millecoquin Lake, Mackinac County, on June 17, 1948. This watershed is known to support a moderately large sea lamprey spawning run. Mr. B. L. Foresman of Alger, Michigan, reported finding a 13-inch sea lamprey in the stomach of a 4 3/4-pound brown trout. This trout was taken in the Rifle River, Ogemaw County, during the month of May, 1948. Like the Millecoquin, the Rifle River has a sizable sea lamprey run.

These records would indicate that mature sea lampreys, regardless of their size or habits, are not immune to attack by large, predatory game fishes. Many more are undoubtedly destroyed by such fishes than ever come to the attention of interested observers.

---

[7] Identified by Dr. Marvin Clinton Meyer of the University of Maine.

The sea lamprey appears most vulnerable to attack by birds and mammals while on its spawning beds. On June 22, 1947, the partially devoured carcasses of several sea lampreys were found on the bank adjacent to a crowded spawning riffle in the Little Ocqueoc River, Presque Isle County. Tracks of a raccoon at the carcasses and lamprey teeth found in nearby raccoon scats identified the predator. Less conclusive evidence found several days later on the Ocqueoc River indicated that a mink may have captured a partially devoured sea lamprey that was found. I have also noted several domestic dogs which enjoyed capturing spawning sea lampreys and dragging them out on the bank; they were seldom eaten by the dogs in the presence of the observer.

During late June, 1948, a great blue heron was observed on several occasions fishing in one of the scattered spawning riffles in the Ocqueoc River (T. 36 N., R. 3 E., Sect. 33). Although this bird could not be approached closely at any time, it was observed on one occasion in the act of capturing and swallowing a spawning sea lamprey.

The peak of spawning activity in the Ocqueoc River in both 1947 and 1948 was accompanied by daily concentrations of gulls (presumably herring, ring-billed, and Bonaparte's gulls) which flew into the most heavily used spawning areas each morning. They were observed picking up both spawning, and spent and dead sea lampreys. Their activities may account, in part, for the seeming scarcity in some spawning areas, of dying and dead lampreys that had completed their spawning activities.

Migratory sea lampreys, even in areas of deep water, are preyed upon by the gulls. Several employees of the Manistique Pulp and Paper Co. and Mr. Howard Loeb of the Fish Division reported observing (in 1947) sea gulls capturing migratory sea lampreys as they rose to the surface in "boils" below the tailrace of the paper mill on the Manistique

River. This phenomenon is so common during the peak of migration in that river and the actions of the gulls so comical as they attempt to swallow 14- to 18-inch lampreys that it provides consistent amusement for mill employees during this period.

Of all avian and terrestrial predators, the gulls apparently constitute the only significant natural enemy of the sea lamprey during migration and spawning in Michigan streams. However, the total effect of their predatory activities upon the migrant and spawning populations has not kept them from becoming more abundant and increasing their range.

The basic source of references in the literature to natural enemies of adult sea lampreys is the observations of Surface (1899) on this lamprey in Cayuga Lake, New York. Surface presented records of predation upon adults by: (Mammals) raccoons, muskrats, rats, mink, weasels, foxes; (Birds) hawks, owls, herons, bitterns; and (Reptiles) the water snake. He reported also having seen a bowfin (*Amia calva*) eat an adult sea lamprey in an aquarium.

All of these animals or closely related counterparts are present in our Michigan watersheds and each, on occasion, undoubtedly takes a small and inconsequential toll.

## V. Spawning habits and spawning requirements of the sea lamprey.

### Methods.

The data upon which the following discussions are based were collected exclusively in the Ocqueoc River watershed between April 29 and July 3, 1947, and April 11 and August 10, 1948, when the spawning run of sea lampreys in each year was observed. In 1947, the beginning, peak and conclusion of spawning activity was observed, and a survey of the physical characteristics and intensity of spawning in each area of the river was made; spawning behavior, sites, and nest construction were likewise studied.

In 1948, the onset, peak and cessation of spawning were observed in detail in selected areas of the river. Regular visits were made to these sites so that all degrees of spawning activity could be noted and compared with related environmental conditions. Further observations on the spawning behavior of the sea lamprey were made in this year.

Daily records of air and water temperature, water level and weather were obtained in both years so that the effect of these factors upon the spawning and other activities of the sea lamprey could be determined. Such data for 1947 are presented in Tables 1 (weather) and 7 (temperatures and water level) and for 1948 in Table 13.

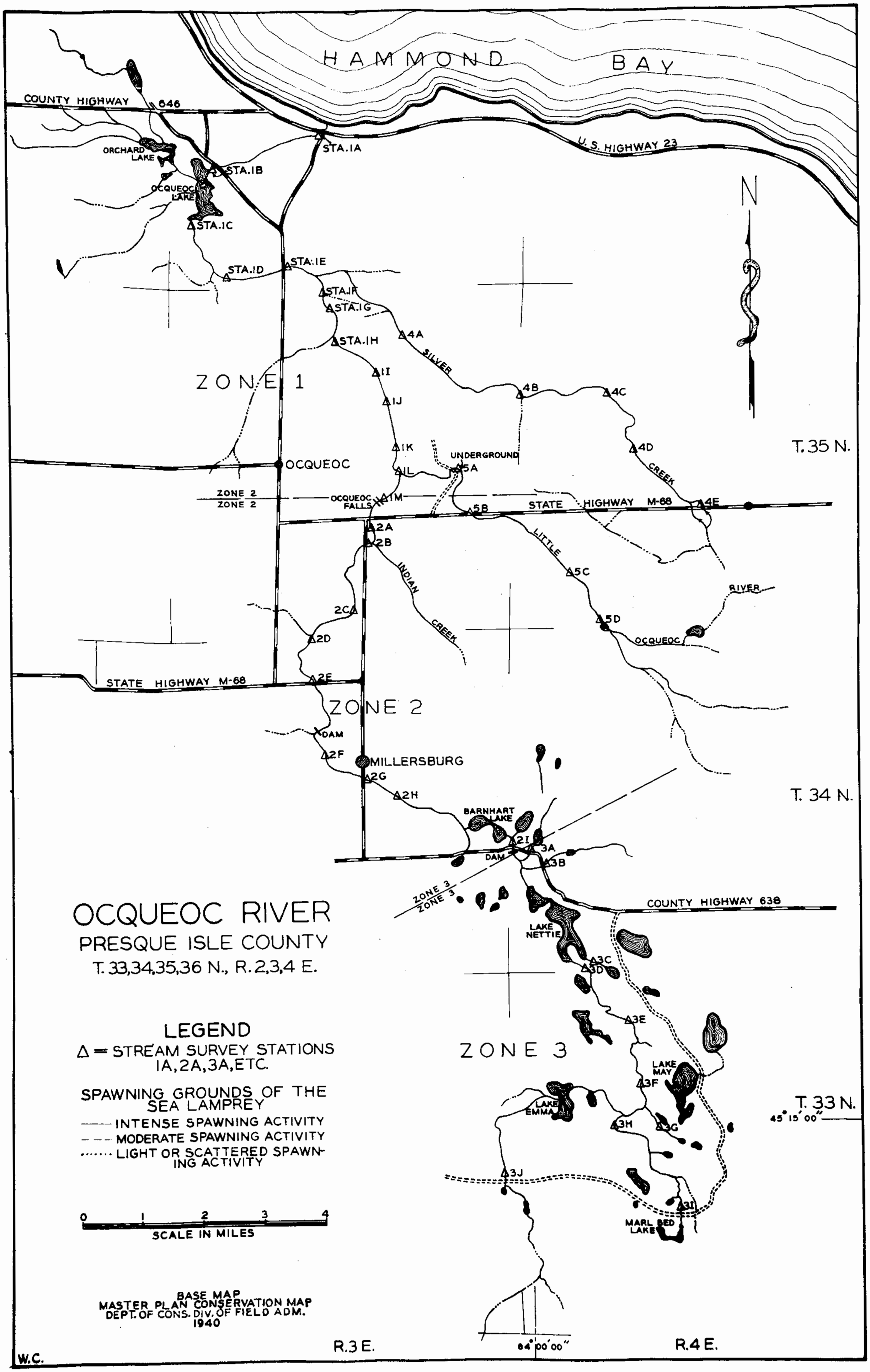
Physical characteristics of the Ocqueoc River watershed.

The geographic location and a generalized description of the Ocqueoc River are presented in a preceding section. Briefly, it drains in a northerly direction to Ocqueoc Lake and thence easterly into Hammond Bay of Lake Huron (Fig. 16). It reportedly embraces 89 miles of watercourse (determined on large scale maps with a map-measurer)[8]. A sizable portion of this area is occupied by intermittent tributaries, many of which flow only during a short period in the spring. From the standpoint of physical characteristics, the river is divided, rather sharply, into three zones (Fig. 16), each representing about one-third of the watershed. These zones form the basis of subsequent

---

[8] Main stream: 13 miles [?]; tributary streams: 76 miles [?]; estimated drainage area: 160 sq. miles. [from] Brown, C. J. D., 1944, Michigan streams--their lengths, distribution and drainage areas. Mich. Dept. Cons., Inst. Fish. Res., Misc. Publ. No. 1, July, 1944.

Figure 16. Map of the Ocqueoc River watershed showing zones and survey stations described in this study and the spawning areas of the sea lamprey in the watershed.


HAMMOND BAY
COUNTY HIGHWAY 646
U.S. HIGHWAY 23
ORCHARD LAKE
OCQUEOC LAKE
STA.IA
STA.IB
STA.IC
STA.ID
STA.IE
STA.IF
STA.IG
STA.IH
II
IJ
IK
IL
IM
OCQUEOC FALLS
N
ZONE 1
OCQUEOC
UNDERGROUND
5A
5B
4A
4B
4C
4D
4E
SILVER
CREEK
T. 35 N.
ZONE 2
ZONE 2
STATE HIGHWAY M-68
2A
2B
INDIAN
CREEK
LITTLE
5C
5D
RIVER
OCQUEOC
2C
2D
2E
STATE HIGHWAY M-68
ZONE 2
DAM
2F
MILLERSBURG
2G
2H
T. 34 N.
BARNHART LAKE
2I
DAM
3A
3B
ZONE 3
ZONE 3
COUNTY HIGHWAY 638
LAKE NETTIE
3C
3D
3E
ZONE 3
LAKE MAY
3F
T. 33 N.
45° 15' 00"
LAKE EMMA
3H
3G
3J
3I
MARL BED LAKE
OCQUEOC RIVER
PRESQUE ISLE COUNTY
T. 33,34,35,36 N., R. 2,3,4 E.
LEGEND
Δ = STREAM SURVEY STATIONS
IA, 2A, 3A, ETC.
SPAWNING GROUNDS OF THE SEA LAMPREY
—— INTENSE SPAWNING ACTIVITY
– – – MODERATE SPAWNING ACTIVITY
....... LIGHT OR SCATTERED SPAWNING ACTIVITY
0 1 2 3 4
SCALE IN MILES
BASE MAP
MASTER PLAN CONSERVATION MAP
DEPT. OF CONS. DIV. OF FIELD ADM.
1940
R.3 E.
84° 00' 00"
R.4 E.
W.C.

discussions relating to the spawning behavior of the sea lamprey. A description of each zone, beginning at the headwaters of the river and working downstream to the estuary follows.

Zone 3.--(Stations 3A-3I, Fig. 16) The river rises in Marl Bed Lake (T. 33 N., R. 4 E., Sect. 28) and from a chain of lakes and marshes in T. 33 and 34 N., R. 42 E. which are scattered over 25 square miles of an irregular sandy drift area (Leverett, 1912). Both main channel and tributaries, except where lakes interrupt the course, flow almost continuously through wide, open marshes, bog meadows, or cedar swamps. In this, the upper third of the river where the main channel travels approximately 8.5 miles, the width of the stream varies from 4 (Station 3I) to 30 feet (Station 3H) and the depth, from 12 to 36 inches. The bottom type was predominantly muck or silt; the velocity of flow was seldom more than sluggish and occasionally in the main channel it was barely discernable (Station 3H). All tributaries examined were of essentially the same nature (Table 11). No channel velocity measurements were made.

The character of the river and its watershed alters rather abruptly in the neighborhood of an old, cement dam (head: 18 inches) located just upstream from the crossing of County Highway 638. This point delimits Zone 3 from its successor, Zone 2.

Zone 2.--(Stations 2A-2I, Fig. 16) Zone 2, the midportion of the watershed, extends from the aforementioned cement dam (Station 2I) downstream to the Ocqueoc Falls through boulder-clay plains (Leverett, 1912). Between these points, the main channel runs about 7.7 miles. At nine survey stations the river ranged from 18 to 50 feet in width and from 5 to 12 inches in depth. Pools were infrequent and where present seldom more than 24 inches deep. The gradient is greater in this zone

Table 11. Summary of the physical characteristics of the Ocqueoc River, Presque Isle County, as determined at the stations indicated. (Data collected between June 21 and July 3, 1947; condition of stream: Approximately mean water level for the season.)

| Zone | Station | Average width (in feet) | Average depth (in inches) | Mean channel velocity [1] (f.p.s.) | General character of flow | Bottom type (dominant type listed first) | Cover; character of watershed |
|---|---|---|---|---|---|---|---|
| 1 | 1-A | (Estuary) | | ... | Sluggish | Sand | ... |
| | 1-B | 47 | 20.0 | 1.9 | Moderate | Clay, gravel, clamshells | Wooded |
| | | (Ocqueoc Lake) | | | | | |
| | 1-C | (Channel braided; partly underground) | | | | Sand | Wooded |
| | 1-D | 34 | 22.0 | 2.3 | Slow-Moderate | Sand and clay | Light second growth; pasture |
| | 1-E | 28 | 29.0 | 2.8 | Slow-Moderate | Sand; some gravel bars | Pasture |
| | 1-F | 50 | 17.5 | ... | Slow-Moderate | Sand; many snags | Heavily wooded |
| | 1-G | 45 | 21.0 | ... | Slow-Moderate | Sand; many snags | Wooded; some pasture |
| | 1-H | 40 | 19.5 | ... | Slow-Moderate | Sand and silt | Wooded; mature hardwood |
| | 1-I | 38 | 21.0 | 2.4 | Slow-Moderate | Sand and clay | Wooded |
| | 1-J | 37 | 24.5 | 2.0 | Moderate | Sand | Wooded |
| | 1-K | 38 | 18.0 | 2.6 | Moderate | Sand | Wooded |
| | 1-L | 27 | 20.0 | 3.5 | Moderate-Rapid | Sand; some gravel | Lightly wooded |
| | 1-M | 32 | 15.0 | 2.5 | Moderate | Gravel and sand | " " |
| 2 | 2-A | 25 | 11.5 | 2.8 | Moderate | Gravel and rubble | Wooded |
| | 2-B | ... | ... | ... | Moderate | Rubble and gravel | " |
| | 2-C | ... | ... | ... | Moderate | Rubble, rock, gravel | " |
| | 2-D | 40 | 7.5 | 3.0 | Moderate | Gravel, rubble | Wooded; some pasture |
| | 2-E | ... | ... | ... | Moderate | " " | Wooded; pasture |
| | 2-F | 23 | 10.0 | 2.5 | Moderate | Sand, occasional rubble | Pasture, marsh |
| | 2-G | 18 | 8.0 | ... | Slow-Moderate | Sand; gravel; rubble | Suburban area |
| | 2-H | 30 | 5.0 | ... | Slow-Moderate | Gravel; small rubble | Partly wooded |
| | 2-I | 50 | 12.0 | 3.1 | Slow-Moderate | " " " | Heavily wooded |
| 3 | 3-A | 4 | 4.0 | ... | Sluggish | Sand and silt | Scrub brush |
| | 3-B | (Intermittent-not flowing) | | | | | |
| | 3-C | 12 | 24.0 | ... | Sluggish | Muck | Marsh |
| | 3-D | 30 - 45 | 1.0 - 4.0 | ... | Sluggish | Muck, silt | Marsh |
| | 3-E | 28 | 30.0 | ... | Sluggish | Muck, silt | Marsh |
| | 3-F | 20 | 24.0 | ... | Sluggish | Muck, silt | Marsh |
| | 3-G | 2 | 6.0 | ... | Sluggish | Muck | Swamp |
| | 3-H | 25 | 18.0 | ... | Sluggish | Muck | Swamp |
| | 3-I | 4 | 12.0 | ... | Sluggish | Muck | Swamp |
| | 3-J | 3 | 8.0 | ... | Sluggish | Muck | Swamp |

[1] Surface velocity X factor of 1.33.

than elsewhere in the river and the mean channel velocity was generally moderate, varying from 2.5 to 3.1 feet per second. Bottom types in the lower half of this zone (Stations 2A-2E) are composed predominantly of a mixture of boulders, rubble, and coarse gravel distributed more or less uniformly in both riffles and shallow pools. Limestone outcroppings near Station 2C produce several low falls (12 to 24 inches). Shallow riffle areas 25 to 100 yards long in which the current is quite rapid are common in this area. Most of the remainder of the zone is characterized by small rubble and gravel except for the area just west of Millersburg. Here, from an old dam located one-half mile below Station 2F, upstream for 1.2 miles, the stream is slow or sluggish and the bottom is sandy or silted. The watershed is wooded, or, in the neighborhood of Millersburg, farmland and pasture (Table 11).

One small, permanent tributary (a spring feeder), Indian Creek, enters the river from the southeast near Station 2A. This creek has a uniformly sandy bottom.

Zone 1.--(Stations 1A-1M, Fig. 16) At the foot of the previously described zone, the river drops over the broken spillway of an old mill dam, 3 feet high, and over two limestone outcrops, 6.0 and 4.5 feet high. The latter are called the Ocqueoc Falls. Below these falls, the character of the river changes again as it flows for 8.8 miles to its mouth through clay and sandy lake bed formations. At thirteen survey stations in this zone, the river ranged from 28 to 50 feet in width and from 15 to 29 inches in depth. It meanders broadly in this zone and deep pools alternate regularly with short riffle areas. Pool depths varied from 24 inches to 9.5 feet. The gradient is somewhat less steep here than in Zone 2 and the mean channel velocity varied from slow to moderate ranging from 2.0 to 3.5 feet per second with current velocities in pools being considerably less than 2.0 feet per second. Bottom types were predominantly sand or sand and gravel, the ratio between the two varying in different areas within the zone (see Table 11). Gravel riffles were characteristic of the first mile of stream bed below Ocqueoc Falls; thereafter, this bottom type became increasingly infrequent being supplanted almost entirely for long distances by sand or sand and clay (Stations 1F-1J and 1C-1D). Outcroppings of clay frequently formed the bed of the stream in the latter areas. Deeper pools had silt or sand bottoms while most shallow pools had bottoms of sand, rubble, and gravel except in predominantly sandy areas.

Snags and waterlogged cut timber are abundant in all parts of the river in the lower two-thirds of this zone (Stations 1A-1J). Old saw-logs lie like jackstraws in many of the deeper pools. Between Stations 1E and 1K, there are about a dozen stream improvement devices in various stages of decay which still produce riffle areas.

The watershed in Zone 1 is a rather densely wooded bottomland with high, steep banks in the upper half of the region and lower, though no less open banks, in the lower half.

The river is interrupted in its third mile upstream from the estuary by Ocqueoc Lake which is 132 acres in extent. This lake is narrow and about one mile long--the river enters at one extremity and flows out at the other.

Three permanent tributaries (other than spring feeders) enter the river in this zone: The Little Ocqueoc River, Silver Creek, and Orchard Lake Outlet.

Physical and chemical properties common to all zones at the time of the nesting survey in 1947 follows. The river was approximately at its mean level or volume of flow for the season (128 cubic feet per second at Station 1B); the color of the water was light brown; the water was clear. Differences found in the chemical quality of the water were small among the several stations in Zones 1 and 2 (Table 12). Dissolved oxygen varied from 7.1 to 8.5 p.p.m.; no free carbon dioxide was present. The water was hard; phenolphthalein alkalinity ranged from 1.0 to 4.5 and methyl orange alkalinity, from 106 to 134 (p.p.m. expressed as $CaCO_3$). The only pollution known to enter the river is derived from scattered cattle watering points, street drainage from the Village of Millersburg (Stations 2F-2G) and septic tank overflow from the Ocqueoc Lake Group Camp (Station 1B).

Water and air temperature and water level records, obtained at Station 1B for the entire period of investigation in 1947 are presented in Table 7. Simultaneous readings of water temperatures by two observers at different stations indicated that an irregular temperature gradient existed in the river. The headwaters (and Zone 3) were warmer than elsewhere in the watershed. For Station 2I, the water temperature averaged 3.0° F. warmer than Station 1B. In Zone 1, above Ocqueoc Lake, the water was the coolest. At Stations 2A-2B, the temperature averaged 2.0° F. colder than at Station 1B. This cooling of the water in the upper portion of Zone 1 is due to the presence of numerous spring feeders in that area and the spring fed tributaries, the Little Ocqueoc River and Silver Creek.

Warming of the water at Station 1B, below Ocqueoc Lake, is probably the result of its passage through that body of water.

Table 12. Summary of water analyses made in the Ocqueoc River, Presque Isle County, in 1947. (Depth of water samples: 3 to 6 inches below surface; water color for all stations: light brown; no turbidity.)

| Zone | Station | Date 1947 | Time | Temperature (Degrees F.) Air | Water | Sky | Wind | Oxygen (p.p.m.) | Carbon dioxide | ph-th | M.O. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1-B | 6/27 | 5:45 PM | 73 | 73 | Partly overcast | SW-light | 7.8 | 0.0 | 3.0 | 134 |
| 1 | 1-E | 7/2 | 1:00 PM | 71 | 66 | Clear | NE-light | 8.0 | 0.0 | 4.0 | 127 |
| 1 | 1-M | 6/28 | 5:00 PM | 74 | 81 | Clear | SW-light | 7.1 | 0.0 | 4.5 | 110 |
| 2 | 2-D | 6/30 | 2:00 PM | 75 | 78 | Clear | SW-very light | 7.2 | 0.0 | 2.0 | 115 |
| 2 | 2-G | 6/30 | 3:00 PM | 78 | 82 | Clear | SW-very light | 8.5 | 0.0 | 2.5 | 107 |
| 2 | 2-I | 6/30 | 4:00 PM | 79 | 77 | Clear | SW-very light | 7.4 | 0.0 | 1.0 | 106 |
| 1 (Little Ocqueoc River) | 5-A | 7/2 | 3:00 PM | 67 | 62 | Clear | NE-light | 5.5 | 0.0 | 1.0 | 118 |

## Duration of the spawning season.

The spawning of the sea lamprey, like that of many fishes, is strongly influenced by water temperature. In the Ocqueoc River, spawning activity commenced at mean daily water temperatures of 52.5° F. to 53.0° F. at a time when daily fluctuations remained above 50° F. The peak of spawning activity occurred when mean daily temperatures rose above 58.0° F. to 60.0° F. and when, at the same time, daily fluctuations seldom dropped below 60° F. Spawning occurred among late migrants at mean daily temperatures as high as 75.5° F. with daily fluctuations to 78° F. Rapid drops in water temperature, up to and during the peak of spawning activity, caused very noticeable declines in both nest building and spawning. Following the peak, fluctuations above the 60-degree level had no perceptible effects upon spawning activity.

Fluctuations in water level and volume of flow and the presence of some turbidity with rising waters had no evident influence upon sea lamprey spawning except in so far as they were related to changes in water temperature.

The weather in successive years varies so greatly, with consequent effects upon stream conditions, that the assignment of the spawning season to calendar periods is an unreliable procedure. In general, however, sea lamprey spawning in the Ocqueoc River may begin as early as the last week in May and continue until the last week in July. The peak of spawning activity evidently occurs sometime during the first three weeks in June and usually lasts about two weeks.

In 1947, the first sea lamprey nest was constructed on the night of June 3-4 about one-half of a mile below Ocqueoc Falls (Station 1L-1M; 8.8 miles above mouth). The mean water temperature during this period was 53.0° F. (range: 50°-55° F.). Forty-eight hours later, when the mean daily water temperature had risen to 56.0° F., 28 nests had been built in an area 750 feet long which included the first nest. The peak of spawning activity in the 0.5-mile stretch immediately below the Ocqueoc Falls (Stations 1L-1M) occurred between June 16 and 23 when the mean daily water temperatures ranged between 58.0° F. and 67.0° F. and the daily fluctuations seldom fell below 60° F. Sustained drops below the 60-degree level brought corresponding declines in nest building and spawning activity. By July 3, spawning activity in this area was virtually concluded; only 21 spawning or spent sea lampreys were found in the river between Stations 1L and 1M on this date.

In Zone 2, the peak of spawning activity followed that in Zone 1, below the falls, by about five days. On June 25, neither spawning nor spent sea lampreys could be found in this area.

On June 25, spawning activity was first noticed below Ocqueoc Lake (Stations 1A-1B). It continued sporadically there until July 19 when the last spawning pair was observed (mean daily water temperatures, June 25-July 19: 66° F. to 73.0° F.).

In 1948, all areas of the river were watched closely for the beginning of spawning and after that was observed, spawning activity was followed closely in six sample areas distributed throughout Zones 1 and 2.

The spring of 1948 was warmer and earlier than in 1947. The first nest was constructed on May 22 in precisely the same riffle, a short distance below Ocqueoc Falls, on which the first nest built in 1947 was found. The mean daily water temperature on this date was 53.0° F. (range: 51°-55° F.). On May 24, in a 750-foot reach below Ocqueoc Falls, 14 nests had been started and in two of these nests spawning had been completed. On May 26, construction had been started on, or spawning had been completed in, 85 nests in this area. The mean water temperature on this date had risen to 55.0° F. (range: 52°-58° F.). Further temperature rise was accompanied by two waves of spawning activity in the 0.5-mile portion from Stations 1L to 1M; one was between June 1 and 5 and the other between June 10 and 16 when the mean daily water temperatures rose to and varied between 60.5° F. and 66.5° F. and when daily fluctuations seldom dropped below 60° F. The decline in nest building and spawning activity between June 6 and 9 accompanied a recession in water temperatures from the initially high temperatures of the period, June 1 to 5. The last spawning activity observed in this area was on July 5 when eight spawning or spent sea lampreys were observed between Stations 1L and 1M. The mean daily water temperature on this date was 70.0° F.

Spawning activity, which commenced just below Ocqueoc Falls, was restricted until June 1 to a 0.5-mile area (Stations 1L-1M) immediately below the falls. On that date nest construction began at Stations 1E and 1K in lower reaches of the zone. Peak activity at these stations followed that in the area immediately below the falls by an appropriate period.

On June 5, spawning activity commenced more or less uniformly throughout Zone 2, above the Ocqueoc Falls (Stations 2A, E, H and I). At this time, mean daily water temperatures were 66.0° F. or higher. The peak of spawning activity occurred between June 8 and 15 and had ceased entirely in Zone 2 by June 22.

Again, as in 1947, belated spawning activity took place below Ocqueoc Lake (Stations 1A-1B). The first spawning pair were observed here (Station 1B) on June 16; thereafter, spawning continued erratically until July 28 when two pairs, the last seen in this season, were observed spawning. Mean daily water temperatures during this period varied from 63.0° F. to 75.0° F.

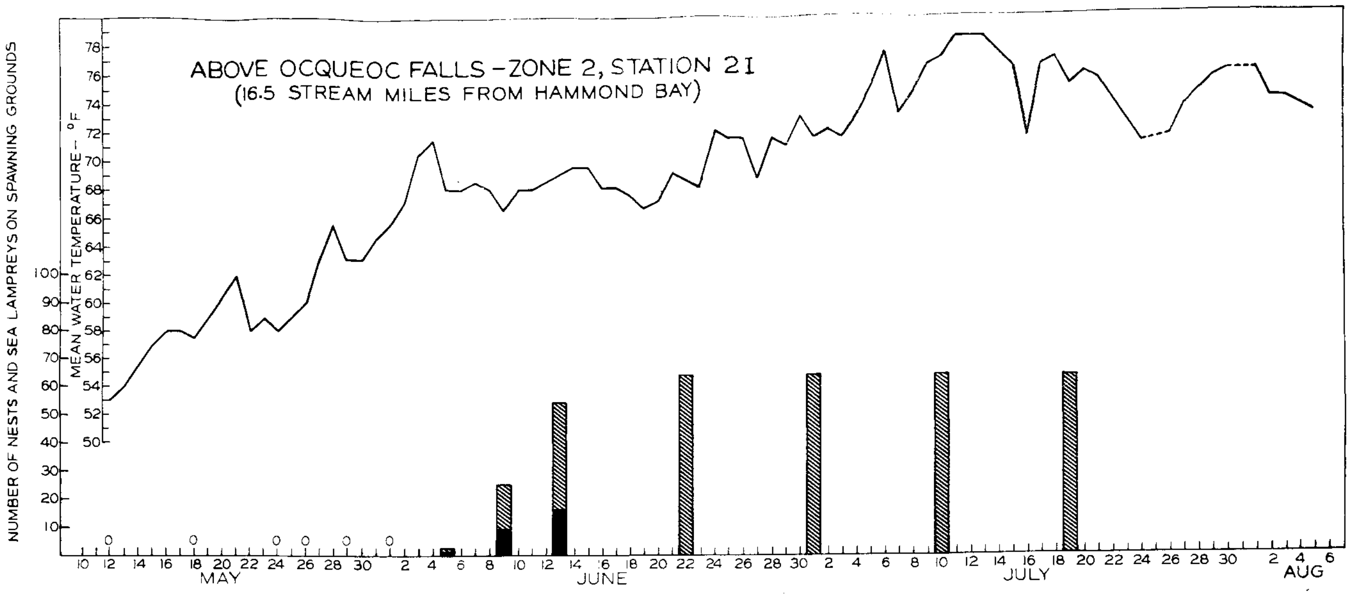
A graphic comparison of the duration and intensity of sea lamprey spawning in 1948 below Ocqueoc Lake (Station 1B), below the Ocqueoc Falls (Stations 1L-1M), and at the head of Zone 2 (Station 2I) is presented in Figure 17. Mean daily water temperatures have been plotted in this figure to show their variation in relation to the onset and initial increase in the intensity of spawning activity.

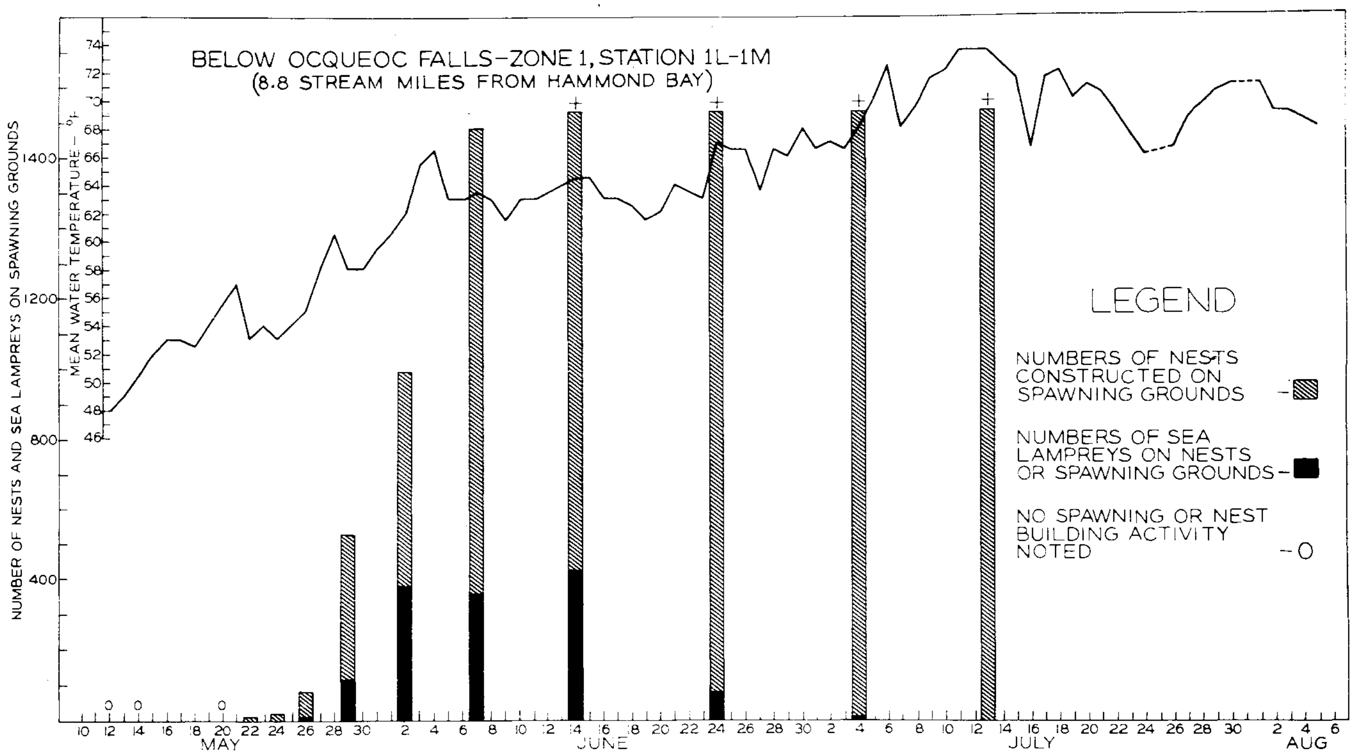
## Pattern and extent of spawning activity and its relation to certain stream characteristics.

In 1947, 5,664 completed sea lamprey nests were counted in the Ocqueoc River. Of these, 2,768 or 48.9 percent were found between the mouth of the river and the Ocqueoc Falls (Zone 1), and 133 or 2.3 percent were found in Silver Creek and the Little Ocqueoc River, tributaries of the main stream in this zone. In Zone 2, above the Ocqueoc Falls, 2,763 or 48.8 percent of the total were present. No spawning activity occurred in Zone 3 (Table 14). It is estimated from these figures, with due consideration for the spawning habits of the species, that between 10,000 and 11,000 sea lampreys spawned in the Ocqueoc River in 1947.

On the basis of a comparison of sample areas, it is concluded that the distribution of spawning activity in 1948 was essentially the same although there is some evidence that the run was larger in the latter year than in 1947. A comparison of sample stations follows:

Figure 17. Numbers of nests and sea lampreys on the spawning grounds at certain stations on various dates during the 1948 spawning season.


ABOVE OCQUEOC FALLS - ZONE 2, STATION 21
(16.5 STREAM MILES FROM HAMMOND BAY)
NUMBER OF NESTS AND SEA LAMPREYS ON SPAWNING GROUNDS
MEAN WATER TEMPERATURE - °F
MAY
JUNE
JULY
AUG


BELOW OCQUEOC FALLS - ZONE 1, STATION 1L-1M
(8.8 STREAM MILES FROM HAMMOND BAY)
NUMBER OF NESTS AND SEA LAMPREYS ON SPAWNING GROUNDS
MEAN WATER TEMPERATURE - °F
LEGEND
NUMBERS OF NESTS CONSTRUCTED ON SPAWNING GROUNDS
NUMBERS OF SEA LAMPREYS ON NESTS OR SPAWNING GROUNDS
NO SPAWNING OR NEST BUILDING ACTIVITY NOTED - O
MAY
JUNE
JULY
AUG

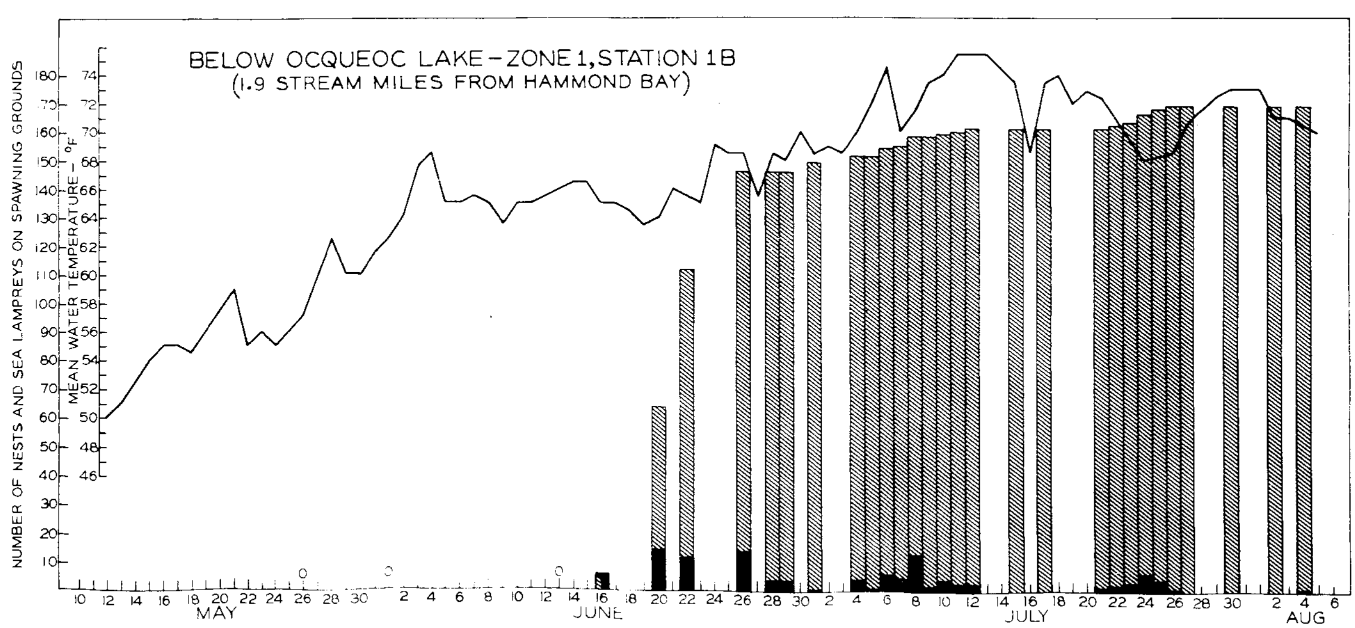

BELOW OCQUEOC LAKE - ZONE 1, STATION 1B
(1.9 STREAM MILES FROM HAMMOND BAY)
NUMBER OF NESTS AND SEA LAMPREYS ON SPAWNING GROUNDS
MEAN WATER TEMPERATURE - °F
MAY
JUNE
JULY
AUG

Table 13. Daily minimum, maximum and mean water temperatures, air temperatures, water gauge readings and weather records for the Ocqueoc River: April 11-August 20, 1948.[1]

| Date 1948 | | Time | Water temperature (Degrees F.) Minimum | Mean | Maximum | At visit | Air temperature (Degrees F.) | Water gauge (in inches)[2] | Weather | Wind |
|---|---|---|---|---|---|---|---|---|---|---|
| April | 11 | 3:30 PM | 40 | 40.0 | 40 | 40 | 46 | 36.5 | Light overcast | C |
| | 12 | 6:30 PM | 39 | 40.0 | 41 | 40 | 44 | 37.5 | High cirrus | C |
| | 13 | 6:00 PM | 39 | 39.5 | 40 | 40 | 44 | 34.0 | " " | C |
| | 14 | 8:00 PM | 40 | 41.5 | 43 | 43 | 44 | 30.0 | Clear | E |
| | 15 | 8:00 PM | 43 | 45.5 | 48 | 48 | 53 | 28.0 | Overcast | S |
| | 16 | 5:15 PM | 43 | 45.0 | 47 | 44 | 43 | 27.5 | Clear | NW |
| | 17 | 3:30 PM | 44 | 46.0 | 48 | 47 | 48 | 26.5 | " | C |
| | 18 | 5:00 PM | 44 | 46.0 | 48 | 44 | 47 | 26.0 | Rain | C |
| | 19 | 5:20 PM | 44 | 45.0 | 46 | 44 | 42 | 30.5 | Light overcast | C |
| | 20 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| | 21 | 12: Noon | 44 | 45.0 | 46 | 45 | 46 | 30.0 | Clear | C |
| | 22 | 1:30 PM | 45 | 46.0 | 47 | 46 | 56 | 28.0 | " | S |
| | 23 | 1:30 PM | 46 | 48.0 | 50 | 50 | 63 | 26.0 | Overcast, warm | S |
| | 24 | 3:30 PM | 49 | 50.0 | 51 | 50 | 55 | 26.0 | Overcast | S |
| | 25 | 1:00 PM | 48 | 49.5 | 51 | 51 | 65 | 26.0 | Light overcast, warm | NE |
| | 26 | 12: Noon | 50 | 52.5 | 55 | 54 | 52 | 25.0 | Overcast | NE |
| | 27 | 10:45 AM | 53 | 54.5 | 56 | 56 | 49 | 28.5 | " | N |
| | 28 | 12:15 PM | 54 | 55.5 | 57 | 55 | 54 | 33.5 | Clear | SE |
| | 29 | 12:35 PM | 53 | 54.5 | 56 | 56 | 51 | 32.5 | " | ENE |
| | 30 | 11:55 AM | 54 | 55.5 | 57 | 55 | 59 | 29.5 | " | NW |
| May | 1 | 12:30 PM | 52 | 55.0 | 58 | 56 | 55 | 27.0 | " | E |
| | 2 | 10:00 AM | 54 | 56.0 | 58 | 56 | 48 | 25.5 | " | ENE |
| | 3 | 11:55 AM | 54 | 56.0 | 58 | 56 | 48 | 24.0 | " | NE |
| | 4 | 11:30 AM | 55 | 56.0 | 57 | 56 | 56 | 23.0 | Overcast | E |
| | 5 | 11:15 AM | 54 | 55.5 | 57 | 55 | 60 | 21.5 | Clear | E |
| | 6 | 12:15 PM | 54 | 56.0 | 58 | 56 | 54 | 21.5 | Rain | NW |
| | 7 | 12: Noon | 52 | 54.5 | 57 | 53 | 38 | 23.5 | Cloudy, cold | NW |
| | 8 | 9:45 AM | 50 | 52.0 | 54 | 50 | 37 | 23.5 | Clear | N |
| | 9 | 10:15 AM | 49 | 51.5 | 52 | 50 | 40 | 22.5 | Cloudy | N |
| | 10 | 10:45 AM | 48 | 50.0 | 52 | 50 | 43 | 21.5 | Clear | E |
| | 11 | 10:50 AM | 49 | 50.5 | 52 | 50 | 40 | 21.0 | Overcast | NE |
| | 12 | 10:55 AM | 48 | 50.0 | 52 | 50 | 52 | 20.5 | Clear | NE |
| | 13 | 11:30 AM | 49 | 51.0 | 53 | 51 | 57 | 20.0 | Clear | E |
| | 14 | 12:20 PM | 50 | 52.5 | 55 | 53 | 68 | 19.0 | " | NE |
| | 15 | 11:40 AM | 51 | 54.0 | 57 | 57 | [illegible] | [illegible] | " | E |
| | 16 | 11:00 AM | 53 | 55.0 | 57 | 55 | 49 | 20.5 | Clear | NNW |
| | 17 | 11:40 AM | 53 | 55.0 | 57 | 55 | 68 | 21.0 | " | NNE |
| | | | | | | | [illegible] | 20.5 | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 11 | 10:50 AM | 49 | 50.5 | 52 | 50 | 40 | 21.0 | Overcast | NE |
| | 12 | 10:55 AM | 48 | 50.0 | 52 | 50 | 52 | 20.5 | Clear | NE |
| | 13 | 11:30 AM | 49 | 51.0 | 53 | 51 | 57 | 20.0 | Clear | E |
| | 14 | 12:20 PM | 50 | 52.5 | 55 | 53 | 68 | 19.0 | " | NE |
| | 15 | 11:40 AM | 51 | 54.0 | 57 | 57 | [illegible] | [illegible] | " | E |
| | 16 | 11:00 AM | 53 | 55.0 | 57 | 55 | 49 | 20.5 | | |
| | 17 | 11:40 AM | 53 | 55.0 | 57 | 55 | 68 | 21.0 | Clear | NNW |
| | 18 | 12:15 PM | 52 | 54.5 | 57 | 56 | 53 | 20.5 | " | NNE |
| | 19 | 11:30 AM | 54 | 56.0 | 58 | 57 | 61 | 19.5 | Slight overcast | E |
| | 20 | 09:55 AM | 55 | 57.5 | 60 | 59 | 69 | 18.5 | Cloudy, rain squalls | WNW |
| | 21 | 11:40 AM | 56 | 59.0 | 62 | 56 | 52 | 18.0 | Clear | NW |
| | 22 | 11:10 AM | 53 | 55.0 | 57 | 56 | 55 | 17.0 | Cloudy | NW |
| | 23 | 10:05 AM | 54 | 56.0 | 58 | 56 | 50 | 16.5 | Clear | N |
| | 24 | 10:45 AM | 53 | 55.0 | 57 | 56 | 56 | 16.5 | Overcast | NW |
| | 25 | 11:00 AM | 53 | 56.0 | 59 | 59 | 63 | 16.0 | Clear | NW |
| | 26 | 10:10 AM | 54 | 57.0 | 60 | 59 | 70 | 15.25 | Clear | SW |
| | 27 | 10:00 AM | 58 | 60.0 | 62 | 61 | 72 | 15.0 | Clear | NW |
| | 28 | 11:00 AM | 61 | 62.5 | 64 | 62 | 55 | 14.0 | Rain (AM) | NW |
| | 29 | 10:20 AM | 58 | 60.0 | 62 | 62 | 57 | 14.0 | Clear | NE |
| | 30 | 11:10 AM | 57 | 60.0 | 63 | 63 | 65 | 13.5 | Clear | NW |
| | 31 | 09:45 AM | 59 | 61.5 | 64 | 63 | 66 | 13.0 | Clear | NW |
| June | 1 | 10:35 AM | 60 | 62.5 | 65 | 66 | 74 | 13.0 | Clear | WNW |
| | 2 | 10:45 AM | 62 | 64.0 | 66 | 67 | 78 | 12.5 | Clear, haze | SW |
| | 3 | 11:00 AM | 64 | 67.5 | 71 | 71 | 75 | 12.5 | Clear | NE |
| | 4 | 12:45 PM | 66 | 68.5 | 71 | 69 | 65 | 12.5 | Rain | NE |
| | 5 | 11:05 AM | 61 | 65.0 | 69 | 65 | 56 | 13.0 | Clear | SE |
| | 6 | 10:45 AM | 63 | 65.0 | 67 | 67 | 66 | 13.0 | " | E |
| | 7 | 11:30 AM | 64 | 65.5 | 67 | 67 | 70 | 12.5 | Overcast | NE |
| | 8 | 11:35 AM | 63 | 65.0 | 67 | 64 | 63 | 11.5 | Haze, smoke | NE |
| | 9 | 11:00 AM | 62 | 63.5 | 65 | 62 | 70 | 12.75 | " " | NE |
| | 10 | 11:20 AM | 63 | 65.0 | 67 | 66 | 68 | 12.5 | Overcast | SW |
| | 11 | 11:30 AM | 63 | 65.0 | 67 | 65 | 63 | 12.5 | Clear | NE |
| | 12 | 11:15 AM | 63 | 65.5 | 68 | 66 | 64 | 12.0 | Cloudy | W |
| | 13 | 09:30 AM | 63 | 66.0 | 69 | 66 | 62 | 12.0 | Clear | W |
| | 14 | 11:15 AM | 64 | 66.5 | 69 | 67 | 74 | 11.75 | " | SW |
| | 15 | 11:45 AM | 63 | 66.5 | 70 | 65 | 63 | 11.5 | " | NE |
| | 16 | 11:40 AM | 62 | 65.0 | 68 | 64 | 65 | 11.5 | " | SW |
| | 17 | 10:55 AM | 62 | 65.0 | 68 | 65 | 66 | 11.25 | " | NNE |
| | 18 | 10:55 AM | 62 | 64.5 | 67 | 65 | 57 | 11.25 | Overcast, rain | NW |
| | 19 | 11:30 AM | 62 | 63.5 | 65 | 64 | 59 | 11.75 | Overcast | NE |
| | 20 | 11:00 AM | 62 | 64.0 | 66 | 65 | 69 | 12.0 | Clear | SW |
| | 21 | 10:40 AM | 64 | 66.0 | 68 | 66 | 67 | 11.75 | Overcast | SE |
| | 22 | 09:45 AM | 64 | 65.5 | 67 | 66 | 63 | 11.75 | Rain | NE |
| | 23 | 12:35 PM | 62 | 65.0 | 68 | 68 | 79 | 14.0 | Clear | SW |
| | 24 | 10:30 AM | 67 | 69.0 | 71 | 69 | 73 | 15.25 | " | SW |
| | 25 | 11:00 AM | 66 | 68.5 | 71 | 67 | 62 | 14.0 | Overcast | W |
| | 26 | 10:20 AM | 65 | 68.5 | 72 | 67 | 68 | 13.25 | " | SE |
| | 27 | 01:15 PM | 62 | 65.5 | 69 | 68 | 72 | 12.75 | Light overcast | NE |
| | 28 | 10:00 AM | 66 | 68.5 | 71 | 68 | 60 | 12.5 | Overcast | E |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 01:15 PM | 62 | 65.5 | 69 | 68 | 72 | 12.75 | Light overcast | NE |
| | 28 | 10:00 AM | 66 | 68.5 | 71 | 68 | 60 | 12.5 | Overcast | E |
| | 29 | 10:50 AM | 66 | 68.0 | 70 | 70 | 70 | 14.0 | Clear | NW |
| | 30 | 09:40 AM | 68 | 70.0 | 72 | 70 | 66 | 14.75 | Overcast | NW |
| July | 1 | 02:15 PM | 65 | 68.5 | 72 | 69 | 66 | 14.5 | Clear | W |
| | 2 | 11:20 AM | 67 | 69.0 | 71 | 68 | 73 | 14.25 | Overcast | SW |
| | 3 | 12: Noon | 67 | 68.5 | 70 | 68 | 78 | 14.25 | Clear | E |
| | 4 | 10:50 AM | 66 | 70.0 | 74 | 73 | 83 | 14.0 | " | SW |
| | 5 | 10:15 AM | 69 | 72.0 | 75 | 75 | 80 | 13.5 | " | SW |
| | 6 | 10:30 AM | 70 | 74.5 | 79 | 71 | 69 | 13.25 | Overcast | NW |
| | 7 | 10:30 AM | 68 | 70.0 | 72 | 70 | 71 | 13.0 | Clear | SE |
| | 8 | 10:30 AM | 69 | 71.5 | 74 | 72 | 75 | 12.75 | " | SW |
| | 9 | 09:55 AM | 71 | 73.5 | 76 | 72 | 78 | 12.25 | Overcast | SW |
| | 10 | 10:45 AM | 72 | 74.0 | 76 | 75 | 85 | 12.0 | Clear | NW |
| | 11 | 11:15 AM | 73 | 75.5 | 78 | 75 | 82 | 11.75 | Clear | ESE |
| | 12 | 01:00 PM | 73 | 75.5 | 78 | 76 | 83 | 11.5 | " | SE |
| | 13 | 04:35 PM | 73 | 75.5 | 78 | 75 | 81 | 11.25 | " | SE |
| | 14 | 01:15 PM | 72 | 74.5 | 77 | 74 | 79 | 11.0 | " | SE |
| | 15 | 04:40 PM | 70 | 73.5 | 77 | 75 | 77 | 10.5 | " | NE |
| | 16 | 05:45 PM | 61 | 68.5 | 76 | 75 | 68 | 10.5 | Cloudy | ... |
| | 17 | 10:15 AM | 71 | 73.5 | 76 | 72 | 75 | 10.5 | Rain | NW |
| | 18 | 11:45 AM | 71 | 74.0 | 77 | 74 | 72 | 10.75 | Clear | NW |
| | 19 | 01:00 PM | 69 | 72.0 | 75 | 74 | 53-76 | 10.5 | " | NE |
| | 20 | 11:00 AM | 70 | 73.0 | 76 | 76 | 59-79 | 10.5 | " | SW |
| | 21 | 12:35 PM | 69 | 72.5 | 76 | 72 | 52-86 | 10.25 | Rain | NE |
| | 22 | 11:00 AM | 69 | 71.0 | 73 | 72 | 62-73 | 10.0 | " | NE |
| | 23 | 10:30 AM | 67 | 69.5 | 72 | 69 | 56-71 | 10.75 | " | NW |
| | 24 | 05:45 PM | 65 | 68.0 | 71 | 70 | 53-76 | 10.5 | Clear | NW |
| | 25 | | | | All readings for 48-hour period. | | | | | |
| | 26 | 10:15 AM | 66 | 68.5 | 71 | 71 | 51-77 | 11.25 | Clear | NW |
| | 27 | 09:45 AM | 68 | 70.5 | 73 | 71 | 61-83 | 11.0 | Overcast | SW |
| | 28 | 09:25 AM | 69 | 71.5 | 74 | 71 | 54-78 | 10.75 | Clear | W |
| | 29 | 10:00 AM | 70 | 72.5 | 75 | 72 | 57-82 | 10.5 | " | SW |
| | 30 | 10:30 AM | 71 | 73.0 | 75 | 73 | 70-83 | 11.0 | " | SW |
| | 31 | | | | All readings for 48-hour period. | | | | | |
| August | 1 | 11:25 AM | 70 | 73.0 | 76 | 72 | 55-77 | 10.5 | Clear | W |
| | 2 | 01:00 PM | 69 | 71.0 | 73 | 71 | 57-73 | 10.25 | " | SE |
| | 3 | 02:20 PM | 69 | 71.0 | 73 | 71 | 55-77 | 10.0 | " | E |
| | 4 | 07:20 PM | 68 | 70.5 | 73 | 72 | 51-72 | 10.0 | " | W |
| | 5 | 10:50 AM | 68 | 70.0 | 72 | 70 | 47-68 | 10.0 | " | W |
| | 6 | | | | All readings for 48-hour period. | | | | | |
| | 7 | 09:00 AM | 68 | 70.0 | 72 | 70 | 47-74 | 9.75 | " | O |
| | 8 | | | | All readings for 48-hour period. | | | | | |
| | 9 | 11:00 AM | 68 | 70.0 | 72 | 70 | 47-76 | 9.75 | " | NNE |
| | 10 | | | | All readings for 48-hour period. | | | | Rain | |
| | 11 | 03:30 PM | 67 | 69.5 | 72 | 72 | 52-80 | 11.0 | Clear | W |

4

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 25 | All readings for 48-hour period. | | | | | | | | |
| 26 | 10:15 AM | 66 | 68.5 | 71 | 71 | 51-77 | 11.25 | Clear | NW |
| 27 | 09:45 AM | 68 | 70.5 | 73 | 71 | 61-83 | 11.0 | Overcast | SW |
| 28 | 09:25 AM | 69 | 71.5 | 74 | 71 | 54-78 | 10.75 | Clear | W |
| 29 | 10:00 AM | 70 | 72.5 | 75 | 72 | 57-82 | 10.5 | " | SW |
| 30 | 10:30 AM | 71 | 73.0 | 75 | 73 | 70-83 | 11.0 | " | SW |
| 31 | All readings for 48-hour period. | | | | | | | | |
| August 1 | 11:25 AM | 70 | 73.0 | 76 | 72 | 55-77 | 10.5 | Clear | W |
| 2 | 01:00 PM | 69 | 71.0 | 73 | 71 | 57-73 | 10.25 | " | SE |
| 3 | 02:20 PM | 69 | 71.0 | 73 | 71 | 55-77 | 10.0 | " | E |
| 4 | 07:20 PM | 68 | 70.5 | 73 | 72 | 51-72 | 10.0 | " | W |
| 5 | 10:50 AM | 68 | 70.0 | 72 | 70 | 47-68 | 10.0 | " | W |
| 6 | All readings for 48-hour period. | | | | | | | | |
| 7 | 09:00 AM | 68 | 70.0 | 72 | 70 | 47-74 | 9.75 | " | 0 |
| 8 | All readings for 48-hour period. | | | | | | | | |
| 9 | 11:00 AM | 68 | 70.0 | 72 | 70 | 47-76 | 9.75 | " | NNE |
| 10 | All readings for 48-hour period. | | | | | | | Rain | |
| 11 | 03:30 PM | 67 | 69.5 | 72 | 72 | 52-80 | 11.0 | Clear | W |
| 12 | 11:00 AM | 68 | 70.0 | 72 | 69 | 61-81 | 11.5 | Rain | SSW |
| 13 | 11:45 AM | 66 | 68.0 | 70 | 67 | 59-70 | 11.0 | Overcast | NW |
| 14 | 11:35 AM | 66 | 67.0 | 68 | 68 | 50-72 | 10.5 | Clear | NW |
| 15 | 12:35 PM | 66 | 68.0 | 70 | 69 | 54-78 | 10.25 | " | NE |
| 16 | 10:00 AM | 69 | 70.0 | 71 | 71 | 54-77 | 10.0 | " | SE |
| 17 | 10:15 AM | 69 | 71.0 | 73 | 71 | 59-82 | 10.25 | " | ENE |
| 18 | 10:00 AM | 69 | 70.5 | 72 | 71 | 61-74 | 10.5 | Overcast | W |
| 19 | 09:30 AM | 68 | 70.0 | 72 | 70 | 52-75 | 10.5 | Clear | SE |
| 20 | 09:40 AM | 68 | 70.0 | 72 | 71 | 56-78 | 10.5 | " | 0 |

1/ Readings taken at Station 1-B, 100 feet below the outlet of Ocqueoc Lake.
2/ Depth in midstream directly opposite water gauge is approximately 24 inches greater than gauge readings.

Table 14. Extent of sea lamprey spawning activity in the Ocqueoc River watershed in 1947 by zones and areas as determined by counts made of completed nests present after the peak of spawning activity.

| Zone | Area (that between stations listed) | Approximate distance (in miles) | Number of nests | Total nests for area, areas, or zone | Percentage of total nests |
|---|---|---|---|---|---|
| 1 | 1A-1B | 2.0 | 67 | | |
| | Ocqueoc Lake | 1.0 | ... | ... | ... |
| 1 | 1C-1D | 1.0 | 81 | | |
| | 1D-1E | 0.8 | 131 | | |
| | 1E-1F | 0.7 | 78 | | |
| | 1F-1G | 0.3 | 0 | | |
| | 1G-1H | 0.5 | 9 | | |
| | 1H-1I | 0.7 | 0 | | |
| | 1I-1J | 0.4 | 3 | | |
| | 1J-1K | 0.6 | 122 | | |
| | 1K-1L | 0.3 | 114 | | |
| | 1L-1M | 0.5 | 2,163 | | |
| | Ocqueoc Falls | ... | ... | | |
| | (1A-1M) | (8.8) | ... | 2,768 | 48.9 |
| 1 (Tributaries) | Little Ocqueoc River | | | | |
| | 1L-5A | 1.0 | 124 | | |
| | "Underground" | ... | ... | | |
| | 5A-5D | 3.7 | 0 | | |
| | Silver Creek | | | | |
| | Ocqueoc River-4A | 1.7 | 0 | | |
| | 4A-4B | 2.2 | 0 | | |
| | 4B-4C | 1.4 | 9 | | |
| | 4C-4E | 2.5 | 0 | | |
| | (Tributaries) | (12.5) | ... | 133 | 2.3 |
| 2 | Ocqueoc Falls-2A | 0.3 | 0 | | |
| | 2A-2B | 0.3 | 94 | | |
| | 2B-2C | 1.0 | 729 | | |
| | 2C-2D | 0.8 | 683 | | |
| | 2D-2E | 0.8 | 401 | | |
| | 2E-2F | 1.2 | 340 | | |
| | 2F-2G | 0.5 | 60 | | |
| | 2G-2H | 0.5 | 0 | | |
| | 2H-2I | 2.2 | 388 | | |
| | 2I-Dam | 0.1 | 68 | | |
| | (Ocqueoc Falls-2I; Dam) | (7.7) | ... | 2,763 | 48.8 |
| 3 | 3A-3I | (No spawning activity) | | | |
| Totals | | | | 5,664 | 100.0 |

| STATION | NUMBER OF COMPLETED NESTS | |
|---|---|---|
| | 1947 | 1948 |
| (Below Ocqueoc Falls) | ... | ... |
| Station 1B (1,500 feet) | 67[1] | 169* |
| Station 1E (200 feet) | 20[2] | 97* |
| Stations 1L-1M (0.5 mile) | 2,163[3] | 1,483+ |
| (Above Ocqueoc Falls) | ... | ... |
| Station 2E (700 feet) | 52* | 58* |
| Station 2H (1,200 feet) | 147* | 95* |
| Station 2I (400 feet) | 68* | 63* |

* Spawning activity in area completed.
[1] Count on July 3, 1947.
[2] Count on June 20, 1947.
[3] Count on June 28, 1947.

Spawning populations in Zone 2 (above Ocqueoc Falls) were slightly reduced from those present in 1947. I attribute this to lower water levels in 1948 which rendered the Ocqueoc Falls impassable to the sea lampreys at an earlier date. However, an increase, disproportionate to the decline noted above, was observed in spawning activity below the falls. Nesting sites below the falls became so overcrowded that after June 8, when 1,483 nests were counted between Stations 1L and 1M, further counts of the nests in this area could no longer be made accurately. Other areas in the zone displayed an appreciable increase in spawning activity over the 1947 season.

In the various areas in Zone 1 (the estuary to Ocqueoc Falls), the amount of sea lamprey spawning activity in a given area was directly proportional to the amount of gravel, in riffle areas or otherwise, that was present. As will be subsequently demonstrated, gravel or gravel and small rubble are essential for sea lamprey nest construction and without these particular elements (or some suitable substitute), nest construction and spawning do not take place. Between Stations 1L and 1M, immediately below the falls, the stream is characterized by short graveled riffles alternating with deep pools. Bottom types in general are gravels of assorted sizes except the deeper pools which are silted or sandy. The heaviest spawning concentration in the zone (and in the river, for that matter) occurred in this 0.5-mile area. Actually, 78.1 percent of the spawning activity in Zone 1 occurred here. (See Tables 11 and 14 and Fig. 16).

Downstream from this area gravel bottom types disappear rapidly, giving way to sand, and sea lamprey spawning activity decreased accordingly. Between Stations 1F to 1J (1.9 miles) the bottom type was almost exclusively sand and the 12 sea lamprey nests found there in 1947 were limited to about eight small patches of gravel primarily located at, or near, old stream improvement devices. A recurrence of scattered gravel riffles and isolated gravel bars in the lower reaches of the zone above Ocqueoc Lake (Stations 1C-1E) was accompanied by a complete utilization of these areas by spawning sea lampreys.

Seventy percent of the spawning below Ocqueoc Lake (Stations 1A-1B) took place in a 900-foot area immediately below the outlet of the lake. This area is characterized by riffles with bottom types of gravel, clam shells and sand. The balance of the spawning between this area and the estuary took place where infrequent patches of gravel occurred on the generally sandy bottom.

Spawning in the tributary, Silver Creek, was limited to small patches of gravel at, and between, Stations 4B and 4C. These graveled spots were located at highway crossings and were the result of "washing" from the highway grade; other than these instances, the creek has a sandy bottom. Spawning in the Little Ocqueoc River was limited to a 200-yard area of gravel riffles at Station 5A. Passage upstream, beyond this point, is denied the sea lamprey by an "underground"--an area where the river disappears underground, percolates through the sub-surface limestone formations and reforms above ground by the union of numerous, small, spring-like feeders. Downstream from the graveled area noted, the river has a sand, or sand and clay, bottom and no spawning activity was observed.

Bottom types in Zone 2 were predominantly rock, rubble and gravel and this combination occurred more or less uniformly throughout the zone varying only, from place to place, in their relative proportions to each other. Sea lamprey spawning activity was more or less uniformly distributed throughout this zone (Tables 11 and 14 and Fig. 16). Within this zone, spawning activity did not take place in the sandy-bottomed area extending from one-half mile below Station 2F to Station 2G nor did it occur in those areas, occasionally intermediate between riffles, which were characterized by bottom types of rock and large rubble imbedded in silt and/or clay. The farthest point upstream, utilized by the sea lampreys for spawning occurred at the head of this zone at Station 2I. This locality is 16.5 stream-miles from the mouth of the river.

No spawning occurred in either year in Zone 3. The stream bed in this zone is predominantly covered with muck or silt.

Changes in the geographical pattern of spawning activity during the spawning season were consistent for both years. Spawning occurred initially in the area immediately below Ocqueoc Falls (Zone 1, Stations 1L to 1M) and reached its peak there earlier than anywhere else in the river. Six to 10 days after the beginning of spawning in the aforementioned area, spawning activity spread rapidly in a progressive fashion downriver as far as Ocqueoc Lake (Stations 1L to 1C). Peak spawning activity in each area, progressing downstream, was proportionately later than that peak which occurred just below the falls.

In Zone 2, spawning activity commenced uniformly over the entire zone 5 to 12 days later than in the area immediately below Ocqueoc Falls, although water temperatures were consistently higher than in Zone 1. I attribute this to generally less suitable spawning facilities which resulted in a delay on the part of the migrants entering this zone in selecting an acceptable place for nest construction. This delay lasted until an increasing urge to spawn forced them to accept what were evidently sub-optimum nest-building conditions. As it will be shown in a later discussion, the shallow, rock- and rubble-strewn riffles characteristic of Zone 2, offer acceptable, although not eminently suitable, sea lamprey nest-building sites.

The duration of spawning activity was very brief in Zone 2, lasting from nine (1947) to 17 (1948) days. This is attributed to several factors: (1) The spawning run in this zone appears to be composed of early migrants which seem to seek the farthest reaches of the watershed for spawning. Their greater vitality, and high and favorable water levels at the Ocqueoc Falls, facilitate their passage over this obstruction; (2) Later migrants, which might prolong the spawning activity in this zone, are denied access to it by their decreased vitality and increasingly less favorable water levels for passage over the falls. This may, in part, account for the prolonged spawning season and overcrowding of nesting sites immediately below the falls in the latter third of the spawning season; (3) The sea lampreys present in Zone 2, having delayed their spawning activity at suitable spawning temperatures while searching for optimum nesting sites, which did not exist, were compelled (by an increasing urge to spawn) to build their nests and spawn in the briefest possible period.

The appearance, late in the season, of spawning sea lampreys below Ocqueoc Lake has been noted previously. This shift of spawning activity to the lowermost reaches of the river concludes the spawning season. Spawning areas here are scattered and poor and the occurrence of such activity is attributed to migrants, which, being unable to locate the inlet of Ocqueoc Lake, eventually dropped downstream (through the outlet) in order to spawn. Furthermore, I know from observation that some late migrants, not possessing the vitality to journey further, elect to spawn here without attempting to travel further.

## Spawning habits and spawning behavior.

(1) Pre-spawning behavior.--As has been observed in a previous section, adult sea lampreys of both sexes are present in the watershed in the spawning areas for as much as six to eight weeks prior to any attempt on their part to initiate spawning activity. Anatomical studies and the absence of external secondary sexual structures indicate that these early migrants are much less mature sexually than later migrants and evidently must complete the sexual maturing process while in the spawning stream. Later migrants displayed much more advanced stages of maturity upon entrance into the stream and my observations suggest that those arriving on the spawning beds during and after the peak of spawning activity commence their nest building and spawning in a very short period of time.

The first evidence of spawning activity on the part of either sex is the construction of a nest in which the fertilized eggs will be deposited. Nests are constructed by clearing the gravel, rubble, and small stones from a usually circular area and by depositing this movable material in a crescentic ring about the downstream margin of the cleared area. Occasionally, gravel or stones are moved upstream so that in some cases, the nest has a crater-like appearance. Each pebble or stone is moved singly by picking it up with the sucker-like oral disc. Great persistence is shown on occasion where a stone is firmly imbedded in an area of the nest where it does not seem to be desired. The sea lamprey will return time after time to this stone and "worry at it" until eventually it is usually dislodged and can be moved. Very large stones are occasionally moved out of the center of the nest area by dragging them along the bottom with the aid of the current. The largest stone I have had occasion to see moved measured about 4 by 5 by 5 1/2 inches and was dragged about 2.5 feet from the center of a nest area by a 17-inch, male sea lamprey.

The total amounts of material moved by a pair of sea lampreys during nest-building and spawning seem extraordinary. All dislodged materials from three nests in Zone 1 in which spawning had been completed were carefully collected and weighed. In the three nests, 13.2 pounds, 18.0 pounds, and 23.5 pounds of small and large gravel and stones had been moved respectively by each of three pairs of spawners.

Nest construction is usually begun by the male. Early in the season the male may work for 48 to 72 hours on the nest before being joined by the female. During this period a major portion of the nest's construction has usually been completed, and further elaboration by both sexes may only occur in the interval between spawning acts. During mid-spawning season, the male is frequently joined by the female shortly after the nest has been started and both contribute to the building done prior to spawning. At the end of the spawning season, when females frequently appear to be dominant on some spawning beds, nest construction may be initiated by them.

Prior to the beginning of the actual spawning process, certain secondary sexual characteristics develop among both sexes which aid in the identification of the sexes upon the spawning beds. Among the males a very pronounced, rope-like ridge develops on the back from just behind the branchial region to the anterior edge of the first dorsal fin. No such ridge appears among the females; instead, a fleshy "keel" develops from the vent to the caudal fin. The ventral margin of that fin likewise becomes somewhat thickened. The females may also be identified from some distance by the relatively swollen appearance of the body proper (due to the egg mass) in comparison to the smaller head and branchial regions. In spawning males, the branchial region becomes somewhat distended and has a greater diameter than the rest of the body.

(2) Spawning behavior; the spawning act.--The spawning behavior of sea lampreys observed in the Ocqueoc River was primarily monogamous, occasionally polygamous and very infrequently promiscuous. On certain visits to the sample spawning areas studied in 1948, the behavior of all sea lampreys found in these particular areas was carefully observed and recorded. Altogether, 954 nests upon which sea lampreys were present were examined. In 245 of these nests, spawning had not yet begun; sea lampreys present were engaged solely in the construction of the nest. In 393 nests, spawning had been completed and only spent individuals, primarily males, were present in the nests.

Spawning was observed, however, in 338 nests. Of this total, spawning was undertaken by a single pair in 261 nests or 77.2 percent of all instances observed. All observations of the complete spawning activities of individual sea lampreys indicated that these pairs remained mated for the entire spawning venture. In 44 nests or 13.0 percent of the total observed, one male was spawning with two females. Other polygamous combinations observed were one male with three females (6 nests); with four females (2 nests); and with five females (1 nest) (Total: 9 nests--2.7 percent of total). Promiscuous spawning was observed in 6 nests (1.8 percent of total). Combinations of sexes present were two males and two females (1 nest); two males and three females (1 nest); two males and seven females (1 nest); three males and two females (2 nests); and four males and two females (1 nest) (Table 15). Polygamous and promiscuous spawning were generally observed after the peak of spawning activity and I attribute this behavior to one or both of several factors: (1) Females tended to outnumber the males on some spawning areas during the late part of the season, and, (2) overcrowding of the spawning beds in some areas of the river.

Polyandrous spawning, i.e. one female with several males, was observed in 18 nests. In almost every case, during the time the observations were being made, some degree of antagonism was exhibited by the males present in the nest towards each other. This was usually expressed in attempts by one male to drive the other from the nest. This is done by the aggressor by attacking with the mouth and fastening firmly to the victim. The latter replies in kind, and, firmly locked together, they go thrashing downstream with the current. This antagonism was particularly marked among the males of a number of spawning pairs that were observed. When casual males intruded upon their spawning activities, they were promptly driven away

Table 15. Proportions of monogamous, polygamous, and promiscuous spawning among sea lampreys in the Ocqueoc River on various dates in 1948. (Numbers of nests upon which working or spent sea lampreys were found and the number of casual sea lampreys noted in the spawning areas on these dates are also indicated)[1]

| Date of observations (1948) | Total number of nests observed with ♂♂ and/or ♀♀ on them | Number of nests in which following spawning combinations noted | | | | | | | | | | | Number of nests under construction | | Number of nests in which there were: | | Number of casual lampreys in spawning area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1♂+1♀ | 1♂+2♀♀ | 1♂+3♀♀ | 1♂+4♀♀ | 1♂+5♀♀ | 2♂♂+1♀ | 2♂♂+2♀♀ | 2♂♂+3♀♀ | 2♂♂+7♀♀ | 3♂♂+2♀♀ | 4♂♂+2♀♀ | By ♂♂ | By ♀♀ | Spent ♂♂ | Spent ♀♀ | |
| May 29 | 72 | 28 | 2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 17 | 2 | 23 | ... | 3 |
| June 2 | 220 | 74 | 5 | 1 | ... | ... | 9 | ... | ... | ... | 2 | 1 | 56 | 7 | 65 | 25 | 12 |
| June 6 | 222 | 55 | 12 | 2 | 1 | 1 | 7 | ... | ... | 1 | ... | ... | 50 | 11 | 81 | 15 | 12 |
| June 13[2] | 22 | 6 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 5 | 1 | 10 | ... | ... |
| June 14 | 301 | 77 | 15 | 3 | ... | ... | 1 | 1 | 1 | ... | ... | ... | 79 | 4 | 89 | 13 | 18 |
| June 20[3] | 10 | 4 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | 2 | 2 | 1 |
| June 23[3] | 7 | 3 | 2 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... | ... | 1 |
| June 25 | 63 | 8 | ... | ... | ... | ... | 1 | ... | ... | ... | ... | ... | 4 | 3 | 36 | 11 | 4 |
| June 26–July 5[4] | 26 | 6 | 3 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 14 | 3 | 1 |
| July 6[5] | 3 | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... | ... | 1 |
| July 8[5] | 5 | ... | 2 | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | ... |
| July 10[5] | 2 | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | ... | ... |
| July 12[5] | 1 | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Totals | | 261 | 44 | 6 | 2 | 1 | 18 | 1 | 1 | 1 | 2 | 1 | 217 | 28 | 324 | 69 | 53 |
| Percent of total spawning combinations observed | | (77.2) | (13.0) | (1.8) | (0.6) | (0.3) | (5.3) | (0.3) | (0.3) | (0.3) | (0.6) | (0.3) | ... | ... | ... | ... | ... |

1/ Counts represent activity of all live sea lampreys present in area of river examined on given date. Unless otherwise noted data obtained in area between Stations 1L and 1M (Zone 1).
2/ Stations 1F and 2I.
3/ Stations 1B and 1E.
4/ Station 1B and Stations 1L to 1M.
5/ Station 1B.

in the manner described above. I consider this further evidence that under optimum conditions, spawning among sea lampreys is undertaken by pairs which remain mated for the entire spawning period.

The spawning act of the sea lamprey has been more or less elaborately described by Surface (1899), Hussakof (1912), Coventry (1922), and Gage (1928). The following descriptions agree in general, but not always in detail, with the statements of these workers. Briefly, my observations show that the act is accomplished as follows: The female orients herself in the bottom of the nest and anchors herself firmly with the oral disc to a stone or larger piece of gravel imbedded in the floor of the nest, or, to a similar object which has been placed in the upstream margin of the nest during its construction. The male approaches the female generally along the long axis of her body which is parallel to the current. In doing so, he frequently runs his mouth lightly over the anterior half of her body until the branchial zone is reached. At this point the male fastens himself firmly to the female with his mouth. Almost immediately he wraps the posterior third of his body in an abrupt half-spiral about that of the female so that their vents are approximated (Figs. 18, 19). The extrusion of the eggs and milt is preceded and accompanied by a very rapid vibration of the bodies of both individuals for a 2 to 5 second period. Following that, the male releases the female immediately.

The fertilized eggs are carried by the current into the face of the downstream rim of the nest where the majority of them lodge in the interstices between the gravel and stones that have been built up there. Very shortly after the spawning act, one or both of the sexes anchor themselves again to a rock at the head of the nest. With violent body

Figure 18. Male and female sea lampreys at moment of extrusion of eggs and milt. Note small cloud of sand grains behind the pair which have been stirred up by the vibration of their bodies during the act. (Ocqueoc River, Stations 2L-M, June 9, 1948).

Figure 19. Male and female sea lampreys in spawning act. Note how the tail of the male is locked about the body of the female. (Ocqueoc River, Stations 2L-M, June 9, 1948).

vibrations, they stir up a small cloud of sand from the bottom of the nest which, like the eggs, is carried by the current into the spaces in the gravel and stone nest-rim and which imbeds the eggs in place. Reportedly, 20 to 40 eggs are extruded during each act (Surface, 1899). My observations tend to confirm this although I never found a satisfactory way of checking this with some mechanical device. Thereafter, both male and female move about, adding more gravel or stone to the downstream rim of the nest structure. This latter activity may occur between each spawning act or between groups of two or three successive spawning acts.

The interval between spawning acts usually varies from one to five minutes through most of the spawning activity. When both male and female are nearly spent, this interval may last ten minutes or longer.

The duration of spawning by a pair (or other spawning combinations) may be from 16 hours to three and one-half days. The latter instance was noted for a pair of very early spawners in 1947. During the peak of spawning activity in the river, all pairs whose activities were followed closely completed their spawning in approximately 36 to 48 hours. Late in the season, during the month of July, three pairs observed at Station 1B (below Ocqueoc Lake) completed their spawning in approximately 16, 19 and 20 hours respectively. (These checks were made by placing hardware cloth fences around the nests of pairs desired for observation).

The location of the eggs deposited in the nest and those lodging in surrounding areas was determined by carefully dissecting, stone by stone, a series of ten nests in which spawning had been completed. Dislodged eggs were caught in a stream-bottom sampler and the relative proportions in different layers and different areas of the nests were observed.

The distribution of the eggs found in these nests was logical considering the spawning position, spawning act, and the action of the water current passing through and over the nest. In all nests examined, the bulk of the developing eggs were found in a spindle-shaped layer (in both vertical and horizontal dimensions) in the upstream face of the crescentic, downstream margin of the nest. Here they were mixed with fine and coarse sand which filled all the interstices between the pieces of gravel and stone. Superimposed upon this egg-bearing strata was a two- to five-inch layer of medium and coarse gravel among which few eggs or sand grains were present. The water percolated freely through this layer. It was found that among the eggs first deposited by a spawning pair, some were buried as deep as 8.5 inches beneath the highest point of the nest rim. The egg-bearing strata itself, varied from two to four inches at its maximum thickness (Fig. 20). In the lateral plane, the eggs were most commonly distributed over an area equivalent in breadth to the downstream quadrant of the nest (Fig. 20c).

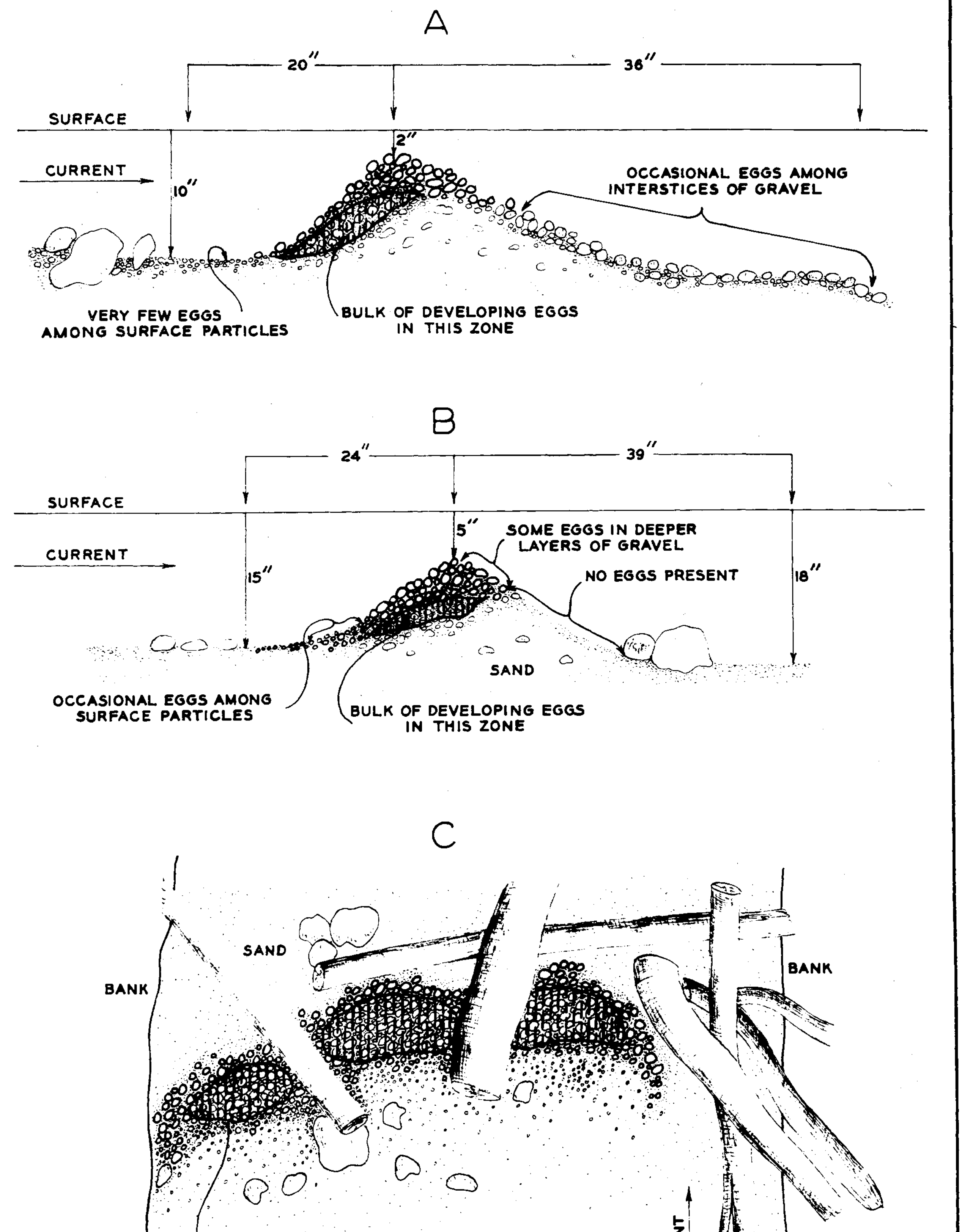
In an area of moderate current, with a generally gravel bottom type, a few eggs were found lodged in the gravel just past the crescentic rim of the nest. Occasional eggs were lodged among the gravel of the stream bed directly behind the nest for a distance of three to four feet (Fig. 20a). In generally sandy areas, where the reverse slope of the nest rim (downstream side) was predominantly sand, eggs carried over the rim of the nest by the current had nowhere to lodge and I observed that these eggs generally were carried by the current into deeper and usually silted areas (Fig. 20b). I believe that there is a high mortality among these eggs due to their complete exposure to predation by small minnows and, ultimately, to their smothering by silt deposition.

Figure 20. Diagramatic sketches of the distribution in depth and area of the eggs in some typical sea lamprey nests:

A. Vertical and linear distribution of eggs in a nest in a gravel-bottomed area.

B. Vertical and linear distribution of eggs in a nest in a gravel- and sand-bottomed area.

C. Area or plan of distribution of eggs in three adjoining nests.


A
20"
36"
SURFACE
CURRENT
10"
2"
OCCASIONAL EGGS AMONG INTERSTICES OF GRAVEL
VERY FEW EGGS AMONG SURFACE PARTICLES
BULK OF DEVELOPING EGGS IN THIS ZONE
B
24"
39"
SURFACE
CURRENT
15"
5"
SOME EGGS IN DEEPER LAYERS OF GRAVEL
NO EGGS PRESENT
18"
SAND
OCCASIONAL EGGS AMONG SURFACE PARTICLES
BULK OF DEVELOPING EGGS IN THIS ZONE
C
SAND
BANK
BANK
CURRENT
AREA OF GREATEST CONCENTRATION OF EGGS IN NEST

(3) Nest construction.--The manner and form of sea lamprey nest construction in the Ocqueoc River varied with the area in the watershed selected for spawning, with the bottom types that were present, and with specific locations within the stream (i.e., particular nest-building site selected).

(Zone 1)

In Zone 1, the general type of nest built was one of various size gravels upon riffles, bars, and flat beds, or scattered patches, of gravel (Fig. 21). Ultimately, all available graveled locations of every description in this zone were completely utilized, although certain types of locations were more suitable for nest construction than were others. In a 0.4-mile area between Stations 1L and 1M, the specific sites of 1,820 nests present were determined. Of this total, 1,043 nests were built on ten long gravel riffles totaling 1,070 feet of linear stream distance (Range in length of individual riffles: 35 - 500 feet); 434 nests were built on isolated, large, transverse gravel bars and short riffle areas; 120 nests were built on scattered, small, transverse bars; 60 nests were built at the upstream or downstream margins of pools or in the deeper areas intermediate between isolated bars or riffle areas; 63 nests were built on linear (parallel to current) graveled areas and 60 on scattered patches or pockets of gravel. These latter two types of sites were in generally sandy-bottomed areas of the river. Of the remainder, 34 nests were built on flat and ridged gravel beds on the outside margin of deep pools at bends in the river, and 6 nests were built in a like location on the inside of a river bend.

Under such conditions, preferred nest-building sites could only be determined by ascertaining in limited areas what sites were utilized

Figure 21. Sea lamprey nest; type characteristic of graveled or gravel bar areas. (Ocqueoc River, Zone 1, Station 1M, June 10, 1948).

first, second, etc. for nest-building. A gravel riffle area, 80 feet long, which lay between deep pools at two bends of the river (Stations 1L-1M), a predominantly sandy-bottomed area at Station 2C, a gravel bed in a bend of the river at Station 1E, and gravel riffles in a small stream (Station 5B) were observed during the spawning season. It was found that, in general, the upstream face of the gravel bars forming the longer riffle areas and that of transverse gravel bars of all descriptions were utilized first for nest construction. Following this, the depressions between, and occasionally the crests of, these bars were used. In such areas, the last sites taken were those within the foot of the pool proper, upstream from the riffle, and those at the head of the pool lying downstream from the riffle (Fig. 22). When all such sites had been preempted, nests appeared on flat, graveled areas along the outside margins of pools, and on linear bars, patches, and pockets of gravel in the sandy areas of the river.

In the lower reaches of Zone 1, above Ocqueoc Lake, graveled areas frequently appeared on the outer portion of bends in the river. These graveled areas were generally composed of a series of crescentic gravel bars, dipping from the shoreline to the deepest water in midstream. Within the limits of such an area, nests were built first on the upstream face of the bars at depths of 12 to 24 inches. Thereafter, similar sites were utilized in shallower water right to the water's edge and to depths of three and one-half feet on the midstream limits of the bars. Areas intermediate between, or upstream or downstream from, the gravel ridges were utilized last (Fig. 23).

In a small stream, the Little Ocqueoc River, a continuous series of closely spaced gravel riffles were present, although the profile of these

Figure 22. Diagram of a gravel riffle in the Ocqueoc River utilized by sea lampreys for spawning. Stippled areas are bars or concentrations of gravel; the location of sea lamprey nests in the area is indicated by unshaded circles. (Station 1L-M, 1947).

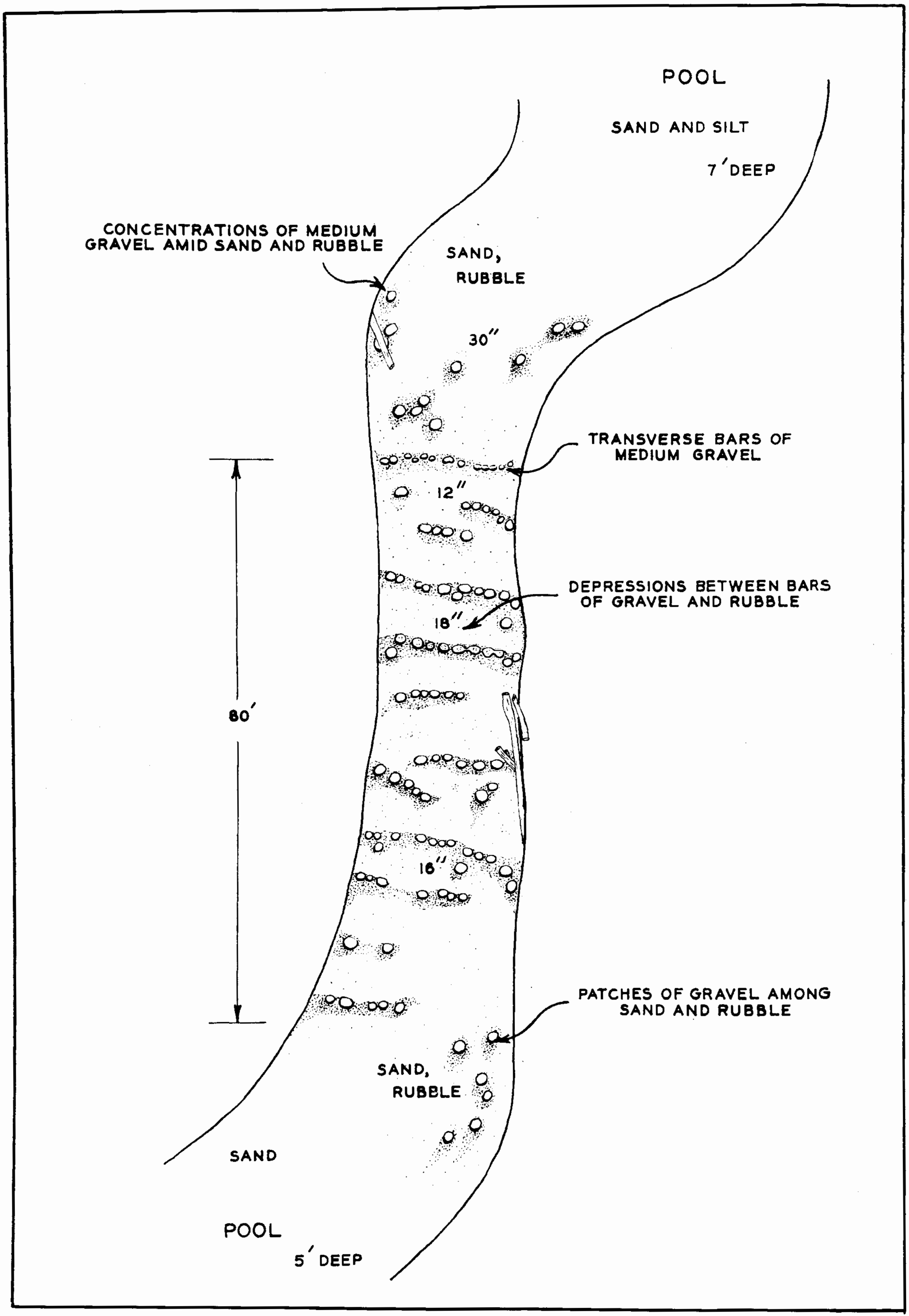
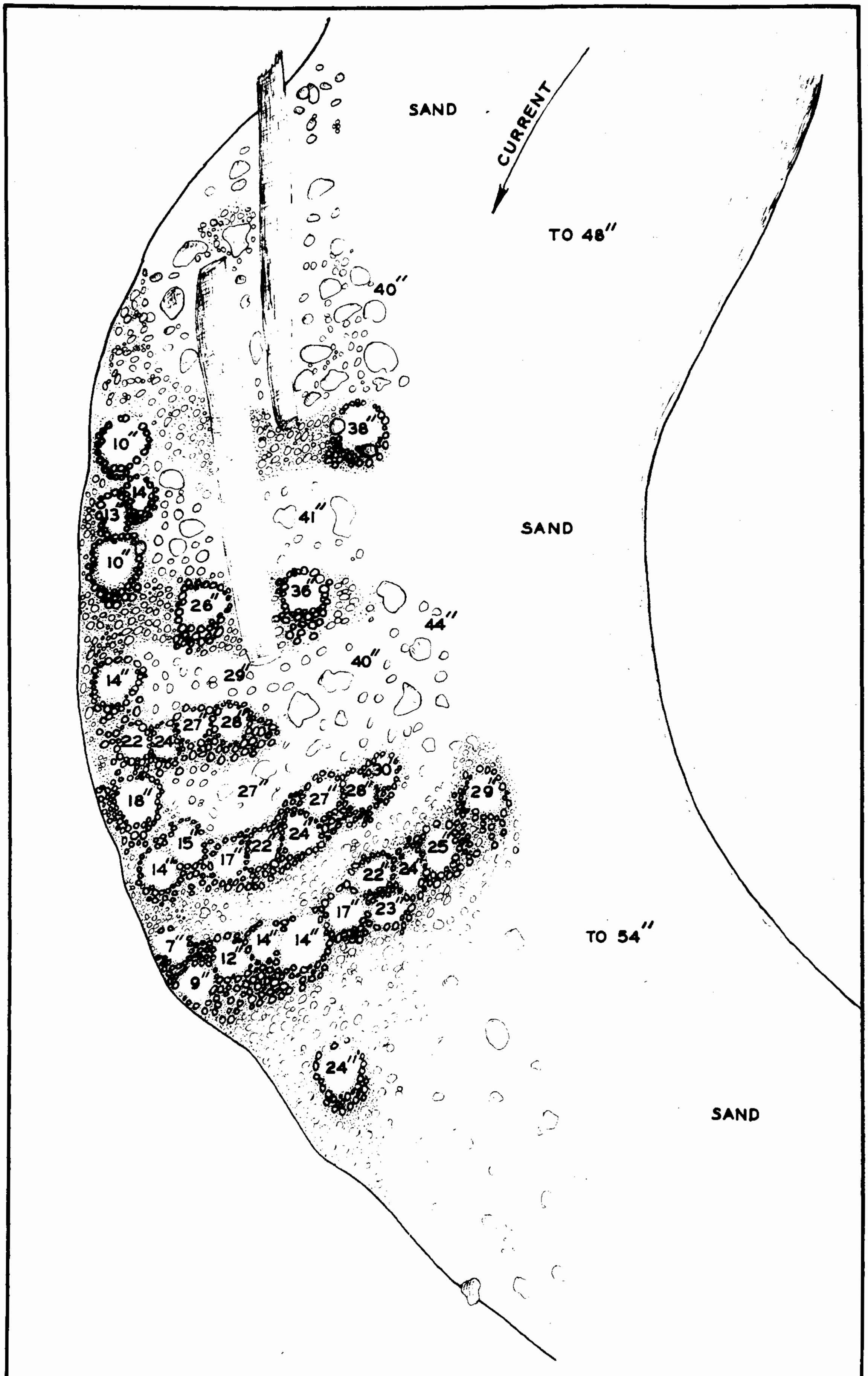

POOL
SAND AND SILT
7' DEEP
CONCENTRATIONS OF MEDIUM GRAVEL AMID SAND AND RUBBLE
SAND, RUBBLE
30"
TRANSVERSE BARS OF MEDIUM GRAVEL
12"
DEPRESSIONS BETWEEN BARS OF GRAVEL AND RUBBLE
18"
80'
16"
PATCHES OF GRAVEL AMONG SAND AND RUBBLE
SAND, RUBBLE
SAND
POOL
5' DEEP

Figure 23. Diagram of the location of sea lamprey nests on a series of crescentic gravel bars in the outside of a bend in the river. Depth in inches to the floor of each nest and at various points within the area are indicated. (Ocqueoc River, Station 2C, June, 1947).


SAND
CURRENT
TO 48″
40″
38″
10″
14
13
10″
41″
SAND
36″
26″
44″
40″
14″
29″
27
28
22
24
30″
18″
27″
27″
28″
29″
15
24
17″
22
25
14″
22″
24
17″
23″
7″
12″
14″
14″
TO 54″
9″
24″
SAND

bars was quite low. Here the sea lampreys selected nest-building sites initially on the upstream face of the gravel bars and laterally in the intermediate areas without much discrimination (Fig. 24).

In Zone 1, sea lamprey nests were built at depths ranging from five inches to five and one-half feet. Most spawning occurred, however, in depths between 12 and 25 inches (depths to center of floor of nest).

In the generally graveled area between Stations 1L and 1M, the average depth of 46 nests was 22.1 inches (range: 8.5 to 24.0 inches) (Table 16); between Stations 1K and 1L, the average depth of 34 nests was 20.2 inches (range: 11.0 to 32.0 inches) (Table 17); and in the generally deeper waters between Stations 1E and 1F, the average depth of 74 nests was 22.4 inches (range: 7.5 to 38.0 inches). It was in this latter area that sea lampreys were observed on six nests built on a gravel bed on the bottom of a deep bend of the river. The depth to these nests was 5.5 feet. In the Little Ocqueoc River (Station 5B), the average depth of 31 nests was 9.0 inches (range: 6.0 to 15.0 inches) (Table 18). For three nests not included in this sample, depths of 5.0, 5.5 and 6.0 inches were recorded (Fig. 24). It is curious to note that in the latter cases, one inch or less of water was passing over the rims of these nests. Spawning had occurred at a similar water level.

Completed nests varied in size from 10.0 to 39.5 inches in diameter. The average diameter was about 19 inches and varied from sample area to sample area as follows: Stations 1L-1M, 22.1 inches; Stations 1K-1L, 21.0 inches; Stations 1G-1H, 19.8 inches; Stations 1E-1F, 18.1 inches. These stations are listed progressing downstream and decreasing average diameters are correlated with decreased amounts of nest-building materials

Figure 24. Diagram of the location of four sea lamprey nests on a gravel bar in a small stream. Depth in inches to the floor of each nest and at various points within the area are indicated. The sea lamprey pictured in the center nest is lying in the bottom of the nest in the characteristic position of a spent male. (Little Ocqueoc River, Station 5B, June, 1947).

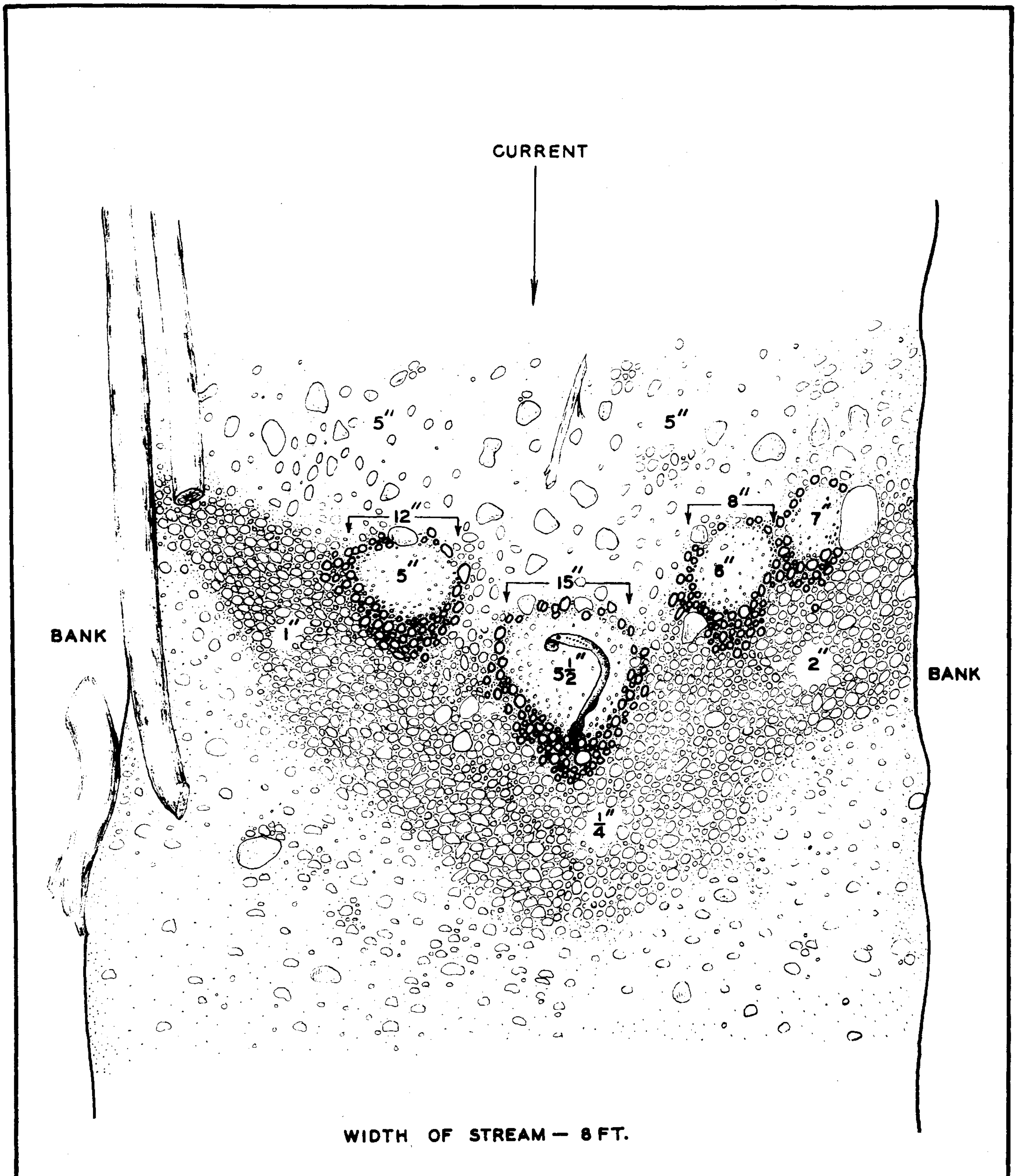

CURRENT
5"
5"
12"
8"
7"
5"
8"
15"
1"
5½"
2"
BANK
BANK
¼"
WIDTH OF STREAM — 8 FT.

Table 16. Depths, dimensions, and materials used in the construction of sea lamprey nests in the Ocqueoc River (Stations 1L to 1M). [All depths and dimensions in inches. Bottom type symbols: "P" - pea gravel, 3/16" to 3/8" in diameter; "M" - marble gravel, 1/2" to 1" in diameter; "E" - egg gravel, 1 and 1/4" to 2 and 1/2" in diameter; "R" - rubble; "S" - sand. All bottom types listed in order of dominance.]

| Depth to center of nest | Dimensions of nest | Downstream rim of nest: Depth to summit | Downstream rim of nest: Materials | Upstream rim of nest: Depth to summit | Upstream rim of nest: Materials | Bottom type--floor of nest | Remarks on location of nest |
|---|---|---|---|---|---|---|---|
| | | (Transverse bar - 3 x 27 feet) | | | | | |
| 12.5 | 27.0 x 35.0 | 4.0 | P, M, E | [1] | R | P, R, S | Forward slope of bar |
| 12.5 | 13.0 | 7.5 | P, M, E | [1] | R | P, R, S | " " " " |
| 11.0 | 23.0 | 4.0 | P, M, E | [1] | R | P, R | " " " " |
| 11.5 | 25.0 | 4.5 | P, M, E | [1] | R, S | P | " " " " |
| 12.0 | 26.0 | 7.0 | P, E | 8.5 | P, E | P | Reverse slope of bar |
| 10.0 | 21.0 | 6.5 | P, M | [1] | R, P | P, R | Forward slope of bar |
| 17.0 | 36.0 | 10.0 | P, M | 13.5 | P, M | P, S | At bank |
| | | (Transverse bar) | | | | | |
| 14.5 | 22.0 | 8.0 | P, M, E | 12.5 | P, R | P, R | Forward slope of bar |
| 12.5 | 30.0 | 6.0 | P, M | [1] | M, R | S, R | Reverse slope of bar |
| 12.0 | 17.0 | 5.0 | Large rock, P, M | 9.0 | S, M | S, P | Forward slope of bar |
| 10.0 | 16.0 | 6.0 | P, M | 8.0 | S, M | P | " " " " |
| 10.0 | 22.0 | 4.5 | P, M, E | 8.0 | P, M | P | Crest of bar |
| 12.0 | 28.0 | 5.0 | M, E | [1] | P, R | P, R | Forward slope of bar |
| 9.0 | 18.0 x 23.0 | 3.0 | P, M, E | 7.5 | S, M, R | P | " " " " |
| 9.0 | 15.0 | 4.5 | P, M | 6.0 | S, M | P, S | " " " " |
| 10.0 | 14.0 | 4.5 | P, M | [1] | S | P, S | " " " " |
| | | (Quieter water between bars) | | | | | |
| 8.5 | 20.0 | 4.5 | P, M, E, R | 6.0 | M, R | P, S, R | Profile of bottom level |
| | | (Transverse bar) | | | | | |
| 10.0 | 19.0 | 3.0 | M, E, R | [1] | M, R | P | Forward slope of bar |
| 8.0 | 22.0 | 2.5 | M, E | 5.0 | M, E, R | P, M | Crest of bar |
| 10.0 | 14.0 | 4.0 | P, M, E | 9.5 | M, R | P, S | Forward slope of bar |
| 10.0 | 14.0 | 3.5 | P, M, E | [1] | M, E | P, S, R | " " " " |
| 10.5 | 19.0 | 3.0 | P, M, E | 8.5 | M, E | P, M | " " " " |
| 10.0 | 19.0 | 3.0 | P, M, E | 8.5 | M, E | P, M | " " " " |
| 13.0 | 28.0 | 5.5 | M, E | 7.0 | M, E, S | P | " " " " |
| 14.0 | 25.0 | 7.5 | P, M, E | [1] | S, R | P, S | " " " " |
| 12.0 | 23.0 | 5.5 | M, E | 9.5 | P, M | P, M | Crest of bar |
| 15.0 | 23.0 | 8.5 | P | 12.5 | M, S | P | Forward slope of bar |
| 13.5 | 16.0 | 9.0 | P, R, M | 12.5 | M, S | S, P | " " " " |
| 13.5 | 15.5 | 9.0 | P, R, M | 12.5 | M, S | S, P | " " " " |
| 16.5 | 29.0 | 9.5 | P, M | 12.0 | M, S | P | " " " " |
| 18.0 | 22.0 x 29.0 | 9.0 | P, M | 15.5 | P, S | P, S | " " " " |
| 17.0 | 30.0 | 10.0 | P, M | [1] | S | P, M, S | Under overhanging bank |
| | | (Gravel bed--quieter water between two riffle areas) | | | | | |
| 13.0 | 25.0 | 7.0 | M, E | 10.0 | M, E | P | ... |
| 15.0 | 22.0 | 9.0 | M, E | 12.0 | M, E | P, S | ... |
| 13.0 | 24.0 | 7.5 | M, E | 9.5 | M, E | P, S | ... |
| 14.0 | 22.0 x 26.0 | 6.0 | M | 13.0 | M, E | P, S | Under overhanging bank |
| 15.0 | 19.0 | 11.0 | P, M | 13.0 | M, E | P | ... |
| 18.0 | 27.0 | 11.0 | P, M | 15.5 | P, M | P | ... |
| 19.0 | 28.0 | 13.0 | M, E | [1] | P | P | ... |
| 24.0 | 25.0 | 17.0 | Snag, E | [1] | P, R | P, R | ... |
| | | (Broad transverse bar) | | | | | |
| 11.5 | 16.0 | 5.0 | E, M | [1] | E, R | P, R | Forward slope of bar |
| 13.0 | 18.0 x 24.0 | 4.5 | E | 11.5 | E, R | P, R | " " " " |
| 14.5 | 17.0 x 23.0 | 5.5 | E | 13.0 | M, E, R | P, R | " " " " |
| 16.0 | 18.0 x 22.0 | 6.5 | E | 15.0 | P, M, R | P, R | " " " " |
| 14.5 | 19.0 | 7.0 | E, M | [1] | P, R | P, R | " " " " |
| 12.0 | 21.0 x 25.0 | 5.0 | M, E | 10.5 | M, E, R | P, R | " " " " |
| Average 13.0 | 22.1[2] | 6.6 | ... | 10.5 | ... | ... | ... |

[1] Upstream rim of nest poorly defined or not elaborated during nest construction. Materials listed are bottom type immediately upstream from nest proper.
[2] Average mean diameter.

Table 17. Depths, dimensions, and materials used in the construction of sea lamprey nests in the Ocqueoc River (Stations 1K to 1L). [All depths and dimensions in inches. Bottom type symbols: "P" - pea gravel; 3/16" to 3/8" in diameter; "M" - marble gravel, 1/2" to 1" in diameter; "E" - egg gravel, 1 and 1/4" to 2 and 1/2" in diameter; "R" - rubble; "S" - sand. All bottom types listed in order of dominance.]

| Depth to center of nest | Dimensions of nest | Downstream rim of nest: Depth to summit | Downstream rim of nest: Materials | Upstream rim of nest: Depth to summit | Upstream rim of nest: Materials | Bottom type--floor of nest | Remarks on location of nest |
|---|---|---|---|---|---|---|---|
| 24.0 | 31.0 x 48.0 | ... | M, E | [1] | S | S, P | |
| 22.0 | 17.0 | ... | P, M | [1] | S | S | Located on small scattered patches of gravel on predominantly sandy stream bed |
| 24.0 | 17.0 | ... | M, E | [1] | S | S | |
| 24.0 | 19.0 | ... | M, E | [1] | S | S | |
| 23.5 | 20.0 x 27.0 | 11.0 | M, E, P | [1] | S | S, P | |
| 14.0 | 11.0 | ... | P | [1] | P | S, P | |
| 11.0 | 37.0 | 4.0 | M, E, P | [1] | S, P | S, P | Gravel riffle behind old log deflector |
| 15.0 | 18.0 | 6.0 | M, E, P | [1] | M, E, P | S, P | |
| 12.0 | 15.0 | 5.0 | M, E, P | [1] | M, P. S | S, P | |
| 15.0 | 25.0 | 6.5 | M, E | 13.0 | P | Clay, P | ... |
| 23.0 | 36.0 x 40.0 | 14.0 | E, S | [1] | P, S | P, S | ... |
| 27.0 | 25.0 x 28.0 | 18.0 | P, M | [1] | S | P, M, S | Midstream |
| 28.0 | 17.0 | 22.0 | M, E, P | [1] | M, S | P, S | |
| 25.5 | 15.0 | 20.0 | M, E, P | [1] | M, S | P | Scattered gravel pockets in midstream |
| 28.0 | 18.0 x 30.0 | 22.0 | Old log, M | [1] | M, S | P, M | |
| 32.0 | 24.0 x 36.0 | 22.0 | M, S | [1] | Clay | P, M | Waterlogged sticks in nest |
| 19.0 | 24.0 x 26.0 | 13.0 | M, E | [1] | Old deadfall | S, P | Midstream |
| 22.0 | 21.0 x 20.0 | 13.0 | M, E | [1] | S | P, M | Forward slope of bar |
| 20.5 | 16.0 | 12.0 | M, E | [1] | S | P, M | " " " " |
| 19.5 | 26.0 | 14.0 | M, E | 14.0 | M, E | P, M | Crest of bar |
| 22.0 | 20.0 | 16.0 | M, E | [1] | S | P | Forward slope of bar |
| 18.0 | 16.0 x 21.0 | 12.0 | M, E | 17.0 | M, E | S | " " " " |
| 11.5 | 16.0 x 19.0 | 3.0 | P, M, E | 10.5 | P | P, S | " " " " |
| 14.5 | 16.0 | 9.0 | E | 11.0 | E, M | P | Crest of bar |
| 19.0 | 19.0 x 23.0 | 11.5 | P, M, E | [1] | S | P, S | Forward slope of bar |
| 24.0 | 18.0 x 21.0 | 15.5 | E, R | [1] | S, R | P, R | " " " " |
| 29.0 | 18.0 | 25.0 | P, M, E | 25.5 | P, M, E | P | Reverse slope of bar |
| 23.5 | 23.0 | 18.5 | P, M, E | 21.0 | M, E | P, S | Forward slope of bar |
| 22.0 | 19.0 x 26.0 | 14.0 | M, E | 19.0 | M, E, R | P | " " " " |
| 20.0 | 21.5 | 11.0 | P, M, E | [1] | S | P | " " " " |
| 16.0 | 16.0 | 8.0 | M, E | [1] | S | P | " " " " |
| 14.0 | 14.0 | 4.0 | M, E | [1] | S | P | Forward slope of bar |
| 12.5 | 14.0 | 4.0 | M, E | [1] | S | P | " " " " |
| 12.0 | 14.0 | 3.5 | M, E | [1] | S | P | " " " " |
| Average 20.2 | 21.0[2] | 12.3 | ... | ... | ... | ... | ... |

[1] Upstream rim of nest poorly defined or not elaborated during nest construction. Materials listed are bottom type immediately upstream from nest proper.

[2] Average mean diameter.

(Tables 16 and 17). The average diameter of nests in the shallow Little Ocqueoc River was 17.7 inches (Table 18). These measurements were taken from tim to rim on the nests. Asymmetrical nests were measured across their longest and shortest diameters and a mean obtained.

Two generalized patterns of nest construction occurred where adequate amounts of gravel were present. The most common of these two was that type built on the upstream face of bars or ridges in the stream. These nests were characterized by high downstream rims, very low or non-existent upstream rims, and tended frequently to be asymmetrical in form (outline) and structure (Fig. 25b). This type was typically found in midstream locations where the current was moderate to swift and where the contours of the bottom had a steep profile. In such nests, the downstream rim of the nest was frequently elaborated to a considerable height--occasionally as much as ten inches above the floor of the nest (Tables 16-18).

The second general type of nest was characterized by a rim of uniform height, a circular outline form, and a generally symmetrical appearance (Fig. 25a). These nests were found at the quieter margins of the stream, along the edge of, and at the head and foot of pools, and in areas intermediate between bars and riffles. Such areas had relatively slower current velocities and flat or low profile bottom contours.

In all types of nests and under all circumstances, I have seen sea lampreys moving stones to the upstream rims of their nests although their success in maintaining this part of the nest structure varies with the nest site and the velocity of the current (as evidenced above). I see no basic functions of this portion of the nest structure other

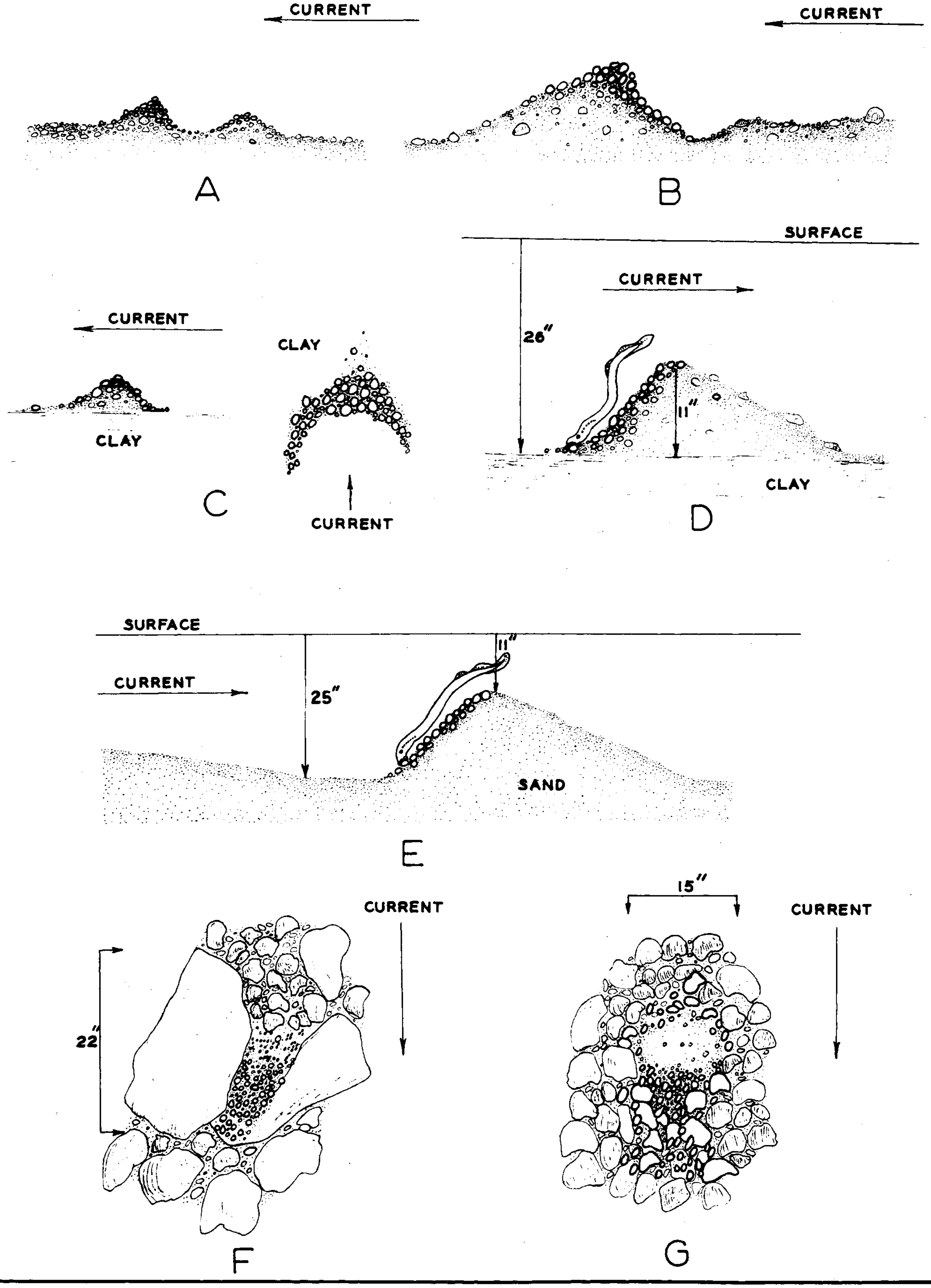
Table 18. Depths, dimensions, and materials used in the construction of sea lamprey nests in the Little Ocqueoc River (Station 5B). [All depths and dimensions in inches. Bottom type symbols: "P" - pea gravel, 3/16" to 3/8" in diameter; "M" - marble gravel, 1/2" to 1" in diameter; "E" - egg gravel, 1 and 1/4" to 2 and 1/2" in diameter; "R" - rubble; "S" - sand. All bottom types listed in order of dominance.]

| Depth to center of nest | Dimensions of nest | Downstream rim of nest: Depth to summit | Downstream rim of nest: Materials | Upstream rim of nest: Depth to summit | Upstream rim of nest: Materials | Bottom type--floor of nest | Remarks on location of nest |
|---|---|---|---|---|---|---|---|
| 7.5 | 20.0 | 2.0 | M, E | 4.0 | M, E, R | P, R | Forward slope of bar |
| 6.0 | 16.0 | 0.8 | M, E | 1.0 | M, E, R | P | " " " " |
| 7.5 | 10.0 | 5.0 | E, R | 4.0 | E, R | P | Intermediate between bars |
| 8.5 | 17.0 | 4.0 | M, E | 7.0 | M, E | P | Midstream |
| 9.0 | 10.0 | 5.0 | E, R | 6.0 | M | P, R | " |
| 10.5 | 17.5 | 11.5 | R, P, E | 8.0 | M, E, R | P, R | " |
| 10.0 | 17.0 x 23.0 | 5.5 | P, E | 8.0 | P, S, R | P, M | Under roof of logs and cedar bows |
| 9.0 | 16.0 | 4.5 | M, large rock | 4.5 | M, E | P | Midstream |
| 6.0 | 18.0 x 20.0 | 2.0 | M, E | [1] | M, E | P | Close to bank |
| 11.0 | 19.0 x 20.0 | 3.5 | M, E | 9.0 | S, P, M | P, S | Midstream |
| 6.0 | 14.0 | 3.0 | P, M, E | 4.0 | M, E | P, S | Forward slope of bar |
| 7.5 | 13.0 x 14.0 | 2.5 | P, M, E | 3.0 | M, E | P, S | " " " " |
| 8.5 | 23.0 | 2.0 | P, M, E | [1] | E, R | P, R | Midstream |
| 8.5 | 13.0 x 21.0 | 2.0 | M, E | [1] | P, R | P | " |
| 10.0 | 22.0 | 3.0 | M, E | 6.0 | P, E, R | P, R | " |
| 10.5 | 14.0 | 5.5 | E, large rock | 8.0 | P, R | P, R | Forward slope of bar |
| 10.0 | 24.0 | 2.5 | M, E | [1] | M, E | P, R | " " " " |
| 7.0 | 13.0 | 2.0 | M, E | [1] | M, E | P, S | Under snags near bank |
| 7.0 | 17.0 | 2.0 | P, M, E | 3.5 | P, M | P | Midstream |
| 7.5 | 23.0 | 1.5 | P, M, E | 4.5 | P, M | P | " |
| 9.5 | 21.0 | 3.5 | M, E | [1] | M, E | P, R | Forward slope of bar |
| 8.5 | 12.0 | 6.0 | P, M, R | 7.0 | M, R | P, M, E | " " " " |
| 10.0 | 22.0 x 24.0 | 2.5 | P, M, E | [1] | M, E | P, M | " " " " |
| 9.0 | 22.0 | 4.5 | E, R, M | 5.5 | R | P, R | Midstream |
| 7.0 | 18.0 | 3.5 | E, R | 4.5 | R | P, R | " |
| 9.0 | 16.0 | 4.0 | P, M | 7.0 | P, R | P, S | Close to bank |
| 15.0 | 20.0 | 3.5 | M, E | 11.0 | E, R | P | Midstream |
| 9.0 | 14.0 | 2.0 | M, E | [1] | E, R | P | Close to bank |
| 11.0 | 14.0 | 7.5 | P, M | [1] | P, M | P | Midstream |
| 12.5 | 25.0 | 6.0 | E, M, S | 10.0 | M, E | P | " |
| 13.5 | 19.0 | 7.0 | Large rock, P, M | 9.0 | P, M, R | P, R | " |
| Average 9.0 | 17.7[2] | 3.6 | ... | 6.1 | ... | ... | ... |

[1] Upstream rim of nest poorly defined or not elaborated during nest construction. Materials listed are bottom type immediately upstream from nest proper.
[2] Average mean diameter.

Figure 25. Sea lamprey nests (see text for discussion).

# SEA LAMPREY NESTS



than an additional repository for materials removed from the center of the nest area and as a provision for anchorages to which the female may attach herself during the spawning act. A single large piece of gravel, a small imbedded stone or stick, or even a hardpan clay bottom has been observed to suffice for the latter requirement.

Nest-building on less favorable sites altered the form of the nest to some degree. Occasional nests were built by clearing an area between two or more large stones which formed walls on each side of the nest. The erratic water turbulence on such sites caused the nest to suffer from some scouring when the spawners were no longer present to maintain it, and it was obvious from an examination of the nests that some considerable mortality of eggs or developing fry resulted.

Where nests were built from a thin layer of gravel and sand upon hardpan clay, the upstream margin of the nest became swept away by the current as did the contents of the floor leaving a crescentic ring of gravel for the nest (Fig. 25c). With no anchorage upstream or down, this structure was slowly demolished by the current and again I found from a dissection of such nests before hatching had occurred that some heavy mortality of eggs or fry resulted.

I believe that in the preceding instance, and in those sandy areas where small, scattered patches of gravel provided nesting sites, the minimal acceptable conditions for sea lamprey nest construction are represented. In the latter case, where pockets of gravel lay ahead of, or against, small hummocks of sand or sand bars, the gravel was placed by the lampreys against the upstream face of such rises (Fig. 25d). The amount of gravel utilized varied, of course, with the available supply. One such nest was observed which consisted of a double layer of 3/4- to 1-inch gravel, approximately one square foot in area, which had been built against a small, sand hummock. All available gravel in the area had been utilized (Fig. 25e). A pair had previously been observed spawning in this "nest." Examination of the nest after the completion of this spawning indicated that very few fertilized eggs were present in it. The potentially high mortality of eggs on such sites as these has been noted elsewhere. Nest construction and spawning were never observed on sites providing a lesser volume of hard, bottom-type elements than in that situation noted just previously.

Miscellaneous odd nesting sites were utilized under snags, and water-logged timber and brush. Immediately below Ocqueoc Lake (Station 1B), riffle areas were created by extensive beds of clam shells. These, with the addition of some moderate amounts of gravel present formed the basic material utilized by the lampreys for nest construction. Such hard objects evidently formed a satisfactory substitute for larger pieces of gravel. The success of spawning on such sites was not determined.

The re-use of nests or nesting sites by late migrants was only observed after all suitable nest-building locations had been utilized. In the latter half of the season in Zone 1, immediately below Ocqueoc Falls, unfavorable water levels at the falls and a reduced vitality among the sea lampreys ultimately forced many of them to spawn in locations that had already been completely utilized. On many transverse gravel bars, this resulted in a complete obliteration of the outlines of the nests of the original spawners. The result was what appeared to be a continuous, straight nest across the entire face of the bar (Fig. 26). Even under such circumstances, several pairs spawning on these ill-defined, continuous structures tended to remain discrete as pairs and spawned across a consistent and limited breadth of the reworked structure.

(Zone 2)

In Zone 2, the general type of nest was one built of gravel, rubble and small rocks in an area which was more or less uniformly composed of varying amounts of these three bottom types (Fig. 25 f, g; Fig. 27).

Little choice was offered the sea lamprey in selecting sites for nest construction in this area of the watershed. Riffle areas of gravel and rubble were more or less level in bottom contour containing few if any bars or ridges as found in Zone 1. Nests were found across the length and breadth of these riffles in a well-distributed pattern--they were seldom built in groups or close to each other. Many of these rubble-strewn riffles had relatively swift currents, and where this occurred, nests tended to be concentrated in the less swift waters nearer the banks.

Individual nesting sites were generally selected where gravels were relatively abundant among the rubble and rock (Table 19). These nests were usually symmetrical in form where the rubble was of such a size that it could be moved and/or utilized in nest construction (Fig. 25g). In rocky or large rubble areas, many asymmetrical types were built (Fig. 25f). Limited amounts of gravel and swift currents restricted most nest construction in such areas to the downstream rim in which the eggs were to be deposited. In predominantly rubble and rock areas, so little gravel was occasionally available that a very

Figure 26. Two pairs of sea lampreys spawning on a transverse gravel bar; a continuous nest which has been reworked by late spawners so that outlines of original nests have been obliterated. (Ocqueoc River, Station 1L-M, June 10, 1948).

Figure 27. Sea lamprey nest; type characteristic of mixed rock, rubble, and gravel areas. (Ocqueoc River, Zone 2, Station 2I, June 8, 1948).

Table 19. Depths, dimensions, and materials used in the construction of sea lamprey nests in the Ocqueoc River (Station 2B). [All depths and dimensions in inches. Bottom type symbols: "P" - pea gravel, 3/16" to 3/8" in diameter; "M" - marble gravel, 1/2" to 1" in diameter; "E" - egg gravel, 1 and 1/4" to 2 and 1/2" in diameter; "R" - rubble; "S" - sand. All bottom types listed in order of dominance.]

| Depth to center of nest | Dimensions of nest | Downstream rim of nest: Depth to summit | Downstream rim of nest: Materials | Upstream rim of nest: Depth to summit | Upstream rim of nest: Materials | Bottom type--floor of nest | Remarks on location of nest |
|---|---|---|---|---|---|---|---|
| 11.0 | 16.0 | 7.5 | P, E, R | 8.0 | P, R | P | Midstream |
| 11.5 | 21.0 | 7.0 | P, E, R | 8.0 | P, R | P | " |
| 10.5 | 18.0 | 6.5 | P, M | 6.0 | P, M, R | P | " |
| 13.5 | 18.0 | 10.0 | P, M | 10.0 | P, R | P | " |
| 13.0 | 18.0 | 6.0 | P, M | 10.5 | P, M, R | P, M | " |
| 11.5 | 20.0 | 8.5 | P, M | 9.0 | P, M | P, R | " |
| 11.5 | 17.0 | 5.0 | P, M | 9.0 | P, M, R | P | Three feet from bank |
| 10.5 | 19.0 | 5.0 | M, E, R | 8.0 | P, R | P | Midstream |
| 13.0 | 20.0 | 7.5 | M | 10.0 | P, M, R | P | Six feet from bank |
| 11.5 | 26.0 | 6.0 | P, M, R | 8.0 | P, M, E | P | " " " " |
| 9.5 | 21.0 | 4.5 | P, E | [1] | P, R | P | Two feet from bank; overhung by bushes |
| 10.0 | 17.0 | 5.0 | P, M, E | 6.5 | P, M | P, R | Midstream |
| 9.5 | 10.0 x 16.0 | 6.0 | P, M, E | 7.5 | P, M, E | P | " |
| 9.0 | 18.0 | 4.5 | P, M | 6.0 | P, M | P | Fifteen feet from bank |
| 12.0 | 17.0 x 21.0 | 6.0 | P, M, E | [1] | P, M | P | Two and one-half feet from bank |
| 9.0 | 22.0 | 3.0 | P, E | 6.0 | P, M, E | P | At current split at head of small island |
| 11.0 | 20.0 | 6.0 | P, M, E | [1] | P, M, R | P | Side channel |
| 11.0 | 19.0 | 6.0 | P, M | 8.5 | P, M | P | Midstream |
| 8.0 | 21.0 | 2.0 | P, M | 4.5 | P, M | P | |
| 13.0 | 22.0 x 25.0 | 5.5 | P, M | [1] | P | P | |
| 11.5 | 17.0 | 6.5 | P, M | 8.5 | P, M | P | Scattered across stream bed |
| 11.0 | 11.0 x 16.0 | 6.5 | P, M | [1] | P, R | P | |
| 12.0 | 15.0 | 6.5 | P, M | [1] | P, M, R | P, R | |
| 9.5 | 13.0 | 5.5 | P, M | 7.0 | P, R, M | P, R | |
| 10.0 | 23.0 x 27.0 | 3.5 | P, M | [1] | P, M, R | P | Three feet from bank; against and alongside of log |
| Average 10.9 | 18.8[2] | 5.8 | ... | 7.8 | ... | ... | ... |

[1] Upstream rim of nest poorly defined or not elaborated during nest construction; materials listed are bottom type immediately upstream from nest proper.

[2] Average mean diameter.

limited nest structure was completed and I presume that the effectiveness of spawning on such sites is limited. Below these nests, eggs could be found lodged (and exposed) among the rubble for many feet downstream.

Among a sample of 25 nests on one of the more favorable spawning riffles in this zone (Station 2B), the depths of the nests averaged 10.9 inches (range: 8.0 to 13.5 inches). These nests averaged 18.8 inches in diameter, varying from 13 to 26 inches (Table 19).

Although a considerable amount of spawning in the Ocqueoc River occurred in this zone, nest-building and spawning conditions are considered less suitable than those areas characterized by gravel bars and ridges in Zone 1. Initially, bottom contours, particularly in most riffles, are low or flat and offer neither resting places for the working sea lamprey nor sites which facilitate the construction of a nest as would the abrupt upstream face of a gravel bar. Heavy and/or unwieldy pieces of rubble must be cleared from the nesting site with some considerable effort by the sea lampreys. These materials and the moderate amounts of gravel available frequently do not form an adequate nest structure. Swift currents over the riffles hinder nest construction and combined with inadequate nest structures result in the sweeping away and probable mortality of many newly spawned eggs.

(General Observations)

Some visible current was present at every nesting site observed in the river. The least current velocity observed in any one spawning location was 1.3 feet per second.[9] The maximum velocity noted in an

---

[9] Channel velocity; surface velocity X factor of 1.33.

area where spawning occurred was 5.2 feet per second in a rubble and gravel riffle. Current velocities in four long and heavily used riffles were 3.6, 3.8, 4.0, and 4.4 feet per second. Two less widely used riffles (poor bottom-types) had velocities of 1.9 and 2.3 feet per second. In areas other than riffles where spawning occurred, velocities of 1.5, 2.3, 2.8, 2.9, and 3.5 feet per second were recorded.

In the Ocqueoc watershed, there was no evident relationship between the degree of cover and/or shade, and the incidence of spawning activity. The earliest, and subsequently one of the most widely used spawning riffles in the river was relatively shallow, contained no "cover" within the stream and was completely exposed to the direct rays of the sun throughout the day. At the other extreme, spawning activity in the Little Ocqueoc River at Station 5B occurred in dense shade where the sun seldom strikes the water. However, since among the earliest spawning sea lampreys, somewhat more activity was displayed during the hours of darkness than during daylight, I suspect that under optimum spawning conditions, all other factors being equal, a preference would be shown by the sea lamprey for "covered" or shaded nesting sites.

(4) Summary of spawning requirements.--It is concluded from these data collected in the Ocqueoc River, that two essential physical conditions, other than suitable water temperatures, must be fulfilled before sea lamprey spawning can be undertaken with any degree of success. First, gravel, 3/8-inch to 2 inches in diameter, or gravel mixed with some other acceptable hard bottom-type (rubble, clamshells, etc.) must be present as the basic elements for nest construction.

Furthermore, some small amounts of sand must be available to which the eggs will adhere and which will imbed the eggs in the interstices of the gravel in the nest rim. Excessive amounts of larger hard bottom-types (bed rock, boulders, large rubble) hinder or prevent spawning. In sandy areas, some small amount of gravel must be present before nest construction and spawning will be attempted by the sea lamprey. Probably the minimal acceptable quantity of gravel under such circumstances is typified in the nesting site described on p. 118 (Fig. 25e).

Second, it is concluded from studies of the mechanics of the spawning act, from the spawning behavior of the sea lamprey, and from the distribution of spawning sites in the river, that at least some current, passing consistently in one direction over the nest, is essential to successful spawning. Very swift currents hinder or preclude spawning and when it does occur under these conditions, many eggs are swept beyond the nest which are lost through exposure, abrasion and predation.

In the total absence of either gravel of the specified sizes, or current, I have never observed spawning to take place and where minimal quantities of either or both exist, I believe that the success of spawning, measured in terms of hatched-fry production, is very low.

The question has been raised as to whether sea lampreys, blocked from their spawning areas in streams by dams or other obstructions, would spawn on the gravel-bottom shoals of the Great Lakes proper. Although there is no direct evidence to indicate whether they do or do not, I do not believe that such spawning occurs. If it does occur, the success of this spawning must indeed be very low. Nest construction, the spawning act itself, and the normal, and presumably successful, deposition of the eggs in the nest are predicated on an uni-directional current passing over the nest; the entire spawning behavior of the sea lamprey reflects a positive orientation to this consistent, uni-directional current. Shoal areas of the Great Lakes frequently possess a bi-directional, or reversing, water movement induced by wave action upon the shore. I cannot see how an ebb and flow water movement (or still water) could elicit the presumably normal responses in the lamprey which would result in an effective nest construction or spawning act. I believe such water action would inhibit both of these activities. Furthermore, in the shallowest areas of the lake shoals, one to three feet in depth, which are comparable to the depths selected in streams by the lampreys for spawning, the abrasive action of gravel particles continually shifting under the impetus of erratic water movement would grind any eggs that had been spawned to bits.

(5) Post-spawning behavior.--Following the completion of spawning, spent females were observed to drop away from the nest almost immediately, drifting downstream to die in quieter eddies or the deeper pools. Experimentally at least, they died much more rapidly after spawning than did the males. This was determined in spawning raceways where ammocoete production was studied. Males, however, cling to the nest for one to three days after spawning is completed, only dropping downstream when completely spent physically and very near death. Such spent males curled themselves in the deepest depression of the floor of the nest where they received the most

protection from the current. There they clung motionless to a piece of gravel or stone (Figs. 24, 28). The position and behavior were so typical, that spent individuals were readily spotted on the spawning beds.

Males and females, dropping downstream and no longer possessing the strength to swim against the current, generally moved tail-first with weak swimming movements against the current. Even at this stage, they still retained a positive response to the stream current.

(6) Adults prevented from spawning.--A preceding discussion considers one possible fate of sea lampreys prevented by barrier dams from reaching suitable spawning areas in streams, i.e., they might spawn on gravel shoals in the lake proper. Such a situation was considered unlikely. There is no positive evidence to date that a diversion of such runs to other streams along the shoreline, with accessible spawning areas, occurs.

A limited amount of experimental evidence suggests that migrants, blocked from stream spawning areas and finding no suitable sites in the estuary or lake proper, die without spawning.

In 1947, 50 migrant sea lampreys (30 males and 20 females) were taken from the Carp Creek weir on May 20 and 24, and on June 15, and placed in live-crates anchored in Ocqueoc Lake at depths of two to four feet. Ten lampreys were placed in each of five compartments which averaged about one and one-half cubic yards of space apiece. An equivalent number of 8- to 11-inch black bullheads were placed in each compartment (None of these bullheads were ever attacked by the imprisoned lampreys). The bottoms of three compartments were of

Figure 28. Spent male sea lamprey clinging to nest after the completion of spawning. (Ocqueoc River, Station 1M, June 8, 1948).

wood, perfectly smooth, and of the remaining two, wood covered with a layer of silt and sand. Lake water temperatures at the depths indicated varied from 53° F. to 75° F. during the course of the experiment.

Initially, all imprisoned lampreys were very restless and moved about almost continuously searching for a way out of the crate. This restlessness became very pronounced on June 25. Between then and June 28, 12 males and 5 females died. Between the latter date and July 3, 9 males and 15 females likewise died. Of the remainder (all males), two died on or before July 11, six on or before July 18, and the remaining specimen expired on July 25.

With the exception of the retention of the unspawned eggs or milt, anatomical and degenerative changes among these dead specimens were comparable with those changes noted among spent sea lampreys. The color of the liver, the degree of reduction of the digestive tract, the loss of vision, and the sloughing off of areas of the skin were all similar (subsequent discussions treat in more detail upon these changes among migrant and spawning individuals).

A logical criticism of this experiment is that the specimens were held at relatively high water temperatures which were atypical of the conditions they might have enjoyed if they had fallen back from a barrier structure into the lake proper. Furthermore, these higher temperatures may have accelerated their demise or hindered a possible recovery from the anatomical changes accompanying sexual maturity. However, four migrant adults were taken from Carp Creek on May 29, 1947, and held in running water aquaria at the Oden State Fish Hatchery. The water temperature in these aquaria averaged 49° F. and varied from 48° F. to 52° F. Either suckers or trout were placed in the aquaria with the specimens.[10]

The lampreys were very active for several days seeking a way out of the tanks. Thereafter, they quieted down and were never active unless disturbed. At no time did they attack either suckers or trout placed with them. Three specimens were killed on June 12, June 28, and August 5, respectively, and examined. Liver color and reduction of the digestive tract in the latter two specimens were comparable with that of spent sea lampreys. The fourth lamprey died on September 3 bearing no evidence of a recovery from the degenerative changes accompanying sexual maturity.

This slender evidence suggests that colder water temperatures merely prolong the existence of an organism that, if barred by circumstances from the climactic act of its life cycle, is destined to die when it has burned up its reserves of energy.

## VI. Physical degeneration of migrants and mortality of post-spawning adults.

Although the preponderance of evidence presented by earlier investigators points rather conclusively to the death of the sea lampreys after the completion of spawning, doubt is still expressed in some quarters as to whether this actually occurs. Surface (1899) and Gage (1928) noted an anatomical degeneration of the intestine (and liver; Gage, 1928) among migrant and spawning populations of lampreys of this species. Surface likewise noted a tendency towards blindness and a sloughing-off of the epidermis among post-spawning

---

[10] Experiment conducted and observations by Mr. R. F. Sharkey of the Oden State Fish Hatchery.

adults. Both writers refer to the absence of "minute ova" in the ovaries of spent females as evidence that the lampreys spawn but once and then die.

If sea lampreys die after spawning, one would expect to find large numbers of dead, spent fish near the spawning grounds. However, this is not so; such fish are not seen in abundance. Surface (1899) attributed this dearth to the fact that most dead and dying lampreys were deposited in the deeper, silted pools of a stream and to the fact that immediately after death, the lampreys decayed with great rapidity under any circumstances. An experiment performed by Surface confirmed these contentions. Both Surface (1899) and Gage (1928) noted instances where the presence of the long, tape-like, persistent notochord was the primary evidence in the stream of a post-spawning mortality of adults.

Gage (1928) performed experiments in holding spawning sea lampreys under various conditions favorable to their recovery and observed that all specimens ultimately died. The most conclusive evidence of mortality in spent lampreys was presented by Surface (1899) for a spawning run of lampreys in a New York stream. He reported that only dead or dying sea lampreys (often badly fungused and barely alive) drifted downstream to a weir and trap operated on the inlet of Cayuga Lake, New York.

All of my evidence, from both field observations (direct evidence) and anatomical studies (indirect evidence), collected during the present investigations confirm the conclusions of Surface (1899) and Gage (1928), that sea lampreys die after spawning. They also show that the sea lamprey in Michigan waters undergoes profound anatomical changes with the advent of sexual maturity and the spawning migration and dies after spawning once.

Observational or direct evidences to support these statements are of two types: those derived from observations on the spawning grounds and those obtained in connection with the operation of sea lamprey weirs and traps.

During the 1947 and 1948 seasons, sea lamprey spawning activity was studied in detail in the Ocqueoc River watershed. During and after the peak of spawning activity, spent and dead or dying adults could always be found on those spawning grounds where thorough examination was possible. Admittedly, spent and dead sea lampreys were never very much in evidence to the casual observer but a careful search under brush tangles, in sloughs, backwaters and in the deeper silted pools revealed many that would ordinarily escape the inexperienced eye. One day's observations should suffice to illustrate this. On June 24, 1947, a 0.6-mile stretch of the Ocqueoc River was carefully censused for spawning and dead sea lampreys. Of 194 individuals seen, 155 were occupied with spawning activity. The remainder, 39 (20.1 percent), dead or very nearly so, were picked up in quiet water or in locations where their bodies would catch under or against logs, brush and stones. Furthermore, an investigation of the deeper, silted pools revealed the presence of many dead lampreys in advanced stages of decay which, because of fragmentation, could not be counted. The remains of most dead sea lampreys present in the watershed lay at the bottom of these deeper pools. The depth of the pools (many to 10 feet or more), the tea-colored water of the river, and a very rapid silting-over and decay of the bodies all combine to conceal from the observer the many dead individuals deposited there by the river current.

In pools, particularly below much-used spawning riffles, dredging activities produced numerous white, tape-like structures; on comparison these proved to be sea lamprey notochords. These notochordal "tapes" were all that remained of decayed sea lampreys. These persistent structures were also found caught against brush and other snags in other parts of the stream.

A contributing factor to the paucity of observable dead in the shallower waters is the scavenging activities of the gulls as has been noted in a previous section of this study. These birds pick up many of the dead and dying that might otherwise be readily visible to the human eye.

These observations, although direct evidence that some or most sea lampreys die following spawning, do not refute the contention that perhaps some individuals recover to spawn in another season. However, the operation of the Ocqueoc River weir in 1945 which has been reported upon by Shetter (1948) offers excellent testimony that very few if any recover from the spawning act. This point has not been elaborated by Shetter. A weir and trap was operated in the Ocqueoc River from April 22 to July 15, 1945. The river overtopped the weir on April 25-28 and again, during the peak of migration, on May 28-June 6. Although 4,608 sea lampreys were trapped, an escapement of perhaps 40 percent of the run occurred. Those that passed the weir were observed spawning subsequently in the watershed. During the entire period of effective operation of the weir (June 6-July 15) following the second over-topping of the structure, only 29 sea lampreys were taken moving downstream.

The inclusive dates of operation allowed ample time during this interval for most, if not all, of any adults that had recovered from spawning and were returning to the lake, to have reached the weir. Furthermore, although the 29 downstream migrants were not examined to determine their condition, I have reason to believe that they were merely upstream migrants moving around within the confines of the stream while seeking a place to spawn. Data collected in 1948 during the frequently interrupted operation of the dam and trap in the Carp Lake River (Emmet County) supports this contention.

In addition to the preceding observations, data obtained from an examination in the laboratory of migrant and spawning sea lampreys offers further supporting evidence, of a less direct nature, on the post-spawning mortality of adults.

First, it has been concluded from a study of the ovaries of both unspawned and spent female sea lampreys that the maturing eggs greatly outnumbered the undeveloped ones present which would have enabled the female to spawn again in another year. Furthermore, no germ-cell stages were found to be present in the ovaries of the spent females examined (Applegate, MS.).[11]

Secondly, a group of observable manifestations of a physical degeneration of migrant and spawning adults was noted in all specimens examined. Although these phenomena of decadence are discussed separately under following subheadings, they should be considered in the light of their cumulative effect upon the individual sea lamprey in order that their significance can be appreciated fully:

---

[11] Applegate, V. C. Sea lamprey investigations. 2. Egg development, maturity, egg production, and percentage of unspawned eggs of sea lampreys, Petromyzon marinus, captured in several Lake Huron tributaries. (I.F.R. Rept. #1161).

(1) Progressive blindness.--All sea lampreys that were found spent and dying upon the spawning grounds were quite blind. The corneas of the eyes of these specimens had lost their sharp, clear quality and were quite milky or cloudy in appearance. These individuals would respond weakly to tactile stimuli--never to visual ones. The onset of this condition was first noted during and after the peak of spawning activity when it was observed that nearly all of the spawning adults nearing the completion of spawning were already blind. As the termination of the spawning period approached, blind individuals were found in progressively less advanced stages of their spawning activities. At these times, the observer could stand astraddle a nest in which a pair were spawning and place the fingers of one hand on each side of the head of one of the spawners as if to grasp it. No response or awareness of the observer's presence was elicited until a physical contact was made with the lamprey's head or body. Only then did the usual avoiding reaction result.

All of the stragglers which composed the end of the Carp Creek run in 1947 displayed some evident loss of vision. In several of the migrants taken during the month of July, the eyes were already milky-white and opaque and these specimens did not respond to visual stimuli. This was likewise true of the late migrants captured in Ocqueoc Lake during July of the same season.

A general increase in migratory activity during daylight hours as the spawning season progresses has been noted previously. The increase in activity during the daytime is much more pronounced on the spawning grounds during the same period and is climaxed with equal spawning activity occurring at all hours of the day and night. It appears that loss of vision parallels ripening of the gonads, that it progresses in severity as spawning time approaches, and that it culminates in total blindness by the time an individual is spent. Other evidence indicates that loss of vision occurs more rapidly among late migrants than among early ones.

(2) Loss of epidermis.--In all dying and freshly dead sea lampreys it was observed that large, irregular patches of outer skin had been lost. With the layer that had been sloughed-off, went its mucous coating and the pigmentation of the variety of spawning colorations which occurred. The deeper layers of the integument which were exposed were a dull, blue-black in color with a vague overprinting of the characteristic black mottling. Those areas upon which the outermost layers still remained could easily be denuded of their covering by a firm stripping action with the hand.

Skin loss was first noticeable in mid-breeding season among live adults which were nearing the completion of spawning. As the spawning period progressed, increasing numbers of individuals were found on the nests which displayed some loss of body covering. At the close of the season, all adults observed at the peak, or later, of their spawning activity had suffered a similar loss. Among live individuals, the most noticeable loss of areas of the skin was found among spent males. These males characteristically cling to, or remain in the bottom of, the nest for a variable period following the completion of spawning. On observation, it seems hardly possible that these males, with their lifeless behavior, with white, opaque eyes and with scaly, broken skin, could still be alive or could live to spawn again.

Much of this loss of body covering may be attributed to abrasion against hard bottom materials during the violent exertions of nest building and spawning. Among the females, further scarring and abrasion of the head region occurs from the male grasping her in that region with his mouth during each spawning act. Since there is no evident repair or replacement of the lost layers, the scarring effects of all abraiding agents are cumulative. Some dying individuals were found almost completely denuded of the outer layer of skin. These conditions rendered the sea lampreys very vulnerable to attack by water molds and many of them displayed visible evidence of fungus infections.

(3) Degeneration of the digestive tract and changes in the color of the liver.--Two phenomena are readily apparent in the dissection of sea lampreys collected during the entire season of migration and spawning. One is a series of changes which occur in the color of the liver; the other is a striking reduction in the size of the digestive tract.

The liver of sexually immature and actively feeding adults is normally a pale reddish-orange. Among male sea lampreys the livers of the earliest migrants still retain this color. However, as the migratory season progresses and the run becomes composed of individuals in more advanced stages of sexual maturity, a series of color changes of this organ become evident. Successively, the color of the liver becomes orange-yellow, sometimes mottled, sometimes of a uniform intermediate shade; yellow; yellow-green, either mottled or of a uniform intermediate shade; and, finally, a bright, light green. The livers of virtually all migrants examined during and after the peak of the spawning run were in advanced stages of change; the colors occurring were yellow, yellow-green, or light green. The color of the liver of all spawning and spent males examined was light green.

The liver color of the earliest migrant females likewise was the reddish-orange characteristic of the organ in sexually immature adults, although it was of a somewhat darker shade. Changes in the color of the liver with increasing sexual maturity differed from those of the males and were less elaborate. The liver in migrant females on successive dates became: reddish-brown; brownish-green, either mottled or of an intermediate shade; and finally, dark green. In the latter half of the run, all females fell in the latter two color categories. The livers of all spawning and spent females examined were dark green in color.

These color changes of the liver are very pronounced in character and differ so distinctly between the two sexes that accurate sex determinations can be made upon sexually maturing or mature adults solely upon an examination of the color of this organ.

When the above observations were made, records were obtained of the stage of sexual maturity, color of the liver, and intestinal and rectal diameters of 478 male and female sea lampreys collected at intervals throughout the migratory and spawning seasons. These data are presented in Tables 20 and 21, sexes separately. The proportion of individuals displaying the color changes described above at various times during these periods may be derived from these tables.

The direct or indirect causes of these color changes in the liver of the sea lamprey are not known. Surface (1899) noted that the livers

Table 21. Sexual maturity, color of liver, and intestinal and rectal diameters of 190 migrant and spawning female sea lampreys from Carp Creek, the Ocqueoc River, and Ocqueoc Lake, Presque Isle County.

| Dates of collection (1947) | Migrant or spawning | Number of specimens | Average total length (in inches) | Number with gonads | | | Color of liver (Number of specimens) | | | Diameter of intestine (in millimeters) | | | Diameter of rectum (in millimeters) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Firm | Soft | Ripe | Reddish-orange | Reddish-brown; Brown-green | Dark green | Minimum | Average | Maximum | Minimum | Average | Maximum |
| May 1-5 | Migrant | 14 | 18.2 | 14 | ... | ... | 2 | ... | ... | 9.5 | 10.8 | 12.0 | 8.0 | 9.0 | 10.0 |
| | | | | | | | | 9 | ... | 7.0 | 9.0 | 10.5 | 5.0 | 6.9 | 7.5 |
| | | | | | | | | | 3 | 7.0 | 7.0 | 7.2 | 4.5 | 5.3 | 6.0 |
| May 11-15 | " | 21 | 17.3 | 14 | 7 | ... | 1 | ... | ... | ... | (10.0) | ... | ... | (8.5) | ... |
| | | | | | | | | 8 | ... | 4.5 | 7.8 | 12.0 | 4.5 | 6.4 | 9.5 |
| | | | | | | | | | 12 | 3.5 | 4.8 | 6.0 | 2.0 | 3.9 | 5.5 |
| May 16-20 | " | 12 | 17.8 | 12 | ... | ... | | 3 | ... | 5.0 | 6.3 | 7.5 | 3.5 | 4.2 | 4.5 |
| | | | | | | | | | 9 | 3.0 | 4.7 | 6.0 | 2.5 | 3.7 | 6.0 |
| May 20-25 | " | 10 | 18.1 | 8 | 2 | ... | | 5 | ... | 5.0 | 5.8 | 7.0 | 3.5 | 4.3 | 5.0 |
| | | | | | | | | | 5 | 3.5 | 4.8 | 6.5 | 3.0 | 3.6 | 4.5 |
| June 1-5 | " | 28 | 17.3 | 28 | ... | ... | | 5 | ... | 4.5 | 5.4 | 6.0 | 4.0 | 4.3 | 5.0 |
| | | | | | | | | | 23 | 3.5 | 4.6 | 5.5 | 3.0 | 3.6 | 4.5 |
| June 6-10 | " | 15 | 17.1 | 14 | 1 | ... | | 3 | ... | 5.0 | 5.7 | 6.5 | 4.0 | 4.7 | 6.0 |
| | | | | | | | | | 12 | 2.5 | 3.6 | 5.0 | 2.0 | 3.0 | 4.0 |
| June 11-15 | " | 32 | 16.7 | 18 | 13 | 1 | | 3 | ... | 4.0 | 4.5 | 5.0 | 3.5 | 3.8 | 4.0 |
| | | | | | | | | | 29 | 1.5 | 3.1 | 5.5 | 1.0 | 2.5 | 4.0 |
| June 16-20 | " | 32 | 16.5 | 9 | 23 | ... | | 2 | ... | 4.5 | 4.8 | 5.0 | 3.5 | 3.8 | 4.0 |
| | | | | | | | | | 30 | 1.5 | 3.1 | 5.0 | 1.0 | 2.5 | 4.0 |
| June 16-20 | Spawning | 4 | 17.4 | ... | ... | 4 | | | 4 | 2.0 | 2.1 | 2.5 | 1.5 | 1.8 | 2.0 |
| June 21-25 | Migrant | 3 | 14.7 | ... | 1 | 2 | | | 3 | 2.5 | 3.0 | 3.5 | 2.0 | 2.7 | 3.0 |
| June 21-25 | Spawning | 8 | 15.0 | ... | ... | 8 | | | 8 | 1.5 | 1.9 | 2.0 | 1.0 | 1.5 | 2.0 |
| June 26-30 | Migrant | 2 | 16.5 | ... | 1 | 1 | | | 2 | 3.0 | 3.0 | 3.0 | 2.5 | 2.5 | 2.5 |
| June 26-30 | Spawning | 6 | 15.2 | ... | ... | 6 | | | 6 | 1.5 | 2.1 | 2.5 | 1.5 | 1.8 | 2.5 |
| July 10-15 | Migrant | 3 | 15.8 | 1 | ... | 2 | | 1 | ... | ... | (3.0) | ... | ... | (2.5) | ... |
| | | | | | | | | | 2 | 2.5 | 2.5 | 2.5 | 2.0 | 2.3 | 2.5 |
| Total | | 190 | | | | | | | | | | | | | |

Table 20. Sexual maturity, color of liver, and intestinal and rectal diameters of 288 migrant and spawning màle sea lampreys from Carp Creek, the Ocqueoc River, and Ocqueoc Lake, Presque Isle County.

| Dates of collection (1947) | Migrant or spawning | Number of specimens | Average total length (in inches) | Number with gonads | | | Color of liver (Number of specimens) | | | Diameter of intestine (in millimeters) | | | Diameter of rectum (in millimeters) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Firm | Soft | Ripe | Orange, Orange-yellow | Yellow, Yellow-green | Green | Mini-mum | Aver-age | Maxi-mum | Mini-mum | Aver-age | Maxi-mum |
| May 1-5 | Migrant | 25 | 17.7 | 25 | ... | ... | 21 | ... | ... | 6.5 | 8.0 | 10.5 | 4.5 | 6.1 | 8.0 |
| | | | | | | | | 4 | ... | 4.5 | 6.3 | 8.0 | 3.5 | 4.8 | 6.0 |
| May 11-15 | " | 31 | 17.4 | 31 | ... | ... | 15 | ... | ... | 5.5 | 7.4 | 12.5 | 4.5 | 6.2 | 11.0 |
| | | | | | | | | 12 | ... | 4.5 | 6.0 | 8.0 | 4.0 | 5.0 | 7.0 |
| | | | | | | | | | 4 | 4.0 | 5.0 | 6.5 | 3.0 | 4.1 | 5.5 |
| May 16-20 | " | 24 | 17.3 | 24 | ... | ... | 10 | ... | ... | 6.0 | 7.5 | 10.5 | 4.0 | 6.0 | 9.5 |
| | | | | | | | | 10 | ... | 4.5 | 5.5 | 7.0 | 3.5 | 4.5 | 6.0 |
| | | | | | | | | | 4 | 3.5 | 4.9 | 6.5 | 3.0 | 3.9 | 5.0 |
| May 20-25 | " | 23 | 17.9 | 23 | ... | ... | 11 | ... | ... | 6.0 | 6.7 | 7.5 | 4.0 | 5.0 | 5.5 |
| | | | | | | | | 4 | ... | 5.0 | 5.1 | 5.5 | 4.0 | 4.5 | 5.0 |
| | | | | | | | | | 8 | 3.5 | 4.4 | 5.0 | 3.0 | 3.4 | 4.5 |
| June 1-5 | " | 50 | 17.1 | 50 | ... | ... | 7 | ... | ... | 4.5 | 5.6 | 7.5 | 3.5 | 4.5 | 6.0 |
| | | | | | | | | 17 | ... | 5.0 | 5.5 | 6.0 | 3.5 | 4.5 | 5.0 |
| | | | | | | | | | 26 | 2.5 | 4.1 | 5.0 | 2.0 | 3.4 | 4.5 |
| June 6-10 | " | 28 | 17.1 | 25 | 2 | 1 | ... | 9 | ... | 4.5 | 5.6 | 6.5 | 4.0 | 4.8 | 6.0 |
| | | | | | | | | | 19 | 2.0 | 3.3 | 5.0 | 1.5 | 2.7 | 4.5 |
| June 11-15 | " | 39 | 16.7 | 38 | 1 | ... | 1 | ... | ... | ... | (5.0) | ... | ... | (4.0) | ... |
| | | | | | | | | 12 | ... | 4.0 | 4.4 | 5.0 | 3.0 | 3.7 | 4.0 |
| | | | | | | | | | 26 | 1.5 | 2.9 | 5.0 | 1.5 | 2.5 | 4.0 |
| June 16-20 | " | 30 | 16.0 | 29 | 1 | ... | ... | 15 | ... | 3.0 | 4.0 | 5.0 | 2.0 | 3.3 | 4.0 |
| | | | | | | | | | 15 | 2.5 | 3.2 | 4.0 | 2.0 | 2.8 | 4.0 |
| June 16-20 | Spawning | 11 | 15.6 | ... | ... | 11 | ... | ... | 11 | 1.5 | 2.0 | 2.5 | 1.0 | 1.6 | 2.0 |
| June 21-25 | Migrant | 5 | 17.3 | 5 | ... | ... | 1 | ... | ... | ... | (5.0) | ... | ... | (4.0) | ... |
| | | | | | | | | 3 | ... | 4.0 | 4.1 | 4.5 | 3.0 | 3.7 | 4.0 |
| | | | | | | | | | 1 | ... | (2.0) | ... | ... | (2.5) | ... |
| June 21-25 | Spawning | 7 | 16.5 | ... | ... | 7 | ... | ... | 7 | 2.0 | 2.1 | 2.5 | 1.0 | 1.8 | 2.0 |
| June 26-30 | Migrant | 3 | 15.7 | 3 | ... | ... | | 3 | | 3.0 | 3.5 | 4.0 | 2.5 | 2.8 | 3.5 |
| June 26-30 | Spawning | 11 | 16.2 | ... | ... | 11 | ... | ... | 11 | 1.5 | 2.1 | 2.5 | 1.0 | 1.7 | 2.0 |
| July 10-15 | Migrant | 1 | (14.7) | ... | ... | 1 | ... | ... | 1 | ... | (2.0) | ... | ... | (2.0) | ... |
| Total | | 288 | | | | | | | | | | | | | |

-138a-of spent specimens were green in color and ascribed it to a general accumulation of catabolic wastes. It has been suggested that these color changes result from the successive accumulation in the liver of dominant qualities of the bile pigments (bilirubin, urobilin and biliverdin) following conversion from one to the other by either oxidative or reductive processes. However, the sequence of reactions that would necessarily be involved seems somewhat irrational. Certainly, these color changes in the liver signify a profound alteration in the normal metabolism of the organism which perhaps, is associated with the sexual maturing process. They further signify, if not an actual degeneration of this organ, at least a serious, and possibly irreparable, impairment of its normal functioning.

An "atrophy" of the digestive tract of migrating and spawning sea lampreys was reported by earlier workers (Surface, 1899; Gage, 1928); I too observed this condition. Specifically, it was noted that with increasing sexual maturity and associated cessation of feeding, the diameter of the digestive tract gradually decreased until, at the time of actual spawning it was reduced to a mere hollow thread, one to two millimeters in diameter.

The digestive tract of the sea lamprey may be likened to a straight tube which travels directly from the mouth to the anus. The regional differentiation of the tract, present in higher vertebrates, is only obscurely indicated. Anteriorly, a short gastral or stomach zone is present; posteriorly, a short rectal zone is more readily distinguishable. Between these lies the "intestine" which may be identified by thicker walls and greater structural rigidity than the other zones possess and by the presence of a typhlosole.

In order to demonstrate the reduction in this organ, measurements were made of the diameters of the intestinal and rectal zones of the digestive tracts of 478 sea lampreys. All measurements were made to the nearest half-millimeter with dividers and a steel rule. The samples utilized for these measurements were collected at intervals throughout the migratory season and upon the spawning beds. These data are presented in Tables 20 and 21, sexes separately. For each sex, the range and average of intestinal and rectal diameters have been tabulated first by date of collection and as to whether migrant or spawning sea lampreys were examined. Secondly, these data have been further subdivided and grouped according to the color of the liver of the specimen examined as it was observed that the latter phenomena was the most simple recorded measure of the individual's degree of sexual maturity. The validity of this association may be verified in the striking correlation between the two changes (Tables 20 and 21).

A spawning run, as it progresses in time through migratory and spawning periods is composed of individuals in increasingly advanced stages of sexual maturity. Among the earliest migrants studied, the average diameters of the intestine varied from 7.4 to 10.8 millimeters. The average diameters decreased throughout the run until among late arrivals, maximum intestinal diameters averaged 4.1 millimeters. Further reduction occurred during the journey upriver and upon the spawning grounds. The diameter of the intestine of specimens collected while spawning never exceeded 2.5 mm.; they were occasionally reduced to a diameter of 1.5 mm. Rectal diameters were consistent throughout in their progressive reduction, like those of the intestine, although invariably somewhat lower in value.

It is important to note that these diameter measurements represent only a partial measure of the decrease in the digestive capabilities of the intestines of the specimens studied. As will be subsequently demonstrated, an increasingly greater amount of potential digestive and absorptive surface of the intestine is lost with each small decrease in diameter. The word "potential" is used advisedly since my studies indicate that no feeding takes place during the time in which this reduction is occurring.

Cross-sections were prepared from the mid-portion of the intestines of a series of sea lampreys to determine more precisely the changes in gross structure and histology which occurred during its reduction in size. This material was collected from sexually immature, actively feeding adults, from migrants in varying stages of sexual maturity and from adults taken from their spawning redds. In all intestional sections from 20 specimens taken before and during migration and during and after spawning were examined.

With the exception of the sexually immature specimens, intestines were removed from live material and preserved in F-A-A solution. Sections were imbedded, cut at 10M and stained in Harris' Haemotoxylin and Eosin. A series of photomicrographs of these sections were prepared for selected specimens (Figs. 29-37).

The intestine of a sexually immature adult is circular or ovoid in outline; its lumen is U-shaped. Into the lumen projects a typhlosole which commences anteriorly on the dorsal side of the intestine, describes a partial spiral, and terminates on the ventral side. The typhlosole does not extend more than half way across the lumen. It carries both an artery and a larger vein. Many slender, closely-spaced longitudinal

Figure 29. Section of intestine of sexually immature and actively feeding adult taken in Grand Traverse Bay; total length--9.6 inches; color of liver--orange. X23.2.

Figure 30. Section of intestine of migrant sea lamprey; male; total length--13.1 inches; color of liver--orange. X23.2.

Figure 31. Section of intestine of migrant sea lamprey; female; total length--16.5 inches; color of liver--brown-green. X23.2.

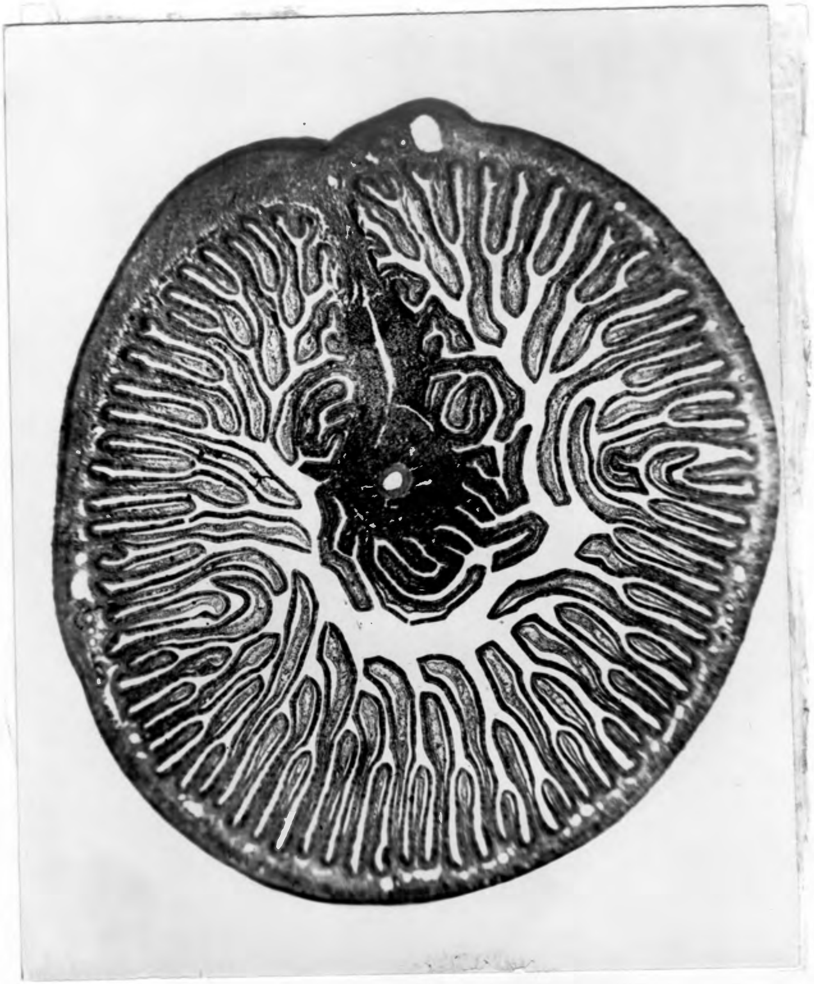


Figure 32. Section of intestine of migrant sea lamprey; male; total length--16.3 inches; color of liver--yellow-green. X23.2.

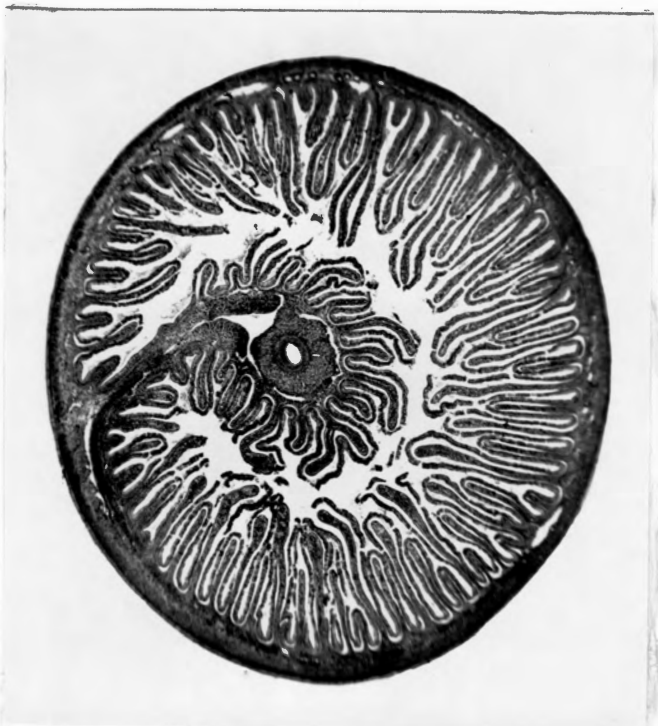


Figure 33. Section of intestine of migrant sea lamprey; female; total length--15.8 inches; color of liver--brown-green. X23.2.

Figure 34. Section of intestine of migrant sea lamprey; female; total length--16.9 inches; color of liver--dark green. X23.2.

Figure 35. Section of intestine of migrant sea lamprey; female; total length--15.9 inches; color of liver--dark green. X23.2.

Figure 36. Section of intestine of spawning sea lamprey; male; total length--14.6 inches; color of liver--light green. X23.2.

Figure 37. Section of intestine of spawning sea lamprey; female; total length--17.8 inches; color of liver--dark green. X23.2.

folds or rugae arising from both the walls of the intestine and from the typhlosole likewise project into the lumen (Fig. 29).

The intestine is covered with a visceral peritoneum (serosa) composed of both simple and stratified squamous epithelial cells in different places. Beneath this lies a relatively undifferentiated muscular layer. The lumen is lined with pseudo-stratified columnar epithelial cells, which may or may not be ciliated, and a variable number of secretory cells. A mucosa of connective tissue forms a core for each of the many ruga and is present at the base of the folds also. Many small capillaries enter the rugae from the walls of the intestine.

Even among the earliest migrant sea lampreys, some constriction of the lumen is evident (Fig. 30). As this cavity becomes more severely constricted, the rugae become contorted and bent upon themselves (Fig. 31); a part of the evident reduction in the lumen is due to crowding of the folds as the intestine first shrinks. Following this, these structures become increasingly truncated and aborted in shape as the diameter of the intestine declines. A fusion seemingly occurs at the bases of the rugae and many disappear entirely (Figs. 32-35).

In spawning sea lampreys the rugae are reduced, in cross section, to blunted, misshapen knobs. Many folds have disappeared and some of those that remain are broadly fused at their bases. At this, the most reduced stage, the typhlosole, is almost devoid of rugae, and, with its large artery and vein, dominates the lumen of the intestine (Figs. 36-37).

Aside from a gradual loss in the volume of tissue present, no specific changes were observed to occur in the histologic characteristics of the serosal and muscular layers. However, some very striking changes were noted in the structure of the epithelial lining of the intestine. As noted previously, this tissue is composed of pseudo-stratified columnar epithelium in the sexually immature adult. It was found that a virtual retrogression of this layer occurred as the gross changes previously recorded progressed. Among migrants in the earlier stages of sexual maturity, more and more simple columnar cells formed the lining of the lumen apparently replacing the pseudo-stratified columnar ones. As maturity increased and the intestine became more and more constricted, the simple cell type increasingly dominated the lining. In subsequent stages the columnar cells became progressively shorter and broader. This was culminated in those specimens, taken on the spawning grounds, in which this lining was composed almost exclusively of simple, cuboidal cells.

Although reduced in number and size, the blood vessels and capillaries retained a highly functional appearance. This may be verified by an examination of the artery and vein in the typhlosole as found in Figures 29-37. Furthermore, very few degenerate or dead cells either free or attached, could be distinguished in any of the sectioned material studied; only apparently living, if somewhat altered, cells appeared to be present. No marked or progressively changing dehiscence of lining cells into the lumen of the digestive tract was observed. These facts suggest that the general regression of all tissue layers present in the intestines of sexually maturing sea lampreys results from an active autolysis, i.e., a resorption and digestion of these tissues. It seems entirely feasible that such resorbed cellular material could be utilized by the sea lamprey; subsequent to the time it ceases feeding it must migrate often long distances upstream and collaterally must complete the formation of its sexual products, and finally, must construct its nest and spawn.

It is within the realm of possibility that a regeneration of tissues might take place in the intestine of a spawned-out adult. However, this is deemed highly unlikely. I believe that the functional characteristics and the digestive capabilities of this organ have been so severely reduced that such a regeneration could hardly occur.

(4) Discoloration of flesh.--The flesh of sexually-immature, adult lampreys taken in the Great Lakes was found to be uniformly white and of an appearance not unlike that of many other fishes. In virtually all of the migrating sea lampreys captured, it was found that certain localized areas of the flesh displayed varying amounts of a bluish discoloration. This discoloration occurred primarily in a band immediately beneath the integument, along the dorsal septum and around the median skeletagenous elements (notochord, etc.). Furthermore, in the most mature specimens, a light bluish tint was imparted to all portions of the flesh.

I presume that this discoloration is the result of the deposition of catabolic wastes in the flesh consequent to the decline in the functional capabilities of the digestive tract and associated organs of elimination.

## VII. Some economic characteristics of spawning runs.

This discussion is not concerned with the matter of control of lamprey populations in the upper Great Lakes, but rather with the potential commercial utilization of sea lampreys taken either by control devices or by a possible commercial trapping enterprise. This matter has been given some attention with the object of determining compensatory uses for this predator in the event that the control of its numbers is deemed either physically or financially impractical.

The major uses to which sea lampreys, trapped on their spawning runs, might be put are as follows: (1) Food--for human consumption or as animal farm (mink, fox ranches, etc.) or fish hatchery rations; (2) reduction for oil, fertilizer, meal, or derived by-products; (3) reduction for medicinal products; and, (4) sale as biological specimens.

Certain of these uses have been tentatively explored and the results are herewith summarized and discussed.

Preliminary experiments indicated that spawning run sea lampreys were quite unpalatable. In 1947, 12 fresh sea lampreys taken from the Carp Creek weir were smoked by a Mr. Emil Plath of Rogers City, Michigan. Mr. Plath has smoked meat and fish commercially for 35 years and was particularly interested in determining if the lampreys would make a saleable smoked product. The results were discouraging. The smoked lamprey flesh was streaked with black from the original blue discoloration of the flesh (accumulated waste products); its appearance was unappetizing and the texture of the flesh was soft or "mushy." The most unfortunate characteristic, however, was an acrid, unpleasant odor, characteristic of the lampreys but unlike the usual "fishy" smell of other fishes, which the flesh gave off. This alone inhibited any enjoyment of the actual taste of the flesh itself.

I have prepared and cooked fillets from fresh specimens on two occasions. These preparations likewise displayed unpleasant discolorations of the flesh after cooking; its texture was somewhat soft. The taste of the flesh was not exceptional; its enjoyment was obliterated by the indefinable, acrid odor of a decaying lamprey which was present even in the cooked material.

Even if a cooking technique were developed which would allay the aforementioned odor, I believe that it would be extremely difficult to market fresh lampreys either in the round or drawn. Over a period of two years, the reactions of numerous laymen to the appearance of fresh specimens were noted. The slimy skin, the snake-like appearance, and the ugly mouth and head brought forth expressions from outright disgust to a complete disinterest in experimenting with them as food. I judge from this that if the lampreys are ever marketable as food they will only be so as fresh or canned fillets.

Reduction of sea lampreys for oil or associated medicinal products appears equally unpromising. In 1947, at the request of Dr. John Van Oosten, six specimens were sent to the Fishery Technological Laboratory, Seattle, Washington (U. S. Fish and Wildlife Service), for analysis of oil content and the Vitamin A potency of that oil. The results of these tests are summarized in the following paragraph extracted from a letter from that laboratory to Dr. Van Oosten:[12]

"With Vitamin A selling at about 11 cents per million units, it is evident that it would not be feasible to remove the livers or eggs from the lamprey as the cost of the labor involved would probably be greater than the value of the material separated. We recognize that a sample based upon only six individuals may not be representative. However, even if the analyses had been ten times higher, the material would still be of doubtful value. It therefore seems unlikely that the sea lamprey will ever be a commercial source of Vitamin A. The only possibility would be to use the lamprey for reduction purposes. The oil thus obtained might be of a high enough potency to warrant its sale for its Vitamin A content."

The greatest obstacle to developing any of the proposed or tested uses of spawning run sea lampreys would be the excessive cost of each pound of lamprey flesh produced. It has been demonstrated

---

[12] Data quoted with permission of Dr. John Van Oosten, In Charge, Great Lakes Fishery Investigations, U. S. Fish and Wildlife Service. Text of complete report is appended.

that even large runs (in numbers) constitute a relatively small poundage of lamprey flesh. The sea lamprey run in the Ocqueoc River, estimated at 10,000 individuals, would have a total weight of 4,062 pounds. The latter poundage would produce approximately 1,000 pounds of meal and 68 pounds of oil. To produce this poundage would require the operation of a weir and trap that would capture all migrants. This trap must be built according to certain minimum requirements in order to be efficient and must be in operation for three and one-half months with a seasonal average of three salaried employees in continual attendance. At present wage levels and costs of construction of such traps, the cost of production per pound is obviously out of all proportion to the profit that might be derived from the products. For example, had the trap been run in 1948 the estimated cost for labor and weir maintenance would have been about $1.00 per pound of whole lampreys. If the cost of weir and trap construction and development is distributed over a ten-year period and added in, the cost per pound of produced whole lampreys is raised to about $1.40. Each pound of whole lampreys would produce one-quarter pound of meal and/or 7.6 grams of oil. The costs indicated are those "at the pier." Additional expenditures must be met for handling, transportation, processing and marketing.

In spite of these data, it is suggested that whole, frozen sea lampreys be tested as supplementary rations for fish hatcheries and animal farms. Such sales (or consignments within an organization) and sales as biological specimens may in some small measure reimburse the agencies expending funds for sea lamprey control.

The picture painted by the preceding comments is quite discouraging. It is not intended to be so. It is merely an evaluation based on present known facts and figures relative to spawning runs, and the economic feasibility of the utilization of sea lampreys in the major categories of uses noted.

INSTITUTE FOR FISHERIES RESEARCH

Vernon C. Applegate

Approved by A. S. Hazzard

Typed by M. J. Lambert

## VIII. Literature cited

Bangham, Ralph V.
1946. Parasites of northern Wisconsin fish. Trans. Wisc. Acad. Sci., Arts and Lttrs, Vol. 36 (1944), pp. 291-325.

Beckman, William C.
1948. The length-weight relationship, factors for conversions between standard and total lengths, and coefficients of condition for seven Michigan fishes. Trans. Amer. Fish. Soc., Vol. 75, 1945, pp. 237-256.

Breder, C. M., Jr.
1926. The locomotion of fishes. Zoologica, Vol. IV, No. 5, pp. 159-297.

Cameron, T. W. M.
1945. Fish-carried parasites in Canada. Can. Jour. Comp. Med., Vol. 9, pp. 245-254, 283-286, 302-311.

Coventry, A. F.
1922. Breeding habits of the landlocked sea lamprey. Univ. of Toronto Studies, Biol. Ser., No. 20, Publ. Ont. Fish. Res. Lab., No. IX.

Gage, Simon Henry
1928. The lampreys of New York State - Life history and economics. N. Y. State Cons. Dept., Biol. Surv. of the Oswego River System, Suppl. to 17th Ann. Rept., 1927, pp. 158-191.

Hussakof, Louis
1912. The spawning habits of the sea lamprey, Petromyzon marinus. Amer. Naturalist, Vol. 46, 1912, pp. 729-740.

Kennedy, W. A.
1948. Sufficient samples for quality control in whitefish. Fish. Res. Bd. of Can., Bull. No. LXXVI, pp. 1-11.

Leverett, Frank
1912. Surface geology and agricultural conditions of the southern peninsula of Michigan. Mich. Geol. and Biol. Surv., Publ. No. 9, Geol. Ser. No. 7, pp. 1-144.

Plehn, Marianne
1924. Practice of fish diseases. Typewritten Ms. (translation), 1941.

Shetter, David S.
1948 (?) A brief history of the sea lamprey problem in Michigan waters. Trans. Amer. Fish. Soc., Vol. 76, 1946. (In press).

Surface, H. A.
1899. Removal of lampreys from the interior waters of New York. N. Y. State, 4th Ann. Rept. Comm. Fish, Game and Forests, 1899, pp. 191-245.

Van Cleave, Harley J. and Justus F. Mueller
1934. Parasites of Oneida Lake fishes. Pt. III. A biological and ecological survey of the worm parasites. Roosevelt W'life For. Exp. Sta., Roosevelt Wild Life Annals, Vol. 3, No. 3, pp. 161-334.

## APPENDIX I

Fishery Technological Laboratory
2725 Montlake Boulevard
Seattle 2, Washington

August 7, 1947.

Dr. Van Oosten,
Institute for Fisheries Research,
Division of Fisheries,
Michigan Department of Conservation,
University Museums Annex,
Ann Arbor, Michigan.

Dear Dr. Van Oosten:

Reference is made to Mr. Applegate's letter of July 14, 1947, informing us of his shipment of six frozen sea lampreys to our laboratory. On arrival, the sea lampreys had an average weight of 188 g. The male livers had an average weight of 4.7 g and the female livers had an average weight of 2.5 g. The average weight of the eggs in each of the females was 45.7 g.

The following is a tabulation of the results of our analyses:

| Material Analyzed | Oil Content | Vitamin A Potency of Oil | Vitamin A Potency of Material Analyzed |
|---|---|---|---|
| | Per Cent by Weight | U S P Units Per Gram | Millions of Units Per Pound |
| Male Flesh | 3.67 | 1000 | 0.0167 |
| Female Flesh | 1.76 | 1400 | 0.0112 |
| Eggs | 15.6 | 570 | 0.0404 |
| Male Liver | 19.0 | 2100 | 0.181 |
| Female Liver | 5.4 | 10000 | 0.245 |

With Vitamin A selling at about 11 cents per million units, it is evident that it would not be feasible to remove the livers or eggs from the lamprey as the cost of the labor involved would probably be greater than the value of the material separated. We recognize that a sample based upon only six individuals may not be representative. However, even if the analyses had been ten times higher, the material would still be of doubtful value. It therefore seems unlikely that the sea lamprey will ever be a commercial source of Vitamin A. The only possibility would be to use the lamprey for reduction purposes. The oil thus obtained might be of a high enough potency to warrant its sale for its Vitamin A content.

Yours very truly,

Bruce Sanford,
Chemist.

cc: Mr. Vernon C. Applegate.
Dr. A. S. Hazzard.