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The series ceased independent publication after Volume 19, Article 2, and was merged into the *Bulletin of the Peabody Museum of Natural History* monograph series after 1967.

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STUDIES ON THE MARINE RESOURCES
OF SOUTHERN NEW ENGLAND

VIII. THE BIOLOGY OF THE LONGHORN SCULPIN,
MYXOCEPHALUS OCTODECIMSPINOSUS MITCHILL,
WITH A DISCUSSION OF THE SOUTHERN
NEW ENGLAND "TRASH" FISHERY

By James E. Morrow, Jr.
Bingham Oceanographic Laboratory
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VOLUME XIII, ARTICLE 2

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1 This paper is based on a dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Yale University.
ABSTRACT

The study of the longhorn sculpin arose as a part of the program of the Bingham Oceanographic Laboratory in its study of the potential marine resources of southern New England. Carried out at a time when the sculpin was not subject to predation from fishing, this study is, therefore, an investigation of a fish population under relatively normal conditions. Specimens and other data were collected chiefly from Block Island Sound between April 1943 and June 1946. The method of sampling commercial catches is described and its reliability discussed.

The longhorn sculpin is an abundant resident species in the North Atlantic coastal waters of North America, ranging from New Jersey to Nova Scotia. Its history is reviewed, including names and description. Synonyms and references are listed and detailed descriptions of generic and specific characters are given. Allometric growth is demonstrated in the eye and in the longest dorsal spine.

The length-weight relationship is treated in some detail. The dangers of basing the length-weight equations on insufficient samples are enumerated, together with the factors affecting such usage. The several forms of the coefficient of condition are compared and discussed. Variations in the coefficient of condition are shown to have a definite seasonal rhythm, which has been correlated with sexual activity and other phases of general physiological activity. Growth in length and weight are not synchronous. The value of the gastrosomatic index as an indicator of the rate of feeding is pointed out.
The breeding habits of the species and the sexual cycles of males and females are described. Spawning occurs between late November and the end of January, with large fish tending to spawn later than do the smaller individuals. Each female lays about 8,000 eggs per year. Development of the fertilized egg appears to require not longer than three months, probably less. Sexual maturity is reached in the third year. The tendency shown by this fish to spawn on clean, hard sea bottoms, laying its eggs in cavities in sponges, shells, etc., is described. It is suggested that variations in the length of the spawning season may be accounted for by temperature.

Age determination in fishes is discussed from the historical and practical aspects and criteria for estimating age from the otoliths are described. A method has been devised for estimating age and growth rates from the otoliths. On the basis of this method, the average lengths of sculpins of various ages are: 1 year, 5.6 cm; 2 years, 18.2 cm; 3 years, 24.3 cm; 5 years, 27.4 cm; 9 years, 30.2 cm. The age composition of the population has been estimated, and it is suggested that the catchable portion of the population is made up chiefly of individuals between two and five years old. Fluctuations in abundance are also examined. Annual length-frequency curves suggest that the year-classes of 1939 and 1940 were exceptionally large and were followed by several much smaller year-classes. Although the catch-per-unit-of-effort of sculpins declined rather sharply throughout the period sampled, the decline is not statistically significant.

Seasonal movements and migrations were investigated by direct observation of the abundance of the sculpin and by tagging over 4,000 individuals. Returns from the latter method were disappointingly low, which is ascribed to lack of commercial utilization of this fish at the time of the experiments. On the basis of field observations, it is apparent that the sculpin moves offshore in the spring and summer and onshore in the fall and winter. However, contrary to suggestions in the literature, these movements are not closely correlated with temperature. There is strong evidence that males and females do not migrate synchronously. Males dominate the catch in warm weather, females are more abundant in winter. It is suggested that the seasonal movements may represent the expression of some cycle of endocrine activity.

The food habits of the sculpin have been examined in detail. Analyses of the contents of over 500 stomachs, taken throughout the year, show the dominant food items to be the decapod, *Cancer irroratus*, and the amphipod, *Leptocheirus pinguis*. All told, at least 47 different species of animals were found, indicating that the longhorn sculpin is to be considered as an omnivorous carnivore.

The recent southern New England "trash" fishery is described. Beginning in the last few months of 1948, this fishery increased rapidly in intensity until, just prior to its abrupt halt in the spring of 1950, the two major ports in the area studied were receiving nearly 2,000,000 pounds of trash fish per month. In discussing the possible effects of this fishery, it is pointed out that the degree of fishing pressure represented by this figure will probably reduce the stocks of trash fish to a noticeable extent. Consequently, interspecific competition against "good" fish will probably be reduced, and the latter may be expected to increase to a greater or lesser degree. For this reason, trash fishing may be expected to have a beneficial effect on the fishing industry as a whole. Trash fishing may also be expected to supplement the fisherman's income in the winter, when landings of good fish are low. A research program,
involving study of the biology and ecology of the important species and the collection of detailed catch statistics on a regular continuing basis, is recommended to provide data on which to base regulations to insure optimum production.

INTRODUCTION

The longhorn sculpin, found in the littoral zone of the North Atlantic Coast of the United States and Canada, is not only common but is one of the more abundant fishes of the area. Bigelow and Welsh (1925) state that it is the most numerous of the sculpins of the Atlantic Coast. However, the longhorn is of little commercial importance.

Of the life history and habits of the longhorn sculpin practically nothing is known. The best general account at present is that of Bigelow and Welsh (1925), who report that it is omnivorous in its feeding habits, that it "carries out more or less definite inshore and offshore journeys" which "are induced by temperature," that it spawns in November and December, the eggs being demersal, and that "nothing definite is known of the rate of growth of this fish nor of the age at which it matures."

The present study of the longhorn sculpin arose as a natural part of the research program of the Bingham Oceanographic Laboratory in its study of the potential marine resources of southern New England. In initiating this program, it was believed that only by an analysis of the biology of the various elements of the local fauna and their interrelationships with each other could the intelligent utilization of these resources be achieved. The data on which this study is based were obtained from a commercial fishery directed chiefly at the winter flounder (Pseudopleuronectes americanus) in southern New England waters. A survey of this fishery by Merriman and Warfel (1948) showed that from August 1943 to July 1946 the longhorn sculpin constituted 20.8% by numbers and 13.3% by weight of the catch of a commercial dragger operating in and near Block Island Sound. Here is immediate and obvious economic justification for an examination of the longhorn. Yet it must be remembered that any life history study of adequate breadth presents problems in both the pure and applied aspects of biology. The sound practical applications are so intimately associated with the theoretical aspects that it is well-nigh impossible to make a sharp separation. Indeed, even were it possible to do so, the two phases are mutually interdependent to such an extent
that separation would serve no purpose. Too much fisheries work has been done with naught but the economic aspect in mind. Such an attitude completely ignores the fact that an animal community is a complex unit, the understanding of which necessitates the elucidation of the behavior and life processes of each of the various components. Further, most fisheries investigations have been confined, of necessity, to studies of abnormal conditions of commercially important species. Thus, Walford (1948) says,

This is the pattern that has been repeated in various localities to solve special problems during the whole history of our biological fisheries research. There develops an anomalous condition (in this case diminution of the fish stocks below a level which people remembered as having once been much higher); an interested special group of people requests that the condition be investigated; after due legislative procedure, scientists are assigned to the problem; to understand the cause of the undesirable condition, the scientists try first to learn about the time when the condition was satisfactory (i.e., the normal pattern), but because systematic past records are nearly always fragmentary or lacking, this effort usually proves fruitless. Then, because they are expected to devise a remedy for the conditions in a reasonable time, they make deductions and recommendations from what data they can assemble. Such an investigation may not be conducive to learning much about the normal, because it is bound by too many limitations, for the anomalous condition is usually sharply delimited in scope. It is limited in time to the memory of the current generation, often even to such a short period as a season or two. It is limited ecologically to the affected species which are of most economic value.

The net effect of our preoccupation with problems of this kind is that we neither cover enough ground in our research or make fast enough progress toward the ideal goal. . . . What can we do to speed up the rate of progress? We can be sure that the most drastic events, the undesirable situations, the anomalies, will continue to generate public support for special investigations, and we will have to continue to conduct them. But at the same time, we must try by all means to get better support for the systematic, less spectacular studies of normal conditions, which in the long run will give us more efficiently what we need to know about the anomalous situations.

A study of the longhorn sculpin, therefore, is not only an investigation into normal conditions, but more especially it will serve as part of an over-all plan for the study of a marine community. It is hoped that completion of the latter will establish general principles that may be applicable over an extended field.
ACKNOWLEDGMENTS

Before proceeding further, it is a pleasant duty to acknowledge the assistance of many persons who have helped in the prosecution of this work. The members of the staff of the Bingham Oceanographic Laboratory, past and present, have contributed their time and effort in the assembly of the data on which this paper is based. Daniel Merriman, director of the Bingham Laboratory, has given constant encouragement and advice, both in the field and in the laboratory. E. F. Thompson has contributed many stimulating suggestions, especially with regard to determining age and growth rates. Y. H. Olsen established numerous personal contacts with various fishermen, thereby greatly facilitating field work, and H. E. Warfel made many of the collections. F. E. Smith has helped in the early stages of identification of invertebrates in the stomach contents analyses, and F. G. Wood has given useful advice on photography. The drawing of the sculpin (Fig. 1) was done by Miss Shirley P. Glaser. Mrs. David Calhoun, secretary at the Bingham Laboratory, suffered for several years as recorder in the fishy atmosphere of the dissecting room and typed the original manuscript.

The Connecticut State Board of Fisheries and Game has aided through a grant to the Bingham Laboratory, part of which was used for the purchase of the fish necessary for this study.

A number of people associated with the fishing industry have given assistance. J. H. Bindloss of Stonington, Conn., introduced members of the laboratory staff to boat owners and captains and otherwise assisted in the early phases of the study. The field work was made possible in large measure through the cooperation of a number of fishing boat captains. In this respect, special thanks are due Captain Ellery Thompson of New London, Conn., on whose vessel, the ELENA, the vast majority of the field work was done. Captain W. H. McLaughlin of the MARISE, Stonington, Conn., Captains Gabriel Andrew, and Bonaventura Gargano of the BETTY II, New Haven, Conn., Captain E. C. Post of the JANE, West Haven, Conn., and Captain Manuel Dutra of the VIOLA D., Provincetown, Mass., have also assisted, especially in the tagging experiments. In addition, several collections were made on Captains Aldo and Roscoe Bacchiocchi's BABY II, Stonington, Conn., and some experimental drags were made on the Rowe Oyster Company dredger RIVAL under Captain James Bakelaar.
Figure 1. The longhorn sculpin, *Myxocephalus octodecimspinosus* Mitchill.
MATERIALS AND METHODS

The present paper is a part of the general study of southern New England fish populations being carried out by the Bingham Oceanographic Laboratory and is based upon specimens and data collected in the course of that study. Most of the collections were made in or near Block Island Sound and Fishers Island Sound. Several samples came from an area about 15 miles SSE of Point Judith, R. I. (the Mussel Bed). One sample was taken and a few fish were tagged in Cape Cod Bay. Other samples came from Long Island Sound, off New Haven, and part of the tagging was done in Long Island Sound between Point Herod and Smithtown Bay. The date and location of each collection, the boat from which it was taken, and other pertinent data, are given in Appendix Table A. The map in Fig. 2 shows the areas where sculpins were collected or tagged.

Each sample from Block Island Sound consisted of one complete haul, including everything that came up in the net. The samples were taken from commercial draggers at approximately monthly intervals from April 1943 to June 1946 except on four occasions when bad weather, illness, or tie-ups intervened (January, February, and December 1945, and April 1946). For nearly all of the collections at least one member of the laboratory staff was on board and complete field notes, including surface and bottom temperatures and salinities, were recorded. During the three-year period, the majority of the samples were taken on Captain Ellery Thompson's dragger ELEANOR. This vessel fishes a modified otter trawl net\(^2\) with a mouth width of 80 feet. The stretched mesh of the body and cod end varied from time to time between $2\frac{1}{2}$ and $4\frac{1}{2}$ inches. In general, nets used on the ELEANOR had a 4-inch mesh in the body and a 3- or 3½-inch mesh in the cod end. Several collections made before August 1943 were taken on W. H. McLaughlin's MARISE and on A. and R. Bacchiocchi's BABY II, both of which used gear slightly different from that of the ELEANOR.

\(^2\) An otter trawl is a broadly conical net which is dragged broad end forward over the bottom of the sea. A chain or other weight is attached to the mouth on the under side (the footrope), and floats are fastened to the upper side (headrope) to keep the net open vertically. The mouth of the net is held open horizontally by the planing action of the otter boards or doors. The body of the net is made of fairly light twine with a large mesh, while the apex of the cone, the cod end, is usually of heavier twine with a smaller mesh. The net is pulled by the towing bridle, two lines which extend one from each door to the boat. When in operation, the mouth of the net is narrowed by water pressure to about half to two-thirds its normal width. Thus, fishing at about two knots, such a net would cover about 12 acres of bottom in a one hour drag. Fig. 3 is a diagram of a typical southern New England style dragger in operation.
Figure 2. Map of Long Island and Block Island sounds. The collections on which this study was based were made in this area. See also Appendix Table A.
On the MARISE the net was usually ballooned. That is, up to 15 or 20 additional floats were attached to the headrope, so that the net had a much wider vertical spread. This results in catching more of the so-called semidemersal fishes (e.g., scup, cod, etc.), which live within 10 or 15 feet of the bottom and perhaps not so many of the truly bottom-living demersal species. The BABY II fished a larger net (120 foot mouth width), but it was rigged in much the same manner as the net on the ELEANOR.

Comparisons of hauls made under comparable conditions but with nets of different mesh size indicate that, within the limits stated here, the mesh size has no appreciable effect on the composition of a catch of sculpins. It was not possible to assess the effect of the different types of rigging, so hauls made with ballooned nets were not used in the estimation of relative abundance. For other purposes, however, there seemed to be no objection to considering all samples as comparable, and this has been done.

In collecting the samples, one complete haul was taken on each occasion. This included everything in the net, fishes, invertebrates, debris, etc. It was customary to try to get an average haul which fairly represented the usual catch both as to volume and variety for the particular time of year. As a check on the adequacy of the sample hauls as measures of abundance, the captains of the ELEANOR and the MARISE kept accurate logs of the catch by species in every haul for more than a year. These data provide a means of estimating the accuracy of the sample catches as indices of abundance. Merriman and Warfel (1948) found that while the trends in relative abundance of species in the samples and in the logs were quite comparable, the samples were not reliable as measures of the actual average catch. Examining the catch of winter flounders, they found that the samples tended to be much larger than the average haul for the same period—in many cases the sample was twice as large as the average. Thus, while the samples are doubtless accurate enough as indicators of relative abundance of various species, they are of dubious value in estimating total production or total population. Any estimate based on these sample hauls would be far larger than the true value.

Each haul was barrelled and iced on the boat and transported by truck to New Haven. Upon arrival at the laboratory the catch was sorted by species. The total length, weight, and sex of each specimen were recorded in all cases. During the first year (April 1943 to June
Figure 3. Diagram of a typical southern New England dragger in operation. Note that the net is dragged from the boom rather than from gallows frames, and that the wings of the net are fastened directly to the doors, without the intervening length of line used in the Vigneron-Dahl rig on larger vessels.

1944) the standard length and vertebral count were also recorded, and otoliths, stomach contents, and gonads were preserved from representative samples of 50 to 100 specimens. Because of the size of some samples it was occasionally necessary, especially in warm weather, to hold part of the catch in cold storage until it could be examined. Although Lemon (1932) found that untreated frozen fish in cold storage may lose over 11% of their weight in two weeks, this method of handling does not seem to have had an appreciable effect in the present study.

DESCRIPTION, CLASSIFICATION AND BODY MEASUREMENTS

Common Names and Range

The longhorn sculpin, like most animals, is known by a variety of common names. Among these are grey sculpin, hacklehead, toadfish, long spined sculpin, bullhead, common sculpin, 18 spined sculpin, sea robin, sea toad, pigfish, sculpin, scorpion, and others. This wide variety of common names is hardly surprising when one considers that its recorded range extends from Labrador (H. R. Storer, 1857) to Virginia (Willughby, 1686). While Storer found two young specimens on the Labrador Coast and Richardson (1836) reported it as plentiful at Newfoundland, the faunal lists of Labrador by Kendall
(1909), Packard (1891), and Stearns (1884) make no mention of it. The Labrador Coast thus appears to be the extreme northern limit of its range. With regard to the southern limit, it seems probable that Virginia, as we know it today, is too far south, for we have found no authentic firsthand record of its occurrence south of Cape May, New Jersey. When Willughby wrote his Historia Piscium (ca. 1650–1660), Virginia included all the east coast of North America between Lat. 37° and 41° N, so that his specimen may well have come from some region other than what is now called Virginia. The faunal lists of Delaware, Maryland and Virginia (Fowler, 1911, 1912; Uhler and Lugger, 1876; Truitt, Bean and Fowler, 1929; B. A. Bean, 1891; Hildebrand and Schroeder, 1928) do not include the longhorn. From New Jersey northward to Nova Scotia and Newfoundland, it is one of the more numerous shore fishes. The area in which the present work was done is thus near the center of its range.

On the etymology of the word sculpin, Holmes (1862) says: “It is rightly named ‘sculpin’ for its scull is full of spines and thorns as sharp as pins.” A better derivation is from the Greek σκόρπις, a scorpion. It is interesting to note that the low esteem in which the sculpin is held has carried over into colloquial American language, for Webster gives a secondary definition of ‘sculpin’ as ‘worthless’ (Webster’s New International Dictionary of the English Language, 2nd Ed. unabridged, 1947).

SYNONYMS AND REFERENCES

*Cottus virginianus*—Willughby 1686 (descr. and fig.); Cuvier 1834, 1836–1849 (name); D. H. Storer 1839a, 1839c (descr.); DeKay 1842 (descr., range); Linsley 1844 (Conn.); D. H. Storer 1846 (descr.); Perley 1852 (New Brunswick, Nova Scotia, food habits).

*Cottus 18-spinosus*—Mitchill 1814 (descr.).

*Cottus octodecem-spinosus*—Mitchill 1815 (descr.); Baird 1873 (name).

*Cottus octodecimspinus*—Cuvier and Valenciennes 1829 (name); Cuvier 1834, 1836–1849 (name); Richardson 1836 (name, Newfoundland), 1837 (name, range); Günther 1860 (name); Putnam 1863 (name); Gill 1865 (name), 1873 (name, range); Jones 1879 (name, Nova Scotia); Goode 1879 (name, range); Goode and Bean 1880 (name); T. H. Bean 1881 (name, Mass. and Nova Scotia); Jordan and Gilbert 1882 (descr.); T. H. Bean 1884 (name); Goode, et al. 1884 (range, habits); Jordan 1887 (name); T. H. Bean 1888

*To substantiate this point, the following is quoted from a letter from a fisherman who caught a sculpin tagged in one of our experiments: “I cannot understand how anyone could spare the time to insert a pin and the value of the discs wasted, on such a low down, prickery, horny, worthless sculpin.”*

(New Jersey); Nelson 1890 (New Jersey); Cox 1895 (New Brunswick).

*Acanthocottus virginianus*—Girard 1851 (name, synon.); Baird 1855 (name, New Jersey); D. H. Storer 1855 (descr., range); H. R. Storer 1857 (2 young specimens, Labrador); Gill 1862 (name); D. H. Storer 1867 (descr., range); Abbott 1868 (New Jersey); Lyman 1872 (Mass.); Jordan and Evermann 1896 (name, range); T. H. Bean 1897 (abundance, N. Y. C.); H. M. Smith 1898 (abundance, spawning time); Jordan 1904 (name, range).

*Acanthocottus octodecim spinosus*—Holmes 1862 (descr., synon., Maine).

*Myoxocephalus octodecimspinosus*—Jordan and Evermann 1898 (taxon., range); T. H. Bean 1901 (range, L. I.), 1903 (Mass., N. J.); Jordan 1905 (name); Fowler 1906 (name); Tracy 1906 (R. I., range); Kendall 1908 (Maine and Mass.); Tracy 1910 (R. I., range); Sumner, Osburn and Cole 1913 (Woods Hole, parasites); Nichols 1913 (N. Y. C.); Kendall 1914 (range); Fowler 1917 (Nantucket), 1920 (Cape May, N. J.); Huntsman 1922 (Bay of Fundy); Bigelow and Welsh 1925 (descr., range, habits, etc.); Jordan 1925 (New England); Nichols and Breder 1927 (N. Y., abundance, range, food); Jordan 1929 (name, range); Breder 1929 (descr., range, diet, movements); Marshall 1930 (renal physiol.); Schroeder 1931 (juveniles); Nash 1931 (renal anat.); Grafflin 1931 (renal physiol.); Marshall and Grafflin 1932 (renal physiol.); Defrise 1932 (renal anat., cytol., physiol.); Grafflin and Ennis 1934 (renal physiol.); Pitts 1934 (renal physiol.); Clarke 1934 (renal physiol.); Vladykov and McKenzie 1935 (Nova Scotia); Edwards 1935 (renal anat.); Grafflin 1935a, 1935b (renal physiol.); Grafflin and Gould 1936 (renal physiol.); Grafflin 1936a, 1936b (renal physiol.); 1937a, 1937b (renal anat.).

*Myoxocephalus octodecimspinosus*—Sharp and Fowler 1904–05 (Nantucket).

*Acanthocottus octodecimspinosus*—Jordan, Evermann and Clark 1930 (name, range).

The following references may refer either to *M. octodecimspinosus* or *M. scorpius*, or to both. The accompanying descriptions are not sufficiently clear to distinguish between the two species.

*Cottus scorpius*—Schoepf 1788 (descr., range); J. V. C. Smith 1833a (descr., fig.), 1835 (name); see also D. H. Storer 1839b, and Gill 1905.

*Cottus scorpinus*—(Probably a misprint of *scorpius*) J. V. C. Smith 1833b (name); see also D. H. Storer 1837.

*Cottus variabilis*—Ayres 1843 (descr.).

**Classification**

The abundance and confusion of sculpin nomenclature is not confined to common names. Following Steller (1741, MS No. 30),
Tilesius (1811) differentiated *Myoxocephalus* from *Cottus*, and ever since then the taxonomy of the sculpins has been confused. This is due in no small part to the existence of local geographical variants (recently discussed by Bolin, 1944), many of which have been described as separate species. Similarly, Hartman (1944) showed that *Myoxocephalus aeneus* and *M. mitchilli* are actually the females and males respectively of *M. aeneus*. Undoubtedly a thorough revision of the family would result in a reduction of the number of recognized species and possibly in the number of genera as well.

Tilesius' work did not become known in the United States for about 70 years after it had been published in Russia. Meanwhile, new species of sculpins were described for the most part as members of the Linnean genus *Cottus*, for which Cuvier and Valenciennes (1829) had designated *C. gobio* as the type.

Subsequently, Girard (1851), examining the Cottidae of North America, separated the marine species from those of fresh water. He retained *Cottus* for the freshwater group, on the basis of Cuvier and Valenciennes' designation, and proposed the name *Acanthocottus* for the marine group. The marine genus was thereafter referred to by various authors as *Cottus* (Perley, 1852; Günther, 1860; Putnam, 1863; Jordan, 1887) or as *Acanthocottus* (D. H. Storer, 1855; Holmes, 1862; Abbott, 1868; H. M. Smith, 1898). Jordan and Gilbert (1882) mentioned Tilesius' name *Myoxocephalus*, but, under the impression that it had been used in a polynomial system, they rejected it. They considered *Acanthocottus* synonymous with *Cottus*, designating the type of the latter as *C. scorpius* L., a marine species, and calling the freshwater group *Uranidea* DeKay.

Later, Jordan and Evermann (1896, 1898) recognized *C. gobio* L. as the type of *Cottus*, according to the designation of Cuvier and Valenciennes. In their former work (1896) they accepted Girard's *Acanthocottus* as valid for the marine coastal sculpins of both the Atlantic and Pacific coasts of North America. In the latter publication (1898) they recognized Tilesius' *Myoxocephalus* as the valid name of the genus and divided it into two subgenera, *Acanthocottus* for Atlantic species with smooth skin on top of head and *Myoxocephalus* for Pacific forms with warty prominences on skin of head. Jordan, Evermann and Clark (1930) retained the same grouping, but they gave full generic rank to each subgenus. Without making a comprehensive and detailed examination of the species of both the Atlantic and Pacific,
it is not possible to venture an opinion on the relative merits of *Acanthocottus* vs. *Myoxocephalus*. Until such work is undertaken, it seems advisable to follow the generic characters used by Jordan and Evermann (1898), considering the two groups as a single genus. Since the latter name antedates the former by 50 years, the proper name for the genus as thus defined is *Myoxocephalus*.

**Generic Characters**

Body generally slender. Skin without scales, sometimes with prickly plates or tubercles. Head large. Mouth rather large, terminal, the lower jaw included. Teeth present on jaws and vomer but not on palatines. Suborbital stay strong and well developed. Preopercle with two strong spines above directed posteriorly, one below pointed downward and forward. Head armed with spines to varying degree, especially on the opercle, nasal, orbital rim and shoulder girdle. Gill membranes forming a fold across the isthmus, the slit behind last gill much reduced or absent. Dorsal fins two, separate, the first short and with sharp slender spines. Lateral line well developed, often with bony or cartilaginous plates. The name from the Greek µνυξ, the dormouse; κεφαλή, head; allusion obscure.

*Myoxocephalus octodecimspinosus* MITCHILL 1814

This species was first described in the polynomial system of Willughby (1686) under the name of *Scorpius virginianus*. The next published descriptions were those of Mitchill (1814, 1815), *Cottus 18-spinosus* and *Cottus octodecem-spinosus* respectively. The characteristic 18 spines,\(^4\) coupled with the great length of the upper preopercular spine, serve to distinguish this species from other sculpins. The problem of synonymy rests simply on the determination of the specific name that is valid under the rules of zoological nomenclature. Only four specific names have been applied definitely to this fish, two of these being corruptions of a third. In chronological order of application, the names are: *virginianus* (Willughby, 1686); *18-spinosus* (Mitchill, 1814); *octodecem-spinosus* (Mitchill, 1815); *octodecimspinosus* (Cuvier and Valenciennes, 1829). The first name, *virginianus*, antedates Linnaeus by more than 100 years and therefore is inadmissible. Of the remaining three, *18-spinosus* is not considered good form, and

\(^4\) After Jordan and Evermann, 1898.

\(^5\) Actually there are 20—on each side there are eight spines on the head, one on the supra­cleithrum and one on the cleithrum.
octodecem-spinosus is a misspelling, an obvious lapsus calami, leaving octodecimspinosus as the valid name of the species. It is probably better form to write the specific name as one word without a hyphen.

It would be difficult to confuse the adult longhorn with any other sculpin, although it superficially resembles *M. scorpius*, but small specimens may be difficult to distinguish from *M. aeneus*. From both of these the longhorn is readily separated by its long upper preopercular spine, which reaches the edge of the gill cover, and by its slimmer body. In addition, the longhorn’s spines are much sharper than those of the other two species, and its anal fin with 14 rays originates under the second or third ray of the second dorsal. In *M. scorpius*, the anal has about 14 rays, but it originates under the fifth ray of the second dorsal, and in *M. aeneus* the anal has only 10 or 11 rays.

The following description is based on an examination of 26 specimens: 12 fresh adult animals (40♂♂ and 8♀♀) from Block Island Sound; ten preserved juveniles (0+ age-group, sex not determined) from Block Island Sound; and four preserved immatures (1+ and 2+ age-groups, 2♂♂ and 2♀♀) from Cape Cod Bay. Pertinent measurements of each group are given in Table I.

Head 2.7 (2.5–3.0) in standard length; depth of body 5.0 (4.5–5.8). D. IX, 16 (VIII–X, 15–17); A. 14 (13–15); P. 18 (16–19); V. I, 4, the first two rays so closely applied to the spine and to each other that the external appearance is of one spine and two rays only. Body tapering, slender. Head rather large. Mouth moderate, the lower jaw included. Maxillary not extending past eye, 2.6 (2.1–3.1) in head. Upper preopercular spine long, reaching posterior edge of gill cover, 3.1 (2.6–3.6) in head, 3.8 (3.0–5.0) times the length of the spine below it; third preopercular spine turned downward; nasal spines strong; a spine at upper posterior margin of orbit, another at end of each occipital ridge; a sharp spine on cleithrum just below and behind opercular spine; supracleithral spine sharp; a short spine on sub-opercle below base of second and third opercular spines. Eye large, 4.2 (3.2–5.1) in head and wider than the concave interorbital space. Skin smooth, no scales; lateral line with a series of imbedded cartilaginous plates. Dorsal fins two, separate, the spinous one higher than the soft; longest spiny ray 2.3 (1.8–3.3) in head. Pectorals reaching anal. Ventral not reaching vent. No slit behind last gill.

Color varying, largely in accord with the background from which a specimen is taken. Ground color ranging from dark olive (e. g.,
1951]  

*Morrow: Myxozephalus octodecimspinosus* Mitchill 17

**TABLE I. COMPARATIVE MEASUREMENTS OF BODY PARTS OF *M. octodecimspinosus*.**

<table>
<thead>
<tr>
<th>Group</th>
<th>SL (mm)</th>
<th>In SL</th>
<th>Max.</th>
<th>UPS</th>
<th>Eye</th>
<th>LDS</th>
<th>LPS in UPS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Body</td>
<td>Eye</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth</td>
<td>Eye</td>
<td>Depth</td>
<td></td>
<td></td>
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<tr>
<td><strong>Cape Cod Bay</strong></td>
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<tr>
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<td>2.9</td>
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<td>2.5</td>
<td>2.7</td>
<td>4.0</td>
<td>2.5</td>
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<tr>
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<td>2.9</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
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<td>4.9</td>
<td>2.1</td>
<td>2.6</td>
<td>3.6</td>
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<tr>
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<td>2.9</td>
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<tr>
<td><strong>Juveniles</strong></td>
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<td>4.9</td>
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<td>4.5</td>
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<tr>
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</table>

Muddy banks off Pt. Herod, L. I.) to pale yellowish green or grey (e. g., sandy bottoms in Block Island Sound), with four irregular dark crossbars often broken up into indistinct blotches. The first dorsal generally dark with irregular light blotches, the second dorsal light with four dark bands coursing diagonally downward and backward. Caudal and pectorals pale with several (3–6) dark crossbands. Anal light with irregular dark mottlings. Ventral side of body white. Said to reach a length of 18 inches, but the largest seen by us measured 37.5 cm (14 inches).
BODY MEASUREMENTS

The relationship between standard length and total length was determined from measurements of 332 specimens from Block Island Sound and New Haven Harbor. This relationship can be expressed by the equation \( Y = 0.11 + 0.83X \), where \( Y \) is the standard length and \( X \) the total length. The correlation coefficient, \( r \), is + 0.968, indicating a close relationship between the two measurements. The \( Y \)-intercept of 0.11 indicates that growth of the tail in relation to the rest of the body is not uniform, the tail growing more rapidly during early life than in later periods. Calculation of the tail length as percent of standard length shows that this allometry is slight in animals over 40 mm S. L. and has practically disappeared by the time a length of 80 mm S. L. has been reached.

Vertebral counts were made on 778 specimens from the same areas taken between April 22, 1943 and May 18, 1944. Of this number, 396 were males and 382 were females. The mean vertebral count for the males is 36.5177 ± 0.694; for the females, 36.5026 ± 0.674; for both sexes combined, 36.5103 ± 0.684. There is no significant difference between the mean number of vertebrae of the two sexes or between
any two collections. However, the area covered was limited. Collections from the extremes of its range, such as the coast of New Jersey and the Bay of Fundy, might very well show racial differences with adequate sampling.

The body measurements given in Table I have been expressed as percentages of the standard length (Table II) and plotted in Fig. 4. Lines of trend have been fitted by eye to each set of measurements. The light lines indicate little or no allometry, while the heavy lines show the presence of differential growth. These trends are based on such a small number of specimens that they cannot be considered reliable. However, a range of 197 mm S. L. is covered, except for that portion between 150 and 220 mm, and the results, even though based on so few measurements, are not without interest. Fig. 4A shows the trends in measurements of the head, depth of body, longest

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TABLE II. COMPARATIVE MEASUREMENTS OF BODY PARTS OF *M. octodecimspinosus* EXPRESSED AS PERCENTAGES OF THE STANDARD LENGTH. THE SPECIMENS ARE ARRANGED HERE IN ORDER OF INCREASING LENGTH. SL = STANDARD LENGTH. MAX. = MAXILLARY. UPS = UPPER PREOPERCULAR SPINE. LDS = LONGEST DORSAL SPINE. LPS = LOWER PREOPERCULAR SPINE.

<table>
<thead>
<tr>
<th>SL (mm)</th>
<th>Head Depth</th>
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<th>Eye</th>
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<th>LPS</th>
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</table>
dorsal spine, and upper preopercular spine. There is no differential growth evident in the head and depth of body, and only a slight degree of negative allometry in the upper preopercular spine. Pronounced positive allometry is present in the longest dorsal spine. The length of this spine increases from about 14.5% of the standard length in the smallest specimens to about 18.5% in the largest animals. Measurements of the maxillary, eye and lower preopercular spine are shown in Fig. 4B. There is no appreciable change with age in the relative length of the maxillary or of the lower preopercular spine. By contrast, the eye shows a pronounced degree of negative allometry in the small specimens and slight negative allometry in the larger animals. This is of particular interest, for there is an abrupt change in the slope of the line of trend at about 80 mm S. L., indicating that a marked change in the manner of growth of this organ occurs early in the second year (p. 47). Apparently the eye grows rapidly during larval and postlarval development and then slows abruptly, resuming growth at nearly the same rate as the rest of the body during the second year.

THE LENGTH-WEIGHT RELATIONSHIP

INTRODUCTION

The relationship between length and weight is one which can yield a great deal of information concerning fishes. Not only does it provide the obvious and practical estimate of the probable weight of a fish of any given length, but analyses of the length-weight relationship can also be highly informative about the rate and manner of growth, productivity, and so on. Unfortunately, adequate analyses of this type do not appear in the literature.

The vast majority of length-weight computations in the past have been based on single samples or at best on samples covering only part of a year. This is due chiefly to the difficulty of obtaining adequate samples throughout the year, and it imposes rather strict limitations on the use of the relationships so derived. The use of length-weight relationships from samples limited in time coverage is permissible only if this limitation is kept strictly in mind. For example, collections made only in the summer may be used to compare conditions in one summer with those in another. But to attempt to generalize about the length-weight relationships from such collections would be an unwarranted extrapolation. Such a procedure involves the assumption that the length-weight relationships are constant throughout the year and
are not affected by such factors as the availability of food, rate of feeding, development of the gonads, spawning, etc. Conceivably this may be true under some circumstances, but a few considerations will serve to show that this assumption is not justified without examination.

With regard to the ripening gonads, in mature fish these organs may account for a considerable portion of the total weight. But after the fish has spawned this weight is lost without any change in length. Under these circumstances it would be remarkable if the length-weight relationship remained unchanged. If the ripe gonadal tissue has been derived chiefly or entirely from additional anabolism, then the weight for a given length should increase as the fish ripens. On the other hand, if the gonad develops at the expense of other tissues of the body, no such change in the length-weight relationship should occur during ripening. After spawning, the weight should drop regardless of the original derivation of the gonadal substance. Obviously, samples of fish taken just before and just after spawning would not be expected to show the same length-weight relationships, and generalizations made from either sample would be invalid. It is imperative, therefore, that generalized equations for estimation of average weight be based upon samples covering the entire year.

In relation to the amount of food eaten, it is known that many fishes consume vastly different amounts of food at different seasons of the year. Especially if the stomach is relatively large, the degree of fullness may in itself alter the length-weight relationship. However, the greatest importance of this factor is as an index of the rate of feeding, which affects the rate of growth. It is not justifiable to assume that growth is uniform in time or that all types of growth are simultaneous. Hence, rate of feeding may have a profound effect upon the length-weight relationship from time to time.

It is apparent, then, that a comprehensive analysis of the length-weight relationship can be based only upon a sufficiently large series of samples spread as evenly as possible throughout the year. For statistical accuracy, fairly large samples are needed. Where sexual differences exist, samples of each sex must be treated separately. Within the limits of the collecting gear, the samples must be random to avoid the personal bias which tends to choose the larger and heavier specimens. It should also be remembered that it is essential to use the logarithmic equations in analyzing the length-weight relationships, for, as Huxley (1932) has pointed out, living growth is a multiplication
of substance. Hence, it is preferable to use a logarithmic scale where equal spaces represent equal multiples rather than an absolute scale where equal spaces indicate equal additions. Thus, on a logarithmic scale it is readily apparent that an increase in weight from 1 to 10 grams represents the same proportional growth as an increase from 10 to 100 grams. This is obscured if an absolute scale is used.

It is now pertinent to consider the type of information which may be obtained from the length-weight relationship. First among these is the estimate of the weight for a given length. This may be determined from the equation $W = cL^n$, or $\log W = \log c + n \log L$, where $W =$ weight, $L =$ length, and $c$ and $n$ are constants; $c$ and $n$ are respectively the initial growth index and the equilibrium constant of Huxley and Teissier (1936a, 1936b). For reasons already outlined, the calculations must be based upon a reasonably complete series of collections.

A second type of information that may be obtained from the length-weight relationship is an index of the relative heaviness or form of the fish. This index, known as the coefficient of condition, condition factor, length-weight factor, etc., is determined from the general equation $C = W/L^n$, where $C =$ the coefficient of condition, $W =$ weight, $L =$ length, and $n =$ an empirically determined exponent. In this form, $C$ is a measure of weight in relation to the mean weight at length $L$, and it may be used to compare the manner of growth of individuals or groups from one sample with each other or with the empirical growth line for that sample. If it is desired to use $C$ to compare several samples with each other, it is then necessary to derive an average value of $n$, here designated as $\bar{n}$, and assume that $\bar{n}$ holds good for all samples. If $n$ is determined separately for each sample and the coefficients of condition calculated on the basis of the separate $n$'s, the values so obtained will be meaningless unless $n_1 = n_2 = n_3$ etc., for it is a mathematical characteristic of the basic equation that $C$ undergoes geometric variations inversely with arithmetic variations of $n$. Failure to recognize this fact has led to a good deal of confusion in the past.

A further limitation to the use of the coefficient of condition lies in the fact that it tends to increase or decrease with increasing length according to whether $n$ is greater or less than $\bar{n}$. This is shown by the following equations:
Let \( n = p \pm q \), and let \( \bar{n} = p \). Then \( W = cL^n \) may be written \( W = cL^{p \pm q} \), or \( W = cL^p L^{\pm q} \). Since \( C = W/L^{\bar{n}} \), \( C = \frac{cL^p L^{\pm q}}{L^p} \), or \( cL^{\pm q} \), or \( \log C = \log c \pm q \log L \), whence \( \frac{d(\log C)}{d(\log L)} = \pm q \).

Hence, trends in condition may be obscured, or false trends appear if the lengths covered by each sample are not the same.

A special form of the coefficient of condition, sometimes called the ponderal index, is derived from the assumption that \( \bar{n} = 3 \), whence its equation becomes \( K = W/L^3 \). The coefficient \( K \) is thus an index of weight in relation to the weight expected if growth in length and weight were isometric.

Although both \( C \) and \( K \) are measures of condition, the usefulness of \( C \) is limited by the fact that its values indicate condition with respect to an empirically determined standard, \( \bar{n} \). Since \( \bar{n} \) often varies between different populations and species (see, for example, Hile, 1936, who found that \( \bar{n} \) for different populations of the cisco, \( Leucichthys artedi \), varied between 1.4 and 3.7 approximately), values of \( C \) for such populations will not be comparable. On the other hand, \( K \) measures condition with respect to isometric growth. Its values, therefore, are completely comparable, not only between different samples or populations of the same species but also between different species.

**Measurements and Calculations**

In the present study of the length-weight relationship, samples were collected almost every month (see Appendix Table A) from June 1943 through May 1946. Samples collected before June 1943 were not used, since they were taken under conditions differing from those adopted as standard after May 1943. Measurements of length to the nearest half centimeter and of weight to the nearest gram were made on every specimen taken in these samples, a total of 9,428 animals. In measuring length, a standard type of measuring board with an offset of 0.5 cm was used. For example, a specimen measuring slightly over 25.5 cm was recorded as being 26 cm long. Similarly, a fish measuring between 26 and 26.5 cm was recorded as having a length of 26.5 cm. This method has the great advantage of centering all measurements about the integers, thus saving a great deal of labor in subsequent calculations.
The average length-weight relationships have been determined from measurements of 2,508 specimens, of which 1,320 were males and 1,188 were females. This reduction from the grand total of 9,428 was necessary to eliminate as far as possible bias from the numerical weight of the larger samples. In this reduction, random subsamples of about 50 specimens of each sex were drawn from the larger samples by the use of the Latin square technique. It was necessary to use a randomizing procedure because examination of the raw data showed that the persons measuring the fish had consistently chosen the larger and heavier specimens first.

The coefficient of condition, $K$, was determined for fish from 23 to 29 cm long for each of 10 to 20 individuals of each length and sex chosen at random from the collections of June 1943 to May 1944 inclusive. These coefficients were averaged and plotted in Fig. 6. The average $K$ for each sample (lengths 23 to 29 cm only) from June 1943 through May 1946 was also determined and plotted in Fig. 7.

To check the effect of the weights of the stomach and gonads upon the length-weight relationship, these organs were weighed from subsamples selected to cover the greatest possible range of lengths. Stomach weights were taken from fish caught in the collections of VIII/16/43 to VI/23/44, and gonad weights came from the collections of VI/15/43 to V/18/44. In using these weights, it has been found convenient to express them as percentages of the total weight. These percentages have been termed the gastrosomatic and the gonadosomatic indices. These indices were computed from the preserved weights of the organs and the fresh weights of the fish. Tests made on the longhorn sculpin and other fishes by weighing the organs fresh and by reweighing them some time after preservation showed that no appreciable error is introduced by this treatment.

**The Average Length-Weight Equation**

The average length-weight relationships of males and females are not identical. For each sex separately, the relationships over the three year period are

\[
\text{Gastrosomatic index} = \frac{100 \times \text{wt. of stomach and contents}}{\text{total weight of fish}}
\]

\[
\text{Gonadosomatic index} = \frac{100 \times \text{wt. of gonads}}{\text{total weight of fish}}
\]
\[ \varphi \varphi W = 0.01375 L^{2.91381}, \text{ or} \]
\[ \log W = -1.86175 + 2.91381 \log L, \]
\[ \varphi \varphi W = 0.01039 L^{3.00250}, \text{ or} \]
\[ \log W = -1.98312 + 3.00250 \log L. \]

These curves are shown in their exponential forms in Fig. 5. It will be seen from Fig. 5 that the males tend to be slightly heavier than the females when the fish are small whereas the reverse is true among the larger animals. The point of intersection is at \( L = 23.4 \text{ cm} \), which corresponds to an age of 2½ to 3 years (p. 47). Olsen and Merriman (1946), working on the biology of the ocean pout, *Macrozoarces americanus*, suggested that the point of intersection of the two length-weight curves represented the size at which sexual maturity was attained. These authors found that mature male ocean pout were heavier than females and reasoned that "... proportionately more food is converted into ovarian tissue and yolk material, due to the exceptionally large size of the gonad, than is converted into testicular tissue by the male; since this material is lost in the process of spawning, the average weight of the females over a full year is less than that of the corresponding males."

Obviously, this line of reasoning cannot be followed with respect to the sculpin, for here the mature females are heavier, on the average, than the males. If the point of intersection of the two length-weight curves represents the size at sexual maturity, then it becomes necessary to assume either that the females eat more than the males or that they become more efficient in converting food into flesh. Until one or the other of these is shown to be true, it does not seem justifiable to consider the point of intersection of the two length-weight curves as indicating the size at sexual maturity.

Further doubt is cast upon such an interpretation by the fact that the length-weight curves for each of the three years covered by this study do not intersect at the same point. The longhorn sculpin reaches sexual maturity in its third year (p. 34) at a length of 22 to 25 cm. This agrees with the point of intersection of the three-year curves, \( L = 23.4 \text{ cm} \) and the curves for 1943–1944, \( L = 22.1 \text{ cm} \). But the curves for 1944–1945 intersect at \( L = 34.8 \text{ cm} \) and those for 1945–1946 at \( L = 26.9 \text{ cm} \). The greater numerical weight of the 1943–1944 data has thus dominated the calculation of the three-year equations and brought the average point of intersection within the
size range given above. Had the two later years been sampled ade­quately, it might be possible to interpret the significance of the point of intersection of the two curves, but at present this cannot be done.

Figure 5. The average length-weight relationships for the period from June 1943 through May 1946.
The Coefficient of Condition

The coefficient of condition used in the present investigation is $K$ rather than $C$. It is now appropriate to examine this coefficient as applied to the longhorn sculpin. Fig. 6 shows that between June 1943 and May 1944 a fairly clear pattern is present in the fluctuations of $K$. This coefficient is high in June, over 1.1 in nearly all cases. Subsequently it declines more or less regularly throughout the summer and fall, reaching a low in October and November. This indicates either
a gradual loss of weight or an increase in length without a correspon-
ding increase in weight. Study of the growth of the otoliths (p. 48) sug-
ests that little growth in length takes place at this time. That the
decline in the coefficient of condition is not a mere reflection of the
lighter weight of the stomach and its contents (Fig. 8) is shown by
comparing the declines in both $K$ and the gastroscopic index be-
tween June and October. The average decline in $K$ during this
period is 0.171. At the same time, the gastroscopic index falls
0.8%, which is not large enough to account for a change of 0.01 in the
value of $K$. The observed change in $K$ is thus nearly 20 times as
great as can be accounted for by the presence of less food in the
stomach. It appears, then, that this decline in $K$ actually indicates
a loss of weight and that the gastroscopic index is an indicator of the
rate of feeding and state of nourishment.

Further examination of the fluctuations of the coefficient of condi-
tion (Figs. 6 and 7) brings out the following points. A peak of condi-
tion is reached at the start of the spawning season, approximately
mid-December. This is associated with the prespawning growth of
the gonads, which increase in weight about 10-fold between September
and December (Fig. 8). This increase is nearly sufficient to account
for the observed changes in $K$. The difference in the weights of
ovaries and testes is reflected in the difference in the magnitudes of the
fluctuations of $K$ for females and males.

The subsequent fall in $K$ is associated with spawning and the con-
comitant loss of weight from the gonads. Another factor that should
not be overlooked is the fact that spawning, in addition to causing a
direct loss of weight through the emission of sex products, also places
a physiological strain upon the organism. It is quite probable that
reserves are drawn upon to a considerable degree during this period,
contributing to the decline in $K$.

A rather sharp rise in the coefficient of condition in the early spring
(February–March) is accompanied by an increase in the rate of feeding
and indicates that weight is increasing rapidly. This rapid growth in
weight may be considered as a restoration of reserves lost, from spawn-
ing and other causes, during the winter.

The subsequent fall in $K$ (about April) indicates either loss of weight
or growth in length. Since examination of the otoliths (p. 48) has
shown that this period of the year marks the beginning of rapid growth,
it is probable that the low value of $K$ indicates a spurt of growth in
length at this time. In this period, most of the food intake must be put not towards the maintenance of pre-existing flesh but towards the creation of new flesh along the antero-posterior axis. Similarly, the high $K$ values in May and June can only indicate rapid growth in weight. Thus, growth in length and in weight are not synchronous.

The approximate periods of the annual growth cycle are shown in Fig. 9. It should be noted, however, that these periods are not
sharply defined and may vary from year to year (Fig. 7). However, the same pattern appears to be repeated with a fair degree of regularity. It should also be noted that nearly all the peaks and valleys shown in Fig. 7 are significantly different from each other and from the annual means. These variations in $K$ are thus shown to indicate actual changes in the manner of growth. They cannot be considered as mere random variations about a mean.

**Breeding Habits**

The breeding and spawning habits of the longhorn sculpin are but incompletely known, since no studies have been made on this subject; the little information that is available is contained in more general
works such as those of H. M. Smith (1898), T. H. Bean (1901, 1903), Tracy (1910), Nichols and Breder (1927), and Bigelow and Welsh (1925). Of the longhorn's spawning habits, these last authors say:

All that is known of the breeding habits of this sculpin is that it spawns in November and December about Woods Hole, its eggs sinking together in clumps like those of the shorthorn sculpin, and often being thrown up on the beach in masses. Presumably the spawning season is the same in the Gulf of Maine, but whether it gathers in particular localities or at any precise depth to spawn or does so indifferently on all kinds of bottom is yet to be learned. The presence of sculpins of all sizes, from very young fry to adult, proves that it breeds generally along the coasts of Massachusetts Bay and Maine, probably along western Nova Scotia as well; but in the Bay of Fundy it seems restricted as a breeder to the Scotian side, the absence of young fish on the New Brunswick shore proving that the half-grown and adult fish that are so plentiful there are immigrants either from across the bay or from the Gulf outside.

The present study of its spawning was confined almost entirely to Block Island Sound and the immediate surrounding waters. Gonads preserved from the collections of VI/15/43 through V/18/44 were examined carefully to determine the degree of ripeness. Samples of gonadal tissue were taken from the anterior, center, and posterior portions of several mature gonads (usually three of each sex) from each collection. These were sectioned and stained with Mallory's triple stain for microscopic examination. Additional data on the time of spawning of various age-groups has been derived from the length-frequency distributions of certain samples. Finally, personal observation in the field has played no small part in elucidating certain points.

In the Block Island Sound region the spawning season extends from late November through January and possibly into February, but there is some variation in the duration of active spawning. In the 1943–1944 season, spawning fish were found in the collections of November 21 and December 19, 1943 and January 23, 1944. One female in the collection of February 29, 1944 still contained eggs, indicating that this specimen had spawned only recently, probably some time in February. By contrast, in the spawning seasons of 1946–1947 and 1948–1949, no fish were found in a spawning condition before the middle of December or after the third week in January, a season much shorter than that of 1943–1944. Since the longhorn sculpin spawns only during the coldest part of the year, it is possible that temperature is one of the controlling factors. Granting this
assumption, the shortness of the 1946–1947 and 1948–1949 spawning seasons may be the result of relatively high temperatures. Complete water temperature records are not available, but air temperature records from the U. S. Weather Bureau station at Block Island, R. I. (U. S. Weather Bureau, Climatological data for the United States by sections, vols. 30, 31, 33 and 34) show the average air temperature in the period October 1946 through February 1947 to have been 9.1° C. higher than the average temperature in the corresponding period of 1943–1944. Presumably a corresponding though smaller difference existed in bottom water temperatures as well. Also, temperatures of the bottom water in Block Island Sound taken by members of the Bingham Oceanographic Laboratory on January 11 and February 24, 1949 were respectively 4.1° and 3.8° C. higher than the bottom temperatures taken on nearly the same dates in 1944.

Most of the spawning activity takes place in late December and January. This is indicated by the movements of the gonadosomatic index (p. 28) and by the number of spawning fish in the collections. The gonadosomatic index is rising in November, indicating that the gonads are still increasing in size, but inspection shows that only a few fish are spawning at that time. The peak of the gonadosomatic index is reached in December, and the subsequent fall is rapid. Further decline through February indicates that some spawning activity may be continuing through this month but on a much lower level than in December and January. In the 1943–1944 spawning season, 117 females were examined to ascertain the condition of the gonads. In the collection of November 21, 1943, 20.8% of the females examined had already begun to spawn. In the collection of December 19, 1943, this figure had risen to 34.2%, while in the January 23, 1944 collection it was 85.4%. The collection of February 29, 1944, contained only one female of 18 examined that had spawned recently. The samples are small but the trend is pronounced.

There is some evidence to indicate that younger fish spawn earlier in the season than do older animals. Among the females examined in detail during the spawning season, younger fish made up the greater part of those containing ripe eggs in the early part of the spawning period, but later there were more old fish that contained ripe eggs. Although the smaller number of male specimens examined (49) makes it less certain than with the females, the older males, too, apparently tend to spawn later. This is shown in Table III. Further
Figure 10. Length-frequency distributions of *M. octodecimspinosus* during the spawning season. The upper histograms show the percentages of males, the lower of females; the solid lines and circles indicate the total percentages (both sexes combined). Note the greater prevalence of larger fish in the later part of the season.
evidence on this point is to be found in the length-frequency curves of the samples taken in the spawning season, shown in Fig. 10. These curves represent complete hauls, as described on page 8. It will be noted that there is a tendency for large females to be more numerous in the later part of the season than earlier. When the curves for the same months are combined and analyzed, the results are as in Table IV.

**TABLE III. PERCENTAGES OF SPAWNING FISH FALLING INTO VARIOUS AGE-GROUPS DURING THE SPAWNING SEASON. AGE HAS BEEN DETERMINED FROM THE OTOLITHS (p. 43)**

<table>
<thead>
<tr>
<th>Month</th>
<th>Age-Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0+</td>
</tr>
<tr>
<td>November</td>
<td>♂</td>
</tr>
<tr>
<td></td>
<td>♀</td>
</tr>
<tr>
<td>December</td>
<td>♂</td>
</tr>
<tr>
<td></td>
<td>♀</td>
</tr>
<tr>
<td>January</td>
<td>♂</td>
</tr>
<tr>
<td></td>
<td>♀</td>
</tr>
</tbody>
</table>

**TABLE IV. FEMALES OF VARIOUS SIZE CATEGORIES, EXPRESSED AS AVERAGE PERCENTAGES OF THE TOTAL NUMBER OF FEMALES PRESENT IN COLLECTIONS MADE DURING THE SPAWNING SEASON**

<table>
<thead>
<tr>
<th>Month</th>
<th>Less than 24</th>
<th>24</th>
<th>25</th>
<th>26</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov.</td>
<td>0.3</td>
<td>4.0</td>
<td>11.7</td>
<td>17.9</td>
<td>20.7</td>
<td>21.9</td>
<td>21.0</td>
<td>7.4</td>
<td>0.6</td>
<td>2.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.4</td>
<td>1.5</td>
<td>9.8</td>
<td>15.4</td>
<td>22.9</td>
<td>24.5</td>
<td>12.0</td>
<td>12.0</td>
<td>0.8</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Jan.</td>
<td>0.0</td>
<td>1.3</td>
<td>4.7</td>
<td>10.8</td>
<td>14.3</td>
<td>24.4</td>
<td>13.2</td>
<td>18.4</td>
<td>7.4</td>
<td>3.9</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Females alone have been used in this demonstration, since they far outnumber the males at this time of year. There is a definite tendency for the larger (hence, older) fish to be more numerous in January than in November and December. Undoubtedly this is due to slight differences in the migration patterns of large and small fish. The larger fish move inshore and spawn later than do the small ones. The males show a similar phenomenon, but as a rule they do not include such a wide range of sizes, hence it is not as evident.

Table III indicates that the longhorn sculpin becomes sexually mature in its third year (2+ age-group), or later. However, very few younger specimens were available for examination. Either because of their small size which would permit them to escape from the trawl net, or because of their absence from the fishing grounds, sculpins less than two years old were seldom found. A total of 25 (14 ♂ ♂ and 11 ♀ ♀ ) 1+ age-group fish were taken during the course of this study. All of them were immature. It appears highly probable, then, that the vast majority of sculpins mature in their third year of life, with
perhaps a small percentage remaining immature until the fourth year. No 3+ or older fish were found that were still immature.

Ripening of the gonads has already been mentioned in regard to increase in weight. It was shown that the gonadosomatic index held fairly steady during the spring and summer, began to increase slowly and then rapidly in the fall, reached a peak in December, and then fell off rapidly during January and February. The development of the sex cells follows a similar cycle.

In the spring (June) the testes are filled with spermatocytes, a condition which persists throughout the summer. In September, spermatids begin to appear, and by the end of October these constitute approximately 80% of the male sex cells, the remaining 20% being divided about equally between spermatocytes and sperm cells. In November about equal proportions of sperm cells and spermatocytes are to be found in the testes, and in December and January, the height of the spawning season, sperm cells alone are present. At this time the testes consist of little else but closely packed masses of sperm cells separated by thin walls of connective tissue. Immediately after spawning, practically nothing remains but these connective tissue walls and a thin germinal epithelium. By late February, however, spermatogonia are prominent and spermatocytes reappear in April and May.

A similar cycle occurs in the ovary. In June oocytes with an average diameter of about 0.23 mm are to be found in the ovary, yolk is already accumulating, and small vacuoles have appeared. In August the average diameter is 0.36 mm, while in September it is 0.41 mm. At this stage the egg membrane is well developed. Increase in size, degree of vacuolization and membrane thickness continues until November. During the spawning season (November through January) no further change takes place. The average diameter of the eggs at this time is about 0.85 mm. As early as the last week of January early spawning females have new oocytes with an average diameter of 0.12 mm. Changes through the spring of the year are chiefly in size and the accumulation of a little yolk.

At fertilization the egg of the longhorn sculpin is about 0.85 mm in diameter. Volumetric measurements indicate that the average female produces about 8,000 eggs each year. The color of the eggs is highly variable. The majority are of a coppery green hue, but clumps have been found and others have been observed in the ovary that had a
bluish cast. Still others were reddish brown, brown or orange, and Warfel and Merriman (1944) have reported some as being purple.

Observation of stripped eggs showed that when the ripe eggs come into contact with sea water, the egg membrane swells and becomes strongly adhesive. The eggs stick closely to each other and to anything else they may happen to touch. Twenty-four hours later the membrane is no longer sticky, but the adhesion of the eggs to each other and to other objects remains undiminished. Although stripping and fertilizing were easily accomplished, none of the zygotes so obtained lived more than two or three days.

Development of the fertilized egg apparently does not require longer than three months and probably is completed in a shorter time. Postlarval sculpins, tentatively identified as *M. octodecimspinosus*, have been taken in plankton tows in February and March, and eyed eggs have been found in December and January.

The longhorn seems to spawn throughout the Block Island Sound area without particular choice of locality within the Sound. Nearly all of this bottom is hard mud, sand or gravel. The eggs are to be found either in free clumps or deposited in cavities in solid objects such as clam shells. Egg masses are often found in the dead man’s finger sponge, *Haliclona oculata*. The prevalence with which egg masses are found attached to some object suggests that the spawning act may be quite complex; apparently the eggs are not normally extruded at random to fall where they will but are definitely placed. This seems to be common among the Cottidae. Bigelow and Welsh (1925) have stated that *M. scorpius* may deposit its eggs in hollows and cavities, and Warfel and Merriman (1944) have given a detailed description of the relation between sponges and the eggs of the sea raven, *Hemitripterus americanus*.

It was not possible to make personal observations on spawning habits in areas other than Block Island Sound, but fishermen operating in Long Island Sound off Point Herod, Port Jefferson, New Haven, Bridgeport, etc., report that sculpins are rarely found in those waters during the winter. This may be coupled with the fact that the bottom in this area is generally muddy and is probably unsuitable for the deposition of demersal eggs. Another possible factor is the much lower salinity of Long Island Sound water, about 26°/∞ compared with about 32°/∞ in Block Island Sound.
The question of the determination of age and growth of fishes is one of the oldest and most important in fisheries biology. So many problems in this field depend upon reasonably accurate estimates of age and rate of growth for their complete solution that knowledge of this subject is well-nigh essential. The many methods which have been described for gaining this information fall naturally into two categories; those which are based upon length-frequency distributions and those dependent upon the observation of marks on body structures.

The length-frequency method was originated by G. O. Sars in the 1860's and 1870's and was fully developed by Peterson (1891, 1895). This method is based upon the fact that fish hatched in a given year will vary in length about a mode greater than the mode for fish hatched in subsequent years. Theoretically, this method is of general application. In practice, however, it is seriously limited, for as fish grow older the variation about a mode often becomes greater than the difference between successive modes, thus rendering it impossible to distinguish between older groups. Furthermore, if the sampling does not yield a fair representation of each age-group, or if one group greatly outnumbers others, results from length frequencies are often extremely difficult to interpret. It is usually assumed that the modal value of each age-group in a length-frequency distribution represents the modal size of fish of that age, but this need not be true unless the method of sampling is truly nonselective. In practice, then, length frequencies are not usually of great value beyond the first few years, except as supplements to other observations.

The method of determining age from examination of body structures depends upon the presence of zones of modified appearance brought about by seasonal changes in the growth pattern. If the cycle of seasonal changes can be shown to occur once and only once each year, the pattern may be called an annulus. The majority of temperate water fishes which have been thoroughly investigated have shown the presence of annuli in such structures as the scales, otoliths, vertebrae, head bones, fin rays, etc. Because of the widespread occurrence of this phenomenon and the generally satisfactory results to be obtained from its use, this method has become standard practice in fisheries biology. It is unfortunate that few workers have established, except
by analogy, that the marks selected were actually annuli. Even fewer workers have established the time of formation of the annuli.

Although age determination from skeletal structures is the most satisfactory method thus far developed, it is not entirely free from subjective influence. Each investigator must decide whether or not a given mark on an individual structure is an annulus. For this reason it is not unusual for several persons to examine the same set of material. Under these circumstances accuracy greater than about 85 or 90% is not to be expected. Occasionally reports appear which give an attainment of 98 or 99 or even 100% agreement in determinations of the same material by several persons. It should be realized, however, that if the investigators have been trained by the same person, they will naturally tend to choose the same criteria, and close agreement would be expected. By contrast, several of the foremost fisheries biologists in the United States and Canada were not able to reach complete agreement on the age and interpretation of the scales of a salmon caught recently in the Connecticut River (Merriman and Jean, 1949).

In addition to yielding age determinations, skeletal structures can also be made to provide information about the rate of growth. If it can be shown that a relationship exists between some measurement of a structure and some measurement of the fish, usually the length, then measurements between annuli will represent the growth in a particular year. This method has been applied most notably to scales (Lea, 1910, 1913; Lee, 1912). Summaries and reviews of methods of determining the age and growth of fishes have been given by Dahl (1909), Creaser (1926), Van Oosten (1929), and Graham (1929). An extensive bibliography of the subject has been contributed by Mohr (1927–34).

Among the structures customarily used for age determinations, the otolith appeared to be the most suitable for this work. Therefore the present discussion is largely confined to a consideration of the otoliths.

**Historical Review**

Reibisch (1899) observed changes in the character of the rings of otoliths taken from the plaice, *Pleuronectes platessa*, and suggested that the variations were to be correlated with changes in temperature. However, he misinterpreted the summer and winter rings, for, according to his description and illustration, what is now called the summer
ring was formed in periods of low temperature. In common with Jenkins (1902), he concluded that the otolith was composed of amorphous CaCO$_3$.

Maier (1906) found that the otoliths of flounders and cod were composed of crystalline rather than amorphous CaCO$_3$, and he also showed that the summer ring (i.e., the ring which appears white and opaque by reflected light) is composed of many close-lying layers of material and that the winter ring is not so dense.

By examining otoliths taken at various times of year, Maier was able to observe that the formation of the summer ring began in early April while the first evidence of the winter ring appeared in July. His conclusions may be summarized as follows:

1. The number of complete rings (i.e., rings which completely encircle the otolith) is proportional to the length of the fish.
2. In one year, the otoliths of all fish show a white (summer) ring at the margin from April through June and a dark (winter) ring from July through March.
3. Age determinations by means of otoliths agree with determinations from scales.
4. Age determinations from otoliths agree with those made from length-frequency distributions.

Immerman (1908) made a detailed study of the structure of the otolith of the flounder. He found that it was composed of crystals of CaCO$_3$ held in an organic ground substance which he believed to be derived from the jelly-like connective tissue filling the sacculus of the inner ear. He concluded that the lamellar and radial organization of this organic matrix was the basic structure responsible for the stratified appearance of the otolith. He suggested furthermore that the white and dark appearances of the two types of concentric layers were due to differences in the amount of light reflected from the CaCO$_3$ crystals. According to his interpretation, regions where the organic lamellae were dense and close together produced a slight bending of the crystals, hence a greater amount of reflection and a white appearance; on the other hand, the dark rings represented regions where greater space existed between the lamellae. He also suggested that growth of the otolith depended upon temperature and metabolic rate, an increase in these two factors resulting in a white summer ring.

More recently Hickling (1931) studied the structure of the otolith of the hake, Merluccius merluccius. In most essentials he corroborated
Immerman's work, but he found no evidence to indicate that any bending of the crystalline structures occurred. Hickling interpreted the white summer rings as being caused by the greater thickness of the organic lamellae laid down at this time.

Little is known concerning the causes of the different appearances of the two types of zones in the otolith. Although a number of explanations have been advanced, all rely upon correlations, possibly coincidental, between changes in environment or behavior and the formation of one or the other type of zone. No adequately controlled experimental study of this problem has ever been made.

Cunningham (1905) held the opinion that the opaque summer ring was caused by an increased rate of calcification during warm weather when growth is most rapid and that the translucent winter ring resulted from slow calcification associated with negligible growth during colder weather. But Lea (1911) found no correlation between temperature and growth of herring, although Segerstråle (1932) demonstrated a high positive correlation between the mean July-August temperature and the width of the summer growth zone on the scales of *Abramis brama*. Recently Pickford and Thompson (1948) have found that injections of mammalian anterior pituitary growth hormone stimulated the growth of *Fundulus heteroclitus* but that it did not produce a corresponding change in the growth pattern of the scales and otoliths.

**AGE AND GROWTH IN THE LONGHORN SCULPIN**

The study of age and growth in the longhorn has been based on material taken in the monthly collections (p. 8 and Appendix Table A) from April 1943 through April 1946. Between April 1943 and June 1944, subsamples of otoliths were taken from each haul. Since these subsamples were representative rather than random, it was not possible to make direct estimates of the age composition of the population from them. However, they were suitable for the remainder of the work described here. Details of the procedures are given in the appropriate sections.

**Terminology.** Many studies of the age and growth of fishes have not included definitions and descriptions of the terms employed. This has often led to confusion, for the same terms are sometimes used with varying meaning by different investigators. It seems wise, therefore, to define as precisely as possible the exact meaning of each of the various terms employed in the present paper.
A summer growth zone, or summer ring, is that part of the annual growth pattern of the sculpin otolith which is formed in the period between April and August. A winter ring or growth zone is formed between August and March (see Table V). All of the otoliths used in this work were examined under reflected light. In reflected light the summer ring appears white and opaque while the winter ring looks dark and translucent. (Under transmitted light, these appearances are reversed.) A ring or growth zone is an area of one type of growth extending completely around the otolith. Although a number of authors have followed this criterion in determining the number of rings present, others have considered all complete rings and all fragments or incomplete rings as growth zones. Still others have counted all complete rings and have adopted a subjective attitude on incomplete rings and fragments. Examination of a large number of sculpin otoliths has led to the conclusion that the first method is the most accurate and likely to yield the most reasonable results.

An annual ring is composed of one summer ring and one winter ring as defined in the previous paragraph. The age of a fish is equal to the number of annual rings on its otolith. In describing age, a fish in its first year of life is considered to belong to the 0+ age-group, an age-group being a number of individuals of the same age. Since the kernel point of the sculpin otolith is of the winter growth type, a complete cycle of growth zones has appeared on the otolith by the end of the first summer, when the fish are but eight months old. However, the term first year of life has been extended here to include the time between the spawning of the egg and the start of the formation of the second summer ring. Since the young hatch out some time before summer ring formation begins, the 0+ age-group as thus defined may actually include individuals as much as 16 months old. For convenience, however, fish of the 0+ age-group are considered to be less than one year old. With the same qualification, fish which have completed one year of life, but not two, are in the 1+ age-group. Those which have passed two years, but not three, are called 2+, and so on.

The term age-group is not to be confused with year-class. The latter refers to the year in which the fish were hatched. Since the spawning season covers the period from late November through January, all year-classes have been arbitrarily referred to January of the indicated year. Thus, the year-class of 1941 would include all
those fish spawned in November and December of 1940 and January of 1941.

**The Sculpin Otolith.** The otolith used in the present work is the saccular otolith or sagitta. This lies lateral and slightly ventral to the medulla of the brain and is easily removed with forceps after splitting the skull on the medial line. Viewed from its lateral aspect, the otolith is somewhat elliptical in shape, more or less pointed at the ends. The posterior half is usually slightly wider than the anterior. The dorsal edge is crenate on the anterior quarter while the ventral edge is fairly smooth. The lateral side is concave, the medial convex. A large sulcus (Fig. 11B) is present on the medial side, extending from a point slightly anterior to the center diagonally backward to the upper posterior edge.

The central area of the otolith represents growth during the first year of life. The extreme center, or kernel point, of this first year is of the typical winter growth type, appearing dark by reflected light (Fig. 11C). This is to be correlated with the fact that the eggs are laid in December and January and undergo their larval and postlarval stages during the winter months. Development from the postlarval to the adult shape probably takes place about May. A few postlarval sculpins, almost certainly *M. octodecimensinosus*, taken in plankton tows in Block Island Sound on February 29 and April 19, 1944 and March 5, 1945 had not yet assumed the adult shape. By contrast, a small specimen taken in a salmon weir in the Bay of Fundy on July 4, 1945 and presented by Yves Jean was 24 mm long and had all the characteristic features of the adults. This period of development and subsequent rapid growth is shown by the broad band of white material surrounding the kernel point. The dark ring around the whole central area represents the growth during the second winter.

The different types of growth zones may be seen when the otolith is examined from the lateral side (Fig. 11A). As the photograph shows, the specimen was seven years old (7+ age-group), having seven complete winter rings and seven complete and one incomplete summer rings. The broad white area surrounding the central portion represents growth during the second summer. The third summer ring is not as broad as the second, while the fourth and subsequent summer rings are quite narrow, reflecting the slower growth of mature fish. The winter rings show the same phenomenon but to a lesser degree.
Figure 11. Otoliths of *M. octodecimspinosus*. A. The lateral side of the left otolith #1306, showing annual rings and radial fibers. Winter rings indicated by lines and numbers at left, summer rings at right. This otolith was ground to show details not otherwise visible; X15. B. Otolith #5960 from the medial side to show the sulcus; X8. C. The central portion of #1306, representing the first year of life; X22. D. Otolith #1317, taken May 11, 1943, showing a very early stage in the formation of the summer ring. E. Otolith #2945, taken August 16, 1943, showing complete summer ring. F. Otolith #2436, taken August 7, 1943, showing early winter ring. G. Otolith #5956, taken February 29, 1944, showing complete winter ring. D through G magnified X20.
Materials and Methods. In the present study a total of 760 pairs of otoliths was available. Of this number, 749 were taken from the monthly hauls of April 22, 1943 through May 18, 1944 (p. 8) and the remaining 11 were from small specimens taken at various times and places and by various means.

It was found that the otoliths were impossible to read when examined dry, so a number of fluids were tried in an effort to bring out the details of the zones of growth. A mixture of three parts methyl salicylate to one part benzyl benzoate by volume proved most satisfactory. Xylene and a 1:1 mixture of xylene and ethyl alcohol also proved to be good.

Each otolith in a watch glass with the methyl salicylate-benzyl benzoate mixture was placed on a dark background and surrounded by a plastic diffusing screen. Light from a small microscope lamp was directed through the diffusing screen at a low angle and the examination was made with a dissecting microscope at a magnification of 12.5 X. The lighting proved to be an extremely important factor. Transmitted light was useless, for the otoliths were too thick, while excessive or insufficient reflected light destroyed the clarity of the outer and inner areas respectively. Illumination from the dorsal edge of the otolith was far superior to light from other directions.

Of the 760 pairs of otoliths available, 23 pairs were not readable, and 237 pairs had been broken. Since one or the other otolith of the remaining 500 pairs was frequently broken, it was necessary to use whichever one remained, right or left. Measurements of a random sample of 101 pairs showed no significant difference between the right and the left otolith. When both were available, the left one was always used. Of the 500 specimens, 248 were males and 252 were females.

Measurements were made with an ocular micrometer in the dissecting microscope calibrated at 1 scale unit = 0.909 mm. For convenience, all calculations were carried out in terms of scale units rather than millimeters. The total length of the otolith was read and a similar measurement made on each zone of growth. Measurements for each otolith, with the number, length, weight and sex of the specimen, were recorded on separate cards. From these data the relationship between otolith length and fish length was calculated by the method of least squares.

The width of the otolith was also measured, but since the correlation
between length of fish and width of otolith was low, this measurement was not used. By contrast, the correlation between length of fish and length of otolith was of a high order of significance.

Criteria. In determining age and growth rate from skeletal structures, the following points must be established in order to give a sound basis for the procedure.

1. The rings of the otolith or other structure are annual, or represent some other definite period of time.

2. The rings are formed at the same time each year, and all, or at least most, of the fish in the population form the same ring at the same time.

3. A relationship exists between some measurement of the fish and some measurement of the otolith or other structure.

Of course, the ideal way to establish the first two points would be to examine each of a series of otoliths over a period of several years. Since this cannot be done, the next best method is to examine a number of different otoliths from the same species taken at intervals during the course of a year or longer. The third point is easily established by comparing measurements of the otoliths with the measurements of the fish from which they were taken.

The first step in the estimation of age was to determine the annual

TABLE V. Month-to-month Changes in the Character of the Margin of the Otolith, Demonstrating the Annual Nature of the Zones of Growth

<table>
<thead>
<tr>
<th>Date</th>
<th>Number in sample</th>
<th>Summer No.</th>
<th>Summer %</th>
<th>Winter No.</th>
<th>Winter %</th>
<th>Not readable No.</th>
<th>Not readable %</th>
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<tr>
<td>IV/22/43</td>
<td>88</td>
<td>12</td>
<td>13.7</td>
<td>74</td>
<td>84.0</td>
<td>2</td>
<td>2.3</td>
</tr>
<tr>
<td>V/11/43</td>
<td>18</td>
<td>11</td>
<td>61.1</td>
<td>7</td>
<td>38.9</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>VI/15/43</td>
<td>22</td>
<td>14</td>
<td>63.7</td>
<td>7</td>
<td>31.8</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>VII/19/43</td>
<td>1</td>
<td>1</td>
<td>100.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>VII/24/47</td>
<td>13</td>
<td>12</td>
<td>92.3</td>
<td>1</td>
<td>7.7</td>
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<td>0.0</td>
</tr>
<tr>
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<td>57.2</td>
<td>3</td>
<td>42.8</td>
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<td>0.0</td>
</tr>
<tr>
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<td>52</td>
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<td>80.8</td>
<td>10</td>
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<td>0</td>
<td>0.0</td>
</tr>
<tr>
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<td>15</td>
<td>26.3</td>
<td>38</td>
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<td>4</td>
<td>7.0</td>
</tr>
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<td>100.0</td>
<td>0</td>
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<tr>
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<td>1.0</td>
<td>97</td>
<td>97.0</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>XI/21/43</td>
<td>50</td>
<td>0</td>
<td>0.0</td>
<td>49</td>
<td>98.0</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>XII/19/43</td>
<td>50</td>
<td>0</td>
<td>0.0</td>
<td>49</td>
<td>98.0</td>
<td>7</td>
<td>11.6</td>
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<tr>
<td>I/23/44</td>
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<td>0.0</td>
<td>49</td>
<td>98.0</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
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<td>26</td>
<td>0</td>
<td>0.0</td>
<td>26</td>
<td>100.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>II/29/44</td>
<td>50</td>
<td>3</td>
<td>6.0</td>
<td>46</td>
<td>92.0</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>III/19/44</td>
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<td>45</td>
<td>90.0</td>
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<td>6.0</td>
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<td>14.0</td>
<td>42</td>
<td>84.0</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>V/18/44</td>
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<td>80.0</td>
<td>10</td>
<td>20.0</td>
<td>0</td>
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</table>
Figure 12. Changes in the character of the margin of the otolith. The percentage of the total showing summer margins is read up from the bottom on the left-hand margin. Those showing winter margins are read down from the top on the right-hand margin. The heavy black areas indicate that portion of the total which could not be satisfactorily determined.
nature of the zones of growth. From Table V and Fig. 12 it can be seen that the formation of the summer ring begins in April, that of the winter ring in August and September. Characteristic otoliths, taken at various times of year and illustrating the typical corresponding growth zones, are shown in Fig. 11.

Having established the annual nature of the formation of the growth zones, as well as the fact that most of the sculpins form the same type of zone at about the same time of year, only the relationship between otolith length and fish length remained to be determined.

The relationship between otolith length and fish length was determined for each sex separately. These relationships are nearly linear. In a great many studies of growth rates of fishes, linear relationships have been used with satisfactory results. However, a parabolic relationship gave a significantly better fit here and was used in all computations.

**Growth Rates.** According to the method just described, the relationships between total length of otolith and total length of fish were

$$
\log L_f = 0.619 + 0.884 \log L_0, \text{ or } \\
L_f = 4.16 L_0^{0.884}, \\
\log L_f = 0.609 + 0.903 \log L_0, \text{ or } \\
L_f = 4.06 L_0^{0.903},
$$

where $L_f =$ total length of fish in centimeters and $L_0 =$ total length of otolith in scale units. From these equations the probable length of a fish at a given age may readily be computed.

The figures presented in Table VI are the average lengths at the end of the indicated years. The average $L_0$'s were determined from all otoliths showing the corresponding annual rings. Thus, of the 500 otoliths, all showed one or more annuli and could be used for the calcul-

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>No. of observations</th>
<th>Average $L_a$</th>
<th>Calculated $L_f$</th>
<th>Observed $L_{av}$</th>
<th>No. of observed $L_f$'s</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>1.61</td>
<td>5.6 cm</td>
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<tr>
<td>2</td>
<td>496</td>
<td>5.51</td>
<td>18.2</td>
<td>17.1</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>467</td>
<td>7.40</td>
<td>24.3</td>
<td>25.4</td>
<td>119</td>
</tr>
<tr>
<td>4</td>
<td>315</td>
<td>8.01</td>
<td>26.3</td>
<td>26.5</td>
<td>90</td>
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<td>5</td>
<td>196</td>
<td>8.34</td>
<td>27.4</td>
<td>27.6</td>
<td>75</td>
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<tr>
<td>6</td>
<td>89</td>
<td>8.72</td>
<td>28.6</td>
<td>29.1</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>34</td>
<td>8.91</td>
<td>29.2</td>
<td>31.0</td>
<td>4</td>
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<td>18</td>
<td>9.20</td>
<td>30.2</td>
<td>30.9</td>
<td>14</td>
</tr>
</tbody>
</table>

TABLE VI. Observed and Calculated Total Lengths at Different Ages
lation of $L_f$ at the end of the first year; 496 showed two or more annuli and could be used to calculate $L_f$ at the end of the second year; 467 had three or more annuli, and so on. The observed $L_f$'s were determined from direct measurements on fish collected in 1943 and 1944 during that part of the year when the annulus is formed—that is, April and May.

The agreement between the two sets of lengths is quite good. Apparently some of the three-year-old fish were from a rather fast growing group (p. 52), since the observed average length of three-year-olds is 1.1 cm greater than the calculated length. The older groups, too, appear to have grown somewhat faster than the average, but the difference may be due to the small number of direct measurements.

From Table VI it is seen that at the end of the first year of life (in early April) the longhorn is about 5.5 cm long; at two years, about 18 cm; at three years, a little over 21 cm, etc. From about the beginning of postlarval development to the end of the first year the length increases between six and nine times.\(^7\) During the second year the increase in length is about three times, and during the third year, about one third. Thus, the greatest proportional growth takes place in the first year ($+6\times$), while the greatest actual growth occurs during the second year (12.6 cm).

From these data the growth rates may be determined. Fig. 13 is a graphic representation of the growth rates of males and females by year-classes. The origin of each growth line is to be considered as January first of the indicated year. Point 1 represents May 1 of the following year, point 1.5, September 1; point 2, May 1 of the next year, and so on, the periods corresponding approximately to the periods represented by the summer and winter growth zones.

The most striking feature brought out by Fig. 13 is the fact that by far the greater part of the year's growth occurs between May and August. This is especially true in the first three years. Because of the difficulty of reading the central portion of the otolith, it is not possible to say anything about the division of growth in the first year. However, otolith number 1306 (Figs. 11A and 11C), which was ground on the lateral side, suggests that growth during the first year follows the same pattern as that in the next two years. In the second and third years growth occurs as follows: In the second year the

\(^7\) A few post-larvae, tentatively identified as *M. octodecimspinosus*, taken in plankton tows in February and April 1944 and March 1945, were between 0.7 and 1.0 cm long.
Figure 13. Growth rates in *Myoxocephalus octodecimspinosus*. The heavy lines show the growth of each year-class and are alternately solid and broken for easier distinction. The light lines connect points of equal age, as indicated on the right-hand margin.
average total increase in length is 12.6 cm. Of this, 11.4 cm, or 90.5%, occurs between May and August, while only 1.2 cm, or 9.5%, takes place during the winter. In the third year, the total increase in length is 6.1 cm, with 5.4 cm (88.5%) occurring in the summer and 0.7 cm (11.5%) in the winter. In subsequent years there is a levelling off of the difference between summer and winter growth (Fig. 13), although the summer growth always continues to be somewhat greater than that of the winter. This falling off of growth subsequent to the third year is probably due to two factors. First, the onset of sexual maturity in the third year (p. 34) with its accompanying diversion of nutriment from body growth to the formation of gonadal tissue would tend to retard increase in length. Second, and probably more important, there is the natural and expected slowing of linear growth with increased size.

Another point brought out by Fig. 13 is the fact that the females tend to be slightly longer than the males. Note also (p. 25) that the females are generally heavier than males of the same length. In the year-classes of 1935, 1936, and 1937, the males were larger than the females during the first two years of life, but in the third year, the females overtook the males and thereafter maintained a larger size. It is possible that this, as well as the apparent over-reaching of the 1935 year-class by the 1936 year-class, may be due in part to the small number of individuals involved in the computations. However, such phenomena are by no means unknown in fishes, and they should not be entirely discounted here.

### Age Composition of the Population

Inasmuch as otolith samples were taken only during the course of a single year and were not random samples of the population, it is not possible to draw from them any definite conclusions regarding the age composition of the sculpin population. However, according to Table VII, the majority of the longhorn sculpins in these samples (and probably in that part of the population caught by commercial gear)

<table>
<thead>
<tr>
<th>Age-Group</th>
<th>Per cent</th>
<th>Age-Group</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1+</td>
<td>1.8</td>
<td>6+</td>
<td>4.3</td>
</tr>
<tr>
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<td>22.8</td>
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<td>29.7</td>
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</tr>
<tr>
<td>6+</td>
<td>4.3</td>
<td>11+</td>
<td>0.2</td>
</tr>
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</table>

**TABLE VII. Age Composition of the Otolith Samples of *M. octodecimspinosus***
are between two and five years old. A comparison of the average lengths at various ages (Table VI) with the annual length-frequency curves shown in Fig. 14 will also permit a few estimates and generali-

Figure 14. Annual length-frequency curves. These curves represent the total catch for the indicated years. A. 1943–1944. B. 1944–1945. C. 1945–1946.
ties, but it must be emphasized that these are subject to a number of limitations.

Obviously, any attempt to interpret unimodal length-frequency curves in terms of age-groups must be extremely cautious (p. 37). Too many disturbing factors are present to permit definite statements. The fact that a length-frequency curve known to be composed of a number of age-groups is unimodal suggests in itself that the spread about the modes of the components exceeds the differences between these modes and prohibits simple, accurate interpretation. The possible masking of numerically small groups by a large one also militates against the accurate interpretation of length in terms of age.

The living, growing organism itself introduces complexities in that all individuals or groups of individuals do not grow at the same rate. Thus, the calculated average length of three-year-old sculpins is 24.3 cm, but fish of the 1940 year-class, measured at three years of age, averaged 25.4 cm, indicating that they had grown faster than the average.

Since the selectivity of the collecting gear limits the application of deductions to that part of the population which is caught, it is imperative that significant changes in gear be avoided. In the present study, some unavoidable variations of mesh size existed, and on several occasions the net was ballooned. Collections made with experimental nets of one inch mesh did not differ appreciably from collections made on the same day in the same area with standard 3½" to 4" mesh cod ends. Hence, changes in mesh size have probably had no significant effect upon the annual length-frequency distributions. The effects of ballooning the net have already been mentioned (p. 10).

In the light of the limitations just considered, the interpretation of the age composition of the sculpin population is set forth on a most tentative basis. Fig. 14 shows that the modal length of sculpins taken in the sample catches shifted from slightly more than 26 cm in 1943–1944 to about 28 cm in each of the two subsequent years. This may be accounted for in several ways. The most plausible explanation lies in the assumption of the presence of one or more highly successful year-classes. Reference to Table VI and Fig. 14 indicates that the population in 1943–1944 was probably composed largely of three- and four-year-old animals, representing the year-classes of 1939 and 1940. In both subsequent years, fish of a length corresponding to an age of five or six years were most numerous. It is not improb-
able, then, that the 1940 year-class contributed a large share to the modes of 1944–1945 and 1945–1946, as well as to that of 1943–1944. The curves are thus amenable to the assumption that there were strong and numerous groups in 1939 and 1940 which dominated the population for two successive years; these were followed by two or possibly three much less numerous year-classes. It should be noted that the same effect would be produced if the year-classes of 1941 and 1942 grew much faster than the normal rate. However, the assumption of the existence of more numerous year-classes in 1939 and 1940 seems a more likely explanation.

Obviously, the data presented here include at least one atypical year. On the basis of a three-year survey it is not possible to state whether any particular year or years represent abnormal populations. In general, however, it appears most probable that the catchable portion of the longhorn sculpin population is made up chiefly of individuals between two and five years old.

**Fluctuations in Abundance**

Demersal fishes, such as the longhorn sculpin, are neither evenly distributed over the bottom nor schooled into compact groups. Rather, they tend to be present in loose aggregations. For this reason, a difference of only a few hundred yards in a fishing locality may make a great difference in the abundance of any one species in the catch. Hence, a sample which is typical for one locality may bear but little resemblance to a typical catch from another locality that is only a relatively short distance from it in the same general area. Thus, since short term variations of a few days or weeks may be caused by such variations in locality, they are probably of little importance in reaching estimates of over-all abundance. It is necessary to confine our attention to those long term changes which cover periods of months or years. It is possible that such a change may have occurred in the sculpin population between 1943 and 1946. This was suggested by Merriman and Warfel (1948) in their survey of the Connecticut trawl fishery. These authors observed that the abundance of winter flounders and sculpins decreased as that of the little skate increased. They suggested that either there was competition between the sculpin, winter flounder and little skate, or that the patterns of their life histories and movements were such as to produce an inverse correlation between the abundance of the little skate and of the sculpin and winter flounder.
In the present study, a measure of abundance was obtained by considering a one-hour haul of standard gear (p. 8) as one unit of effort. Hauls longer or shorter than one hour were pro-rated to this standard, and the catch-per-unit-of-effort and the total catch were computed on this basis. The data presented here do not coincide exactly with those of Merriman and Warfel, since the period covered is not quite the same, nor is it divided in precisely the same manner. Even so, the apparent declines in abundance are almost identical.

Examination of the data on total catch and catch-per-unit-of-effort shows that the total catch decreased from 4,351 fish in 1943–1944 to 1,610 fish in 1945–1946, and the catch-per-unit dropped from 484 to 179. At first glance this seems to show a radical change in the abundance of the sculpin, for the figures are in the ratio of $2.7 : 1$, representing a decline of 63%. However, the variation between monthly samples is so great and the number of samples taken each year so few that even a change of this magnitude is of no statistical significance. When the mean catch-per-unit-of-effort for 1943–1944 is compared statistically with that for 1945–1946 it is found that $t = 1.142$ and $P = 0.25$. That is, on the basis of pure chance alone, a difference as great as this would be expected in one out of every four such comparisons. If the data be refined and compared only on the basis of collections made in the same months, it is found that $t = 0.5$ and $P = 0.6$. Hence, there is no real difference in the catch-per-unit-of-effort between the 1943–1944 and the 1945–1946 collections. The seasonal fluctuations in abundance introduce such wide variations about the mean that sampling errors result in large differences in the catchability data and in high values of $P$. It is not justifiable, therefore, to ascribe the apparent decline in abundance to anything other than sampling errors.

**SEASONAL MOVEMENTS AND MIGRATIONS**

Throughout its range from New Jersey to Nova Scotia the longhorn sculpin is considered a resident species, undertaking no considerable migrations north or south along the coast. However, its abundance varies from time to time throughout the year, apparently as a result of more or less definite onshore and offshore movements (Baird, 1855; H. M. Smith, 1898; Nichols, 1918; Breder, 1929). These movements, never subjected to direct study, have been deduced from more or less casual observations of the longhorn’s abundance in field collections made for other purposes.
On the southern New England Coast the longhorn is most abundant in the fall and winter and rather scarce in the summer. By contrast, in the Bay of Fundy it is most abundant in the summer (Huntsman, 1922; Bigelow and Welsh, 1925). The latter authors have suggested that its variations in abundance are related to temperature. They state,

In the estuaries of the Bay of Fundy, however, where the summer temperature of the shoal water is lower than in similar locations in other parts of the Gulf, longhorn sculpins are most plentiful during the warm months and almost all of them move out into the open bay to pass the winter. Along the southern shores of New England, where the coastal waters are much warmer in summer than in most parts of the Gulf of Maine, this sculpin is abundant in autumn and winter, but rarely taken in very shoal water in summer.

These migrations are probably induced by temperature and they are sufficient evidence that this species avoids both the warmest and coldest water—that is, temperatures higher than 55° to 60° and lower than 35°.

The conclusions regarding migrations that have been reached in the present study have been based chiefly upon personal observations in the field and on the relative abundance of sculpins in the monthly hauls. Tagging experiments were carried out also, but they yielded far less information than the two other sources.

Observations and collections in Long Island Sound were made chiefly off Point Herod and Port Jefferson on the Long Island shore and in the vicinity of New Haven on the Connecticut side. Additional observations were made off Clinton, Connecticut and in the neighborhood of Faulkner’s Island. The majority of work in the Block Island Sound area was done in the Sound itself, but the area covered extended from Hatchett Reef on the west nearly to Point Judith on the east, and as far south as the Mussel Bed, an area about 15 miles SSE of Point Judith (see Fig. 2).

Examination of the hauls made within Block Island Sound and calculation of the catch-per-unit-of-effort for each haul (Table VIII) show that the longhorn is most abundant between October and April. During the spring season its numbers in the fishing area decline to the point where an hour’s drag in midsummer will produce fewer than a dozen longhorns. Observations of catches and collections made on commercial boats throughout the area and in Long Island Sound indicate that similar cycles of abundance occur in these areas as well. In Long Island Sound, however, the longhorn is never as abundant as it is further to the east.
TABLE VIII. AVERAGE CATCH-PER-UNIT-OF-EFFORT BY MONTHS IN BLOCK ISLAND SOUND. THESE DATA ARE FROM CATCHES MADE WITHIN THE SOUND ITSELF AND DO NOT INCLUDE CATCHES MADE IN PERIPHERAL AREAS SUCH AS THE MUSSELT BED, FISHER’S ISLAND SOUND, ETC.

<table>
<thead>
<tr>
<th>Month</th>
<th>No. of samples</th>
<th>Av. catch-per-unit-of-effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>3</td>
<td>158</td>
</tr>
<tr>
<td>June</td>
<td>2</td>
<td>77</td>
</tr>
<tr>
<td>July</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>September</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>October</td>
<td>2</td>
<td>121</td>
</tr>
<tr>
<td>November</td>
<td>3</td>
<td>344</td>
</tr>
<tr>
<td>December</td>
<td>2</td>
<td>323</td>
</tr>
<tr>
<td>January</td>
<td>2</td>
<td>169</td>
</tr>
<tr>
<td>February</td>
<td>3</td>
<td>361</td>
</tr>
<tr>
<td>March</td>
<td>2</td>
<td>203</td>
</tr>
<tr>
<td>April</td>
<td>3</td>
<td>419</td>
</tr>
</tbody>
</table>

From these sources it is possible to draw the following conclusions. A general movement off the fishing grounds takes place in the late spring, becoming apparent in May and June. It is most probable that this movement is offshore, but it is not possible to preclude completely the contingency that the sculpins move into relatively nearby areas of rocky bottom where trawl nets cannot sample them. Such a movement has been indicated, for example, in the ocean pout (Olsen and Merriman, 1946). However, the fact that “trash” fishermen (p. 66), working nearly every fishable inshore area, have not caught sculpins in the summer time supports the thesis that there is actually a definite offshore movement. The return journey of the sculpins probably begins in the latter part of August or September, but the main movement does not appear off Block Island until the latter part of October. Thereafter and throughout the winter, movement appears to be more or less random with no particular trend in any direction.

In Long Island Sound, the picture is much less clear. The longhorn is much less abundant here than further to the east and commercial fishing is far less intensive. There appears to be a rather rapid movement of fish to the west in the early spring, followed immediately by an eastward migration. A number of commercial fishermen have independently expressed the opinion that this movement is more or less clockwise in its course. The fish are said to move westward from Block Island Sound as far as the mouth of the Connecticut River, south to the Long Island shore, then westward again. Somewhere west of Port Jefferson, L. I., the fish are said to turn north, and on reaching the Connecticut Coast move eastward again and leave the
Sound. This may be true, but Long Island Sound is so poorly covered by the fishing vessels that it is impossible to rule out the supposition that the fish are merely moving into nonfished areas.

There is strong evidence that males and females do not migrate synchronously. This is to be found in the sex ratios existing in the samples (Table IX). Although the average sex ratio for a whole year is 1 : 1, there is a marked tendency for males to dominate the catch in

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of samples</th>
<th>Percentage of:</th>
<th>Month</th>
<th>Number of samples</th>
<th>Percentage of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Males</td>
<td>Females</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>4</td>
<td>65.9</td>
<td>34.1</td>
<td>Dec.</td>
<td>2</td>
</tr>
<tr>
<td>July</td>
<td>2</td>
<td>78.6</td>
<td>21.4</td>
<td>Jan.</td>
<td>2</td>
</tr>
<tr>
<td>Aug.</td>
<td>2</td>
<td>54.0</td>
<td>46.0</td>
<td>Feb.</td>
<td>3</td>
</tr>
<tr>
<td>Sept.</td>
<td>1</td>
<td>52.0</td>
<td>48.0</td>
<td>Mar.</td>
<td>3</td>
</tr>
<tr>
<td>Oct.</td>
<td>3</td>
<td>57.5</td>
<td>42.5</td>
<td>Apr.</td>
<td>5</td>
</tr>
<tr>
<td>Nov.</td>
<td>3</td>
<td>53.1</td>
<td>46.9</td>
<td>May</td>
<td>3</td>
</tr>
</tbody>
</table>

the spring and summer. In the middle of winter, however, the females outnumber the males by about four to one. Since this period is also the spawning season, it follows that the longhorn is polygamous.

A large part of the field work in the study of the longhorn’s movements consisted in marking and releasing the fish in the hope that the marked individuals would be recaptured and the tags returned to the laboratory. This work was carried on in the spring of 1944 and between September 1946 and June 1947. In these experiments, fish were marked with celluloid disc tags furnished by the Connecticut State Board of Fisheries and Game. This type of tag has been described in detail by Merriman (1941). Briefly, a tag consisted of two celluloid discs, each 0.5 inch in diameter and pierced by a hole in the center. One disc of each pair was printed with directions for returning the tags, the other was numbered. In use, the numbered disc was placed on a nickel pin which was inserted through the flesh near the round of the dorsum. The other disc was then placed on the projecting end of the pin, which was crimped over with a pair of pliers (Morrow, 1947).

Although a reasonably large number of fish were marked in this manner, the return of the tags was disappointingly low. From the total of 4,057 fish marked, only 32 tags, or 0.79%, were returned. Five of these were taken by anglers, the remainder by commercial fishermen or by laboratory members on commercial vessels. Several
factors probably combined to produce such poor returns. First, and by far the most important, was the manner in which sculpins were handled on commercial boats. After the salable fish had been picked out, the trash, including the sculpins, was literally shoveled overboard. Under such conditions, a tagged fish was not likely to be noticed. Undoubtedly the lack of a reward for the return of tags and the lack of publicity for the program outside the Stonington fleet were contributing factors also. Rounsefell and Kask (1945) have emphasized the importance of rewards and publicity in securing good returns, but these factors do not appear to have been as important in the present work as the method of handling. Similar tagging experiments by E. F. Thompson (unpublished) on the winter flounder, a salable fish that is sorted carefully, have yielded much higher returns.

Since the returns of tags were so few, it has not been possible to derive firm support either for or against the existence of a migration pattern. It can only be said that the tag returns do not contradict the hypothesis of an onshore-offshore type of movement suggested by the field observations.

It is difficult to correlate these movements with temperature. The statement by Bigelow and Welsh (1925) that the migrations “are sufficient evidence that this species avoids both the warmest and coldest water—that is, temperatures higher than 55° to 60° and lower than 35°,” does not appear to be correct. In October, when the main onshore migration begins, the bottom temperature in Block Island Sound is between 14 and 15°C (57.2 and 59°F). This is less than 1°C below the yearly maximum reached in August and September (Merriman and Warfel, 1948). The lowest temperature, about 2°C (35.6°F), is reached in February, when the longhorn is abundant. Thus, if it tends to avoid temperatures above 60°F and below 35°F, the temperature limits must be quite sharp. If temperature is the controlling factor, it is also difficult to understand the great scarcity of sculpins in July. The average bottom temperature at this time is slightly lower than in October, when the longhorn is plentiful. In Long Island Sound, the majority of sculpins have disappeared by the end of May, when the temperature is about 10°C (Galtsoff and Loosanoff, 1939) but are most numerous in April when the temperature is between 8 and 9°C (Riley, 1948).

Temperature, then, is evidently not the controlling factor in the longhorn's migrations. It may be a contributing factor, however, for
the eastward offshore movement is more or less coincidental with rising temperature, while the westward onshore migration closely follows the beginning of fall cooling. It is quite possible that the seasonal movements of this fish represent the expression of some cycle of endocrine activity as suggested by Fontaine (1948).

FEEDING HABITS

The food habits of the longhorn have received but scant attention in the past, although the few ichthyologists who have anything to say on the subject are in thorough agreement. Thus Perley (1852) says that the longhorn is "exceedingly voracious"; Nichols and Breder (1927), "omnivorous carnivore"; Breder (1929), "omnivorous, with fish and crustaceans constituting most of its food." Bigelow and Welsh (1925) report that it feeds "chiefly on shrimp, crabs, and mussels, also on hydroids, annelids, amphipods, sundry mollusks, ascideans, squids," as well as 15 species of fishes. Except in such works as these, there is little information on the longhorn's food habits and nothing at all of a quantitative nature.

In the present work, stomach contents were available from the regular collections between April 22, 1943 and June 23, 1944, a representative sample from each catch having been set aside for detailed study. Each sample was preserved in 10% formalin. The samples thus obtained averaged about half a pint in volume, so it was possible to analyze each one completely. The technique of analysis was essentially the same as that described in detail by Olsen and Merriman (1946).

In the examination of stomach contents, the formalin was poured off carefully into a jar and the sample then placed in a flat glass tray. By adding water, shaking gently and pouring off the water and floating particles, a major separation into light and heavy fractions was accomplished. Two or three such washings were usually sufficient to render the sample quite clean and free of debris. Large floating particles (amphipods, etc.) were restored to the heavy fraction before continuing with the examination. The light fraction of the first three samples was examined under a binocular microscope, but since this light fraction proved to be almost entirely digested amorphous material, microscopic examination was discontinued.

The heavy fraction was first sorted without the aid of magnification; items which could readily be separated were placed in separate dishes,
but small objects which were not recognized with the naked eye were examined under a microscope. In this way it was possible to make a complete resolution of the heavy fraction. Where possible, identification was coincident with sorting. Otherwise, all similar items were placed together and identified after the sample had been completely sorted.

After identification had been completed as far as possible, the various parts of the sample were measured by displacement of water in a graduated cylinder and the volumes compared. The light fraction was allowed to stand for an hour in a graduated cylinder, and its volume was read directly from the scale. Of course, this method included the volume of water between the particles, so the percentage volume of this fraction was greater than its true value. However, comparison of these percentages with values obtained for other fish by other methods suggests that this error is not large.

The analyses of 15 samples of stomach contents are summarized in Appendix Table B. The stomach contents of more than 550 fish, representing collections made in each month of the year, were included.

It will be noted that the dominant food items were the crab *Cancer irroratus* and the amphipod *Leptocheirus pinguis*. The former was present in every sample in varying amounts. Thus, in the second collection of November 21, 1943 *Cancer* was present in insignificant numbers (+), while on June 23, 1944 it formed 86% of the total food. The amphipod was present in all but two of the samples, composing as much as 68% of the total. No seasonal preference was shown for these two animals; they were eaten the year around. Similarly, the shrimp, *Crago septemspinosus*, was almost universally present, although in small amounts. This was not true, however, for the spider crab, *Libinia emarginata*, which was eaten by the longhorn almost exclusively in the fall and winter, at which time it formed a considerable portion of the diet. Fishes were present only intermittently, but a good variety of species was represented. The rock eel, *Pholis gunnelis*, was found in two samples. This fish is usually considered to be confined to the shallowest water near shore, but the samples containing it were taken at depths of 15 to 20 fathoms, indicating that it is also present in deeper water.

It was particularly interesting to find small lobsters, *Homarus americanus*, in the stomachs on four occasions, since lobsters of this size are taken so rarely anywhere. Two of these samples were taken
two or three miles off Watch Hill, R. I.; a third came from the region about four miles south of Charlestown Inlet, R. I.; and the fourth, that of February 29, 1944, came from an area eight miles south of Block Island. This distribution suggests that small lobsters may occur more generally around Block Island Sound than was formerly thought (Herrick, 1911).

An over-all inspection of the results of the stomach content analyses clearly indicates the wide variety of organisms that serve as food for the longhorn sculpin. Coelenterates were eaten rarely and in such small amounts that they appear likely to have been ingested accidentally with other food. Annelids were frequently present, represented most often by two unidentified polychaetes; one of these was probably a species of *Lumbriconereis*, but certain identification was not possible. Crustacea formed the vast majority of the articles of diet in every sample, with decapods and amphipods dominating. Isopods, mysids, and cumaceans were eaten only rarely. Mollusks made up only an insignificant portion of the stomach contents. They were eaten infrequently and never in large amounts. Echinoderms were found but twice. Like the coelenterates, mollusks and echinoderms may have been ingested accidentally. Fishes occurred chiefly during the winter and spring, but when present they usually constituted a fairly large per cent of the total. Fish eggs, both its own and those of the closely related *Hemitripterus americanus*, were found in two samples. Additional items of food, found in other samples, included the stomatopod, *Chloridella empusa*, and two more species of fishes, *Syngnathus peckianus* and small *M. octodecimspinosus*. Thus, the longhorn is not averse to cannibalism if the occasion arises or to eating its own eggs.

Appendix Table B gives a clear indication of the demersal nature of this sculpin’s feeding habits. All of the animals eaten are bottom-dwelling organisms. In addition, stones and sand were present in most of the samples. Since the stones were generally absent in the winter time when fishes were most abundant in the stomachs, this may indicate a change in feeding habits. It suggests that the longhorn feeds directly at the bottom in summer and fall, occasionally picking up stones as it does so, whereas in winter the presence of fishes and the absence of stones suggest that it is then feeding slightly above the bottom. There also appears to be a slight tendency for mollusks to be eaten less frequently in the winter, leading toward the same conclusion.
Although the longhorn sculpin exhibits a preference for crustacean food, and for two particular species within this group, it is also apparent that it will eat almost anything. The present analysis has shown the presence of at least 47 different species of organisms in the stomach contents. The longhorn, then, is rightly to be considered an omnivorous carnivore to whom nothing comes amiss.

DISCUSSION

Utilization of Trash Fish

At the present time the longhorn sculpin represents but one of the numerous items in the vast category known to the fishing industry as “trash” fish. This group includes all those fishes which are normally taken but which, for one reason or another, are not marketed for food. Yet many of these fishes are as good as any on the market. On this point, Merriman (1944) has written:

As many scientists and fishermen know, not only are there abundant sources of food in the sea which are little if at all harvested but in some localities a high proportion of the edible catch is discarded either because prejudice or lack of familiarity has prevented an established market for it or because adequate attempts to solve the technical and economic problems of saving it have not been made. Sometimes well over three-quarters of the fish taken by commercial vessels are thrown back as “trash,” much of it dead by the time it is returned to the sea. Yet many of these unmarketed species are not only fit for human consumption but are just as good as those which are normally marketed—if not better. During the past year in this country, there has been an increased tendency towards fuller utilization of this material. But the waste, from the standpoint of both diet and economics, is still appalling, and it is perfectly obvious that by saving the “trash,” the productivity of our fisheries can be greatly expanded without corresponding increases in fishing operations. Much easily available and potentially valuable sea food remains to be used, not only in our own waters but to a varying extent all over the world.

The problem of the utilization of these trash species is one which has occupied the interest and energies of the Bingham Laboratory for a number of years, the need for more and more fisheries products during the war years having stimulated these efforts. Quoting again from Merriman (1944),

Recently it seemed obvious that the laboratory could contribute most to the national effort by turning its energies more directly to the solution of problems of practical application. The field on which attention is being centered comes under the broad heading of the use of marine resources—a line of endeavor which needs little justification in times when our food resources demand the
most critical appraisal. In a relatively short period, the program has been broadened to include a variety of investigations. The solution of some of these problems is of immediate importance; the answer to others should be of significance from a long range point of view. . .

Investigations on a variety of fishes have also been undertaken with the ultimate aim of providing fresh information as to their rational utilization. This work is concerned with those which are already a part of our food supply as well as those which are not at the present marketed but which are available for exploitation.

The study of the longhorn sculpin, then, was begun in 1943 as an investigation of one of the fishes "which are not at the present marketed but which are available for exploitation." The reasons why the longhorn falls into this category will be obvious to anyone familiar with the fish. Although the flesh is of excellent quality and flavor, the edible portion represents only about a quarter of the total body weight. Since the average weight of the longhorn is about half a pound, this results in a yield of about two ounces of edible flesh per fish. When the great difficulties of handling this fish are also considered, marketing this fish as fillets would not appear to be feasible. To yield an adequate return to the fisherman, the retail price would have to be prohibitively high. Marketing in the round would be more practical, but here the rather repulsive appearance of the sculpin (Fig. 1) would certainly militate against its success.

However, there are other possible uses for such an abundant trash fish, particularly in the preparation of stock feeds, fish meals, fertilizers, etc. Undoubtedly it has been used occasionally in the past as fertilizer by local farmers, but within the past two years utilization has begun on a large scale. All along the southern New England Coast, trash fish of all species have been landed and turned into usable products in quantities that are little short of amazing. In New Bedford, Mass. alone, landings of trash fish from April 1 to December 31, 1949 totalled 44,214,000 pounds, averaging nearly five million pounds per month. In Point Judith, R. I. and Stonington, Conn., the two ports which receive the majority of fish taken in Block Island Sound, landings of trash fish for the same period came to 12,934,000 pounds, averaging 1,437,000 pounds per month. From January 1 through April 30, 1950 the trash fish landings at these two ports amounted to 7,783,100 pounds, or 1,945,775 pounds per month. At Stonington, the landings for the 13 months for which data are available averaged 588,000 pounds per month, while at Point Judith the figure was
1,005,600 pounds. The Stonington landings of trash fish have been about twice as great as the flounder landings.

THE SOUTHERN NEW ENGLAND TRASH FISHERY

The southern New England trash fishery began in the latter part of 1948. To some extent this appears to have been a response to the failure of the California pilchard fishery, one of the mainstays of the fish meal industry. In the peak production years from 1936 to 1945, that fishery produced an average of 535,000 tons of fish per year, representing 88.7% of the total Pacific Coast pilchard catch. In addition to pilchard oil and canned sardines, the California pilchard fishery yielded, during the same years, an average of 75,000 tons of pilchard meal per year, representing 79.6% of the fish meal produced in California and 55.8% of the fish meal produced on the Pacific Coast (including British Columbia and Alaska) from all sources. Pilchard meal accounted for more than half of the total U. S. production of fish meal during this period (Fiedler, 1938, 1940, 1941, 1942, 1943, 1945; Anderson and Power, 1946, 1947, 1948, 1949). However, in the poor seasons of 1946–1947 and 1947–1948, production of pilchard meal dropped to 31,182 and 13,555 tons respectively. The latter figure is only 18.1% of the earlier average. In the 1948–1949 season, the catch of pilchard improved considerably, but because of economic and conservation factors, a less-than-normal proportion of the catch went into fish meal. Thus, although 3,062,718 cases of sardines were packed in 1948–1949 as against 2,093,463 cases in 1946–1947, there were only 18,994 tons of meal produced in 1948–1949 compared with 31,182 tons in 1946–1947. Under these circumstances it was only natural that producers of fish meal should turn to other sources of raw material. On the west coast, tuna and mackerel were increasingly utilized for this purpose. On the east coast, the menhaden industry immediately increased its output of meal but did not entirely make up for the drastic loss in pilchard meal. Other items also, such as blue crab and king crab, were utilized to a greater extent than heretofore. In addition, from scraps and gurry of groundfish (cod, haddock, rosefish, and other demersal species) supplied by filleting plants

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and from trash or other fish that did not find a ready market, the production of meal increased from 21,780 tons in 1948 to 33,801 tons in 1949 (U. S. Fish and Wildlife Service, Current Fisheries Statistics No. 520, December, 1949). At the same time, landings of trash fish in southern New England rose from about 2,000 to about 42,000 tons.\(^10\) On an estimated production of one ton of meal from four tons of fish, the increase in trash fish landings could thus have accounted for more than 80% of the increase in the production of meal from groundfish.

However, not all of the trash fish is used for the production of meal. Another major utilization lies in the manufacture of canned fish for cat and dog food. In 1931, four plants packed 52,509 cases of fish pet food, or 2,520,432 pounds. In 1941, 11 plants packed 1,009,515 cases, or 48,456,720 pounds (Fiedler, 1933, 1945). During the war, rationing of containers effectually shut down this industry; in 1943, cat and dog food and 12 other items lumped together as "Miscellaneous fish" accounted for only 25,773 cases. Subsequently, fish pet food was not listed in the statistics of the fish canning industry published by the U. S. Fish and Wildlife Service (Anderson and Power, 1947, 1948, 1949, 1950). In 1947, however, the production of fish for canned animal food was 43,678,272 pounds, while in 1948 it was 63,542,784 pounds, ranking fourth by weight and ninth by value among the canned fish products of the United States and Alaska.\(^11\) This postwar resurgence of this industry has accounted for an undetermined portion of the trash fish landings. In the spring of 1949, approximately 600,000 pounds of trash fish went to canners of cat and dog food each month from Point Judith, R. I. At New Bedford, Mass., nearly all of the trash fish went to meal producers. At Stonington, Conn., the allocations varied widely from time to time. These two items, fish meal and canned animal food, account for such a vast majority of the southern New England trash landings that other uses, such as bait, raw animal food, etc., are insignificant by comparison.

In the early days of this fishery (late 1948), trash landings were more or less incidental to the normal operations of the inshore groundfisherman. That is, no special effort was made to catch trash species. What came up in the net was saved instead of being thrown back, and when a sufficient quantity had been accumulated, it was landed.


Within a short time, however, the demand for trash fish became so strong that many boats often went out primarily for the trash. To some extent, this development served to relieve fishing pressure on many of the regular fishing grounds. For example, before there was a market for trash fish, a fisherman finding few good fish and much trash in his net on the first haul of the day would move to other grounds until his catches showed a profitable percentage of good fish in each haul. By contrast, after the establishment of the trash market, the same man would often stay in the first area he tried, catching what good fish he could and relying on the trash to make up his day's pay. Thus, the pursuit of the good fish became less intensive. Furthermore, although some boats continued to operate on the usual grounds, other trash fishermen tended to go to areas where they would find the trash species in the greatest quantities, areas which were formerly avoided for this very reason. The latter practice appears to have been more common in the Point Judith fleet than at Stonington. Several price rises in 1949, which brought the price of trash to as high as $1.00 per 100 pounds, further encouraged trash fishing, and for a number of boats the good fish became entirely incidental to the trash.

Additional encouragement to trash fishing was found in the methods of marketing and handling. In general, the trash fish were sold while still in the boat. The labor and expense of packing and transporting the trash then fell upon the buyer instead of on the fisherman. By contrast, good fish are generally packed and iced on board as soon as they are caught, and the costs of packing and shipping, as well as dock fees, etc., are borne by the fisherman. Also, because of the greater availability of the trash fish, a boat could get a full load in a much shorter time and make more trips with less labor than was possible for good fish. Thus, operating expenses and the amount of work necessary were lower for trash than for good fish.

This situation continued until the latter part of April 1950. At that time, the price of trash fish suddenly dropped to about 50c per 100 pounds. This occurred throughout southern New England and was not confined to one or two ports. Although there has been no thorough investigation of the causes of the fluctuations in the price of trash fish, it seems probable that this drastic price cut resulted from a more-than-adequate supply of trash coupled with increased production of meal from other sources. Thus, in the first three months of 1950, production of groundfish meal had declined 18.8% from the production
figure for the same period in 1949. By contrast, menhaden meal had increased by 112%, pilchard by 212%, and tuna and mackerel by 51%, resulting in a net increase in fish meal production of 44%.\textsuperscript{12} These facts, coupled with the approaching menhaden season, may provide the explanation for the price reduction during April 1950. Similarly, increases in the price of trash fish in October and November 1949 coincided with the end of the menhaden season. Although these factors may not have affected the cat and dog food canneries, the fish meal industry accounted for the majority of the trash landings and probably influenced the price accordingly.

At the low price of 50c per 100 pounds, trash fishing was far less profitable than good fishing. Most boats therefore returned to good fishing, with the result that trash landings fell to almost nothing. Contributing to the decline was the fact that the dockside buyers and shippers could no longer operate profitably. Even at a price of $1.00 per 100 pounds, the margin of profit for these buyers was extremely small, and when the price was cut, a continuation of operations became financially impractical. Thus, the fall in the price of trash fish resulted is so little profit both to the fisherman and the buyer that it brought about a virtually complete cessation of trash fishing. This situation was expected to continue for some months to come.

However, the future of trash fishing is not entirely black. Although rendering and processing plants in or near New England which must transport their fish some distance are not buying trash (July 1950), plants located in or near the fishing ports apparently are continuing to operate on local trash fish. In July 1950 a plant was under construction at Point Judith, R. I. which was expected to absorb most of the trash landings at that port. In addition, plans are being made for the construction of new plants at other ports. The over-all picture appears to be one of only temporary suspension of trash fishing in the southern New England area. As the menhaden season wanes, the demand for trash fish may be expected to resume. This may be of significant socio-economic benefit to the inshore fisherman, for this presumed demand would come in the winter season when landings of the regularly marketed good fish are at a low level. It would thus serve to supplement the fisherman's income at the very time when it is most needed. With the completion of new trash processing facilities

in locations where the expense of transporting the fish will be at a minimum, it should be possible to maintain a fairly steady demand for trash fish in the areas serving these plants. However, with the pilchard fishery showing steady improvement on the west coast, it is possible that the southern New England trash fishery may not immediately reach its earlier magnitude.

**Possible Biological Effects of the Trash Fishery**

The question immediately arises as to the probable and possible effects of the trash fishery upon the stocks of various species of fishes in the area, and especially (from the standpoint of this paper) upon the sculpin population. The reliability of the answers to this question will depend to a great extent upon accurate knowledge of the life histories of the various species concerned and of the species composition of the trash landings. Complete detailed figures on the relative amounts of the various species of trash fish landed are not available. However, the monthly samples examined at the Bingham Laboratory (p. 8) and other samples and estimates made by us and by the U. S. Fish and Wildlife Service provide some rough estimates of the approximate composition of the trash landings. Thus, samples of trash examined by us at Stonington, Conn. in March and April of 1949 were made up chiefly of hake (*Urophycis tenuis*), with the ocean pout (*Macrozoarces americanus*) second in abundance; third place was occupied jointly by the little skate (*Raja erinacea*) and the longhorn sculpin (*Myoxocephalus octodecimspinosus*). Each of the last two species represented about 4 or 5% of the total. Two samples examined by the U. S. Fish and Wildlife Service in October 1949 (at New Bedford, Mass. and Point Judith, R. I.) contained, respectively, 9.2 and 0.9% of sculpins by weight. Other samples examined from time to time have contained up to 76% of sculpins by weight. In the complete hauls analyzed at the Bingham Laboratory, the sculpin has composed up to 65% by weight of the total trash species. From these data, it appears probable that the trash landings at Stonington and Point Judith have contained about 3,000,000 pounds of sculpins per year.

It is extremely difficult to estimate what portion of this total came from the region sampled in this study. In only a few isolated instances has it been possible to find out where a boatload of trash was caught.

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13 The word 'population' as used in this discussion means 'catchable population.'
Under these circumstances, apportioning the total catch according to the relative areas of the various regions appears to be the only means available. This, of course, assumes that fish are evenly distributed throughout the whole fishing area, which is known to be incorrect. It also assumes that fishing effort and efficiency are likewise evenly distributed, which again is probably incorrect. However, over large areas of reasonably similar conditions, such as are dealt with here, the relative concentrations of the various species will be similar. The little information we have been able to obtain with respect to the distribution of fishing effort indicates that, while differences do exist, they are so correlated with the seasonal distribution of the sculpin (p. 55) as to have little effect on these estimates. Hence, it is reasonable to assume that the landings are more or less proportional to the areas. By this method, then, Block Island Sound and vicinity (p. 8) probably supplied about 600,000 pounds of the total annual catch of sculpins.

The estimation of the total sculpin population of the area is another difficult point, but it is one which must be determined as accurately as possible before the question of the effects of the trash fishery can be approached. The available data allow two approaches. First, the weight of the sculpin population may be estimated on the basis of the relative weights of sculpins and flounders in the sample hauls. Over the three years in which sampling was carried out, the weight of the sculpin catch averaged 36.5% of the weight of the flounder catch in our samples. Applying this figure to the statistics of flounder landings in the same period, it can be calculated that the weight of the sculpin population was somewhere between 1,100,000 and 2,200,000 pounds, averaging 1,667,000 pounds per year. The second approach depends upon estimates of the productivity of the bottom in terms of pounds of fish per acre. These estimates are based on our samples and on logs of the catch by species which were kept by Captain Thompson of the Eleanor and by Captain McLaughlin of the Marise for over a year. These data show that the sea bottom in this region supports up to 80 pounds of sculpins per acre (one sample), but that upon occasion there may be no sculpins present at all (two samples). Having determined the area of the region as accurately as possible from large-scale charts, the estimates described above indicate a sculpin population of between 1,500,000 and 2,100,000 pounds per year. The average of all estimates made by both methods is 1,765,000 pounds of sculpins per year.
This is nearly three times the amount which the trash fishery was estimated to have removed from the same region.

To determine the effect of a certain degree of predation or fishing pressure upon a population, it is necessary to know something about natural mortality and survival. This information is not directly available for the longhorn sculpin, but again it is possible to make some fairly reasonable estimates from other data. However, it should be emphasized that conclusions based on estimates are limited in their validity to the reliability of the estimates themselves.

Before proceeding further, some of the terms and symbols to be used in subsequent discussion will be defined. Let

- \( a \) = total annual mortality rate, i.e., the fraction of the fish present at the beginning of a year which would die during the year from all causes.
- \( m \) = annual mortality rate from fishing, i.e., the fraction of the fish present at the beginning of a year which would die from fishing if there were no other causes of death.
- \( n \) = annual mortality rate from natural causes, i.e., the fraction of the fish present at the beginning of a year which would die from causes other than fishing.
- \( s \) = annual survival rate, i.e., the fraction of the fish present at the beginning of a year which will be present at the beginning of the next year.

Then \( a = m + n - mn \), and also, \( s = 1 - a \). Also, let

- \( r \) = annual rate of recruitment
- \( s_e \) = survival rate from egg to adult
- \( y \) = the number of eggs produced by one female
- \( z \) = percentage of females in the population
- \( X_0 \) = initial size of the population
- \( X_1, X_2, \ldots, X_n \) = size of the population after 1, 2, \ldots, \( n \) years.

Then \( r = (s_e)(y)(z) \), and the size of the population after \( n \) years will be shown by the equation \( X_n = (s + r)^n X_0 \). An estimate of the value of each of the terms defined above can be reached on the basis of existing data.

If the age distribution of the otolith samples, shown in Table VII, is treated as a catch curve (Baranov, 1918; Ricker, 1948), it appears that the natural annual mortality rate, \( n \), is about 0.6. Since the population remained relatively stable (p. 54) at a level \( X \), annual recruitment must then equal 0.6\( X \). That is, 0.6\( X \) new individuals enter the catchable population each year. Assuming further that recruitment is more or less constant throughout the year, with a sex ratio of 1 : 1 (p. 57), there will be \( X/2 \) females spawning each year. Since each
female produces about 8,000 eggs per year, there will thus be 4,000X eggs produced annually. Of these 4,000X eggs, 0.6X must survive to adulthood if the condition of a stable population is to be maintained. This gives a survival rate from egg to adult, \( s_e \), of 0.00015. Since there was no fishing mortality at the time the samples were taken, total annual mortality rate, \( a = \text{natural annual mortality rate} \), \( n = 0.6 \).

With the inception of the trash fishery, however, total and natural annual mortality rates were no longer equal, for an annual mortality rate from fishing, equal to 0.34, had been added (see data, p. 69). From the relationship given previously, the new total annual mortality rate is found to be 0.736, whence \( s = 0.264 \). Assuming that the mortality rates remained at this level and that the survival rate from egg to adult, \( s_e \), did not change, it is now possible to estimate the changes in the population which might be produced as a result of fishing activities. Substituting the various values derived above in the equation \( X_n = (s + r)^n X_0 \), it is found that if the values deduced are reasonably correct, and if the conditions represented by these values do not change, and if no unassessed factors are operating, then the population of the longhorn sculpin in Block Island Sound may be expected to be reduced by continued fishing to 48% of its original level in five years and to 23% in ten years.

It is probable, however, that the actual reduction of the sculpin population will not be as large as the figures given above, which do not take into consideration the effects of inter- and intraspecific competition. Since other trash species, presumably competing for existence with the sculpin, are also being reduced by the fishery, it is reasonable to suppose that interspecific competition may be changed more or less in accordance with the relative catches of the various trash species. Catches of other species relatively greater than those of the sculpin would tend to swing the competitive balance in favor of the sculpin, improving its opportunities for survival and growth, thus minimizing the deleterious effect of the fishery upon the sculpin. Relatively greater catches of sculpins, on the other hand, would tend to have the opposite effect, for the competition would then tend to become more severe. Without further data it is not possible to assess the value of this point or to estimate its effect.

However, a little more can be said about the effects of intraspecific competition. Since an unexploited population is usually a mature
population, dominated by mature animals, the survival of the young is dependent at least in part upon the population pressure. Indeed, in many cases, intraspecific competition appears to be one of the major factors limiting population growth. When the adults are removed, this competition becomes less severe, that is, more food, etc. is available to the younger animals. Reduction in the number of adults, then, would tend to produce an increased rate of survival from egg to adult \((s_e)\). This in turn would tend to increase the rate of recruitment, \(r\), and hence retard the decline in the population caused by fishing. In addition, when reduced intraspecific competition releases more food, etc. to the remaining animals, their growth rate usually increases. This is especially true of fishes. There are even some instances on record wherein, under conditions of optimum fishing pressure, yield has actually increased due to more rapid growth (Swingle and Smith, 1943).

It is obvious, then, that the equation presented on page 70 does not take into consideration all of the factors affecting a population. Un-assessed factors have just been described which would tend to offset to some extent the predicted decline in the sculpin population.

Generalizing from the foregoing discussion, it is to be expected that the stocks of all trash fish would undergo declines of varying magnitude with continued fishing operations. But what effect might the trash fishery have upon those species which are already being exploited? A brief consideration of the demersal environment and its fishery should give some indications.

It is a well known principal of fisheries biology that a given body of water under relatively constant conditions can support only a certain poundage of fish-flesh (Boccius, 1841). This poundage may be all of one species or it may be distributed among several different species, but in either case, assuming full utilization of the environment, the total weight will be about the same. Removal of one species by some sort of selective agency such as fishing will thus allow the other species to increase. This increase will have a fairly direct relationship to the proportion of the environment made available by the removal of the first species. This is the situation that has prevailed in the Block Island Sound area for a number of years. So-called good fish (chiefly the winter flounder) have been removed by fishing while the trash species have not. But with the inception of the trash fishery, this situation changed. The good fish were no longer alone in suffering the predatory effects of a fishery.
Since the trash fishery was carried on by the same boats which otherwise worked on the regularly marketed species, this new development would not be expected to increase the fishing pressure on the good fish. For present purposes, fishing pressure on the good fish can thus be assumed to be constant and can be treated as though it were natural predation. Continuation of the trash fishery, then, should release part of the environment to utilization by nonfished species and by those which are already being exploited at a constant rate. Stated in different words, interspecific competition will be changed in favor of those species not preyed upon by the trash fishery. This means that those species already being fished will have available to them a greater portion of the environment than before. Such a change would be expected to confer an advantage upon the good fish, or at least it should reduce the degree of disadvantage under which they have been existing. For the reasons already outlined, this would tend to increase the stocks of the regularly marketed species. Whether or not these stocks will show a significant increase depends upon whether or not they are able to adapt themselves to the new advantage and are biologically qualified to secure its benefits. In other words, the effect upon one species of the removal of another from the common environment will depend to a large extent upon the degree of overlap in the ecological niches of the two species. Thus, the removal of trash species will be of no benefit to the good species unless the latter can utilize that portion of the environment vacated by the former. For example, with respect to food, the winter flounder, feeding chiefly on amphipods, would benefit but little from removal of the windowpane flounder, which feeds almost exclusively on mysids.

**Conclusions and Recommendations**

In conclusion, then, continued operations of the trash fishery will undoubtedly produce a reduction of the stocks of the fishes which fall into this category. The stocks of regularly marketed species, which have been subjected to a fairly constant fishing pressure for some years past, may be expected to increase. The relative changes to be expected in these two groups will depend upon the complex interrelationships of predation, availability of environment, reproductive capacity, potential growth rates, etc. In its broad aspects, a reasonably heavy trash fishery may be expected to have a beneficial effect on the general fishing industry of the region and to constitute a full
and proper utilization of the available resources. It is inevitable that sooner or later conservation measures will be needed to insure against undue exploitation. But to regulate a fishery so as to provide optimum production requires the possession of adequate and accurate information on the biology of each of the various species concerned, their ecological relationships, the progress of the fishery, and so on. This information cannot be obtained at a moment’s notice. Both time and effort are needed. To wait until a fishery is at a low ebb, to wait until disaster has struck before attempting to gain this knowledge, is illogical and often useless. To prevent the repetition of past errors, the following program is recommended.

1. Study of the life histories of the major species of fishes in the area. Although the U. S. Fish and Wildlife Service, the Bingham Oceanographic Laboratory, and other organizations are already engaged in several such studies, there is an embarrassment of riches with respect to forms whose biology is virtually unknown. Perhaps these studies could be expedited by the establishment of research fellowships for graduate students and others at qualified institutions. Relatively small contributions from each of the various industries benefiting from this work would support an adequate number of fellowships.

2. Day-by-day collection of data on landings at the major ports. This should include a) total landings by weight; b) landings of each species by weight; c) area of capture; d) fishing effort expended; and e) market conditions, such as price, supply, demand, etc. This part of the program would require the full-time employment of at least one person in each port, and would perhaps be most appropriately undertaken by the proper state or federal agencies.

Until these data are collected on a regular and continuing basis, a full understanding of the biology and economics of the industry and the ability to make recommendations for the optimum utilization of our resources, as well as to make predictions for the industry, will be virtually impossible to attain.

SUMMARY

1. Careful examination has been made of various body parts. Allometric growth has been demonstrated in the eye and in the longest spine of the dorsal fin.

2. It has been shown that, contrary to the usual assumption, the length-weight relationship is not constant. The fluctuations have
Morrow: Myxocephalus octodecimspinosus Mitchill

been shown to have a definite seasonal rhythm. Analysis of this rhythm indicates that both the sexual cycle and the general physiological activity are involved in these changes.

3. Careful seasonal examinations have been made of the state of the gonads with respect to weight, gross appearance and histological structure. As a result of these examinations, the breeding season and age at maturity have been defined. The fish mature at two or three years of age, and the breeding season extends from late November through January. The peak of spawning activity occurs in late December and early January.

4. Field observations show that the longhorn sculpin prefers a hard clean bottom for spawning, placing its eggs in cavities in shells, sponges and other objects. Each female lays about 8,000 eggs annually.

5. It has been possible to establish an interpretation of the marks on the otolith of the longhorn sculpin. For the first time, this has provided a satisfactory method of age determination in this fish.

6. A technique has been developed whereby the length of this fish at early ages may be estimated from the otoliths of older specimens; in this way the growth rates of the fish have been established. The average lengths of the fish at various ages are: 1 year, 5.6 cm.; 2 years, 18.2 cm.; 3 years, 24.3 cm.; 4 years, 26.3 cm.; 5 years, 27.4 cm.; 6 years, 28.6 cm.; 7 years, 29.2 cm.; 8 years, 29.8 cm.; 9 years, 30.2 cm. A rough estimate of the age composition of the sculpin population indicates that the majority of sculpins caught in commercial otter trawls are between two and five years old.

7. An attempt has been made to study the migrations of the longhorn sculpin by tagging over 4,000 individuals. However, the number of tags returned has been so small that the results are not illuminating. This is ascribed to lack of commercial utilization of the fish at the time of the experiments, which tended to prevent the return of tags. Field observations and the analysis of the abundance of the longhorn in sample hauls have shown that this sculpin moves offshore in the early summer and onshore in the fall. Contrary to suggestions in the literature, these movements are not precisely correlated with temperature.

8. The food of the longhorn has been examined. The fish is an omnivorous, bottom-feeding carnivore living largely on the amphipod,
Leptocheirus pinguis, and the decapod, Cancer irroratus, but also sampling almost every invertebrate and small fish near the bottom.

9. The recent fishery for trash fish is discussed. The great volume of trash landings in 1949 and 1950 is pointed out, and the reasons for the meteoric rise and fall of this fishery are described. In the space of a few months, landings at two small southern New England ports reached an average of nearly 1,500,000 pounds per month, and in the six months prior to the cessation of trash fishing they averaged nearly 2,000,000 pounds per month. Landings at larger ports were correspondingly greater.

In a theoretical discussion based on some rather rough estimates, it is pointed out that stocks of trash fish in general may be expected to decline, and that the sculpin may suffer serious depletion within ten years. However, continuation of the trash fishery would be expected to have a beneficial effect on the fishing industry as a whole in this region. It is suggested that studies of the biology and ecological relationships of the major species, as well as the collection of catch statistics, should be actively pursued in order to provide data on which to base regulatory measures for this fishery.

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# APPENDIX TABLES

## APPENDIX TABLE A. CATCH DATA FOR *Myoxocephalus octodecimspinosus*

<table>
<thead>
<tr>
<th>Date</th>
<th>Boat</th>
<th>Location</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV/18/43</td>
<td>Rival</td>
<td>New Haven Harbor</td>
<td>Small mesh expt'l trawl</td>
</tr>
<tr>
<td>IV/22/43</td>
<td>Baby II</td>
<td>2-3 mi. off Watch Hill, R. I.</td>
<td>Small mesh expt'l trawl</td>
</tr>
<tr>
<td>V/2/43</td>
<td>Rival</td>
<td>New Haven Harbor</td>
<td></td>
</tr>
<tr>
<td>V/11/43</td>
<td>Marise</td>
<td>3-5 mi. W of Montauk, 1 mi. offshore</td>
<td>No lab member on board</td>
</tr>
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<td>VI/15/43</td>
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<td>No lab member on board</td>
</tr>
<tr>
<td>VIII/7/43</td>
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<td>3 mi. N of Block Island, R. I.</td>
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<td>15 mi. SSE of Pt. Judith, R. I.</td>
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<td>IX/21/43</td>
<td>Eleanor</td>
<td>3 mi. NNE of Block Island, R. I.</td>
<td>No lab member on board</td>
</tr>
<tr>
<td>X/31/43</td>
<td>Eleanor</td>
<td>3 mi. S of Green Hill, R. I.</td>
<td></td>
</tr>
<tr>
<td>XI/21/43</td>
<td>Eleanor</td>
<td>2 mi. ESE of Watch Hill, R. I.</td>
<td></td>
</tr>
<tr>
<td>XII/19/43</td>
<td>Eleanor</td>
<td>5-8 mi. ESE of Watch Hill, R. I.</td>
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</tr>
<tr>
<td>I/23/44</td>
<td>Eleanor</td>
<td>1 mi. S of Noyes Pt., R. I.</td>
<td></td>
</tr>
<tr>
<td>II/20/44</td>
<td>Eleanor</td>
<td>2-4 mi. S of Green Hill, R. I.</td>
<td>Small catch with unusually low proportion of trash fish</td>
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<tr>
<td>II/29/44</td>
<td>Eleanor</td>
<td>8 mi. S of Block Island, R. I.</td>
<td>Tagged 29 sculpins</td>
</tr>
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<td>III/10/44</td>
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<td>2 mi. ESE of Watch Hill, R. I.</td>
<td>Tagged 221 sculpins</td>
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<tr>
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<td>Jane</td>
<td>2 mi. off Pt. Herod, L. I.</td>
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<tr>
<td>IV/19/44</td>
<td>Marise</td>
<td>3 mi. SSE of Watch Hill, R. I.</td>
<td>No lab member on board</td>
</tr>
<tr>
<td>IV/23/44</td>
<td>Eleanor</td>
<td>3 mi. S of Watch Hill, R. I.</td>
<td></td>
</tr>
<tr>
<td>V/18/44</td>
<td>Eleanor</td>
<td>Between New London &amp; Fisher's Island</td>
<td></td>
</tr>
<tr>
<td>VI/23/44</td>
<td>Eleanor</td>
<td>3 mi. N of Block Island, R. I.</td>
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<tr>
<td>VII/13/44</td>
<td>Eleanor</td>
<td>3 mi. N of Block Island, R. I.</td>
<td>Only 7 sculpins in catch</td>
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<td>3 mi. N of Block Island, R. I.</td>
<td>Only 4 sculpins in catch</td>
</tr>
<tr>
<td>IX/26/44</td>
<td>Eleanor</td>
<td>5-6 mi. off Charlestown, R. I.</td>
<td>Only 6 sculpins in catch</td>
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<td>XI/19/44</td>
<td>Eleanor</td>
<td>Quonochontaug to Noyes Pt., R. I., 1 mi. offshore</td>
<td>One haul with small mesh expt'l trawl, one with the regular net</td>
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<td>Marise</td>
<td>2 mi. S of Charlestown, R. I.</td>
<td>Net was ballooned</td>
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<tr>
<td>II/4/45</td>
<td>Marise</td>
<td>5 mi. SSW of Charlestown, R. I.</td>
<td>Net was ballooned</td>
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<td>III/5/45</td>
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<td>4 mi. S of Green Hill, R. I.</td>
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<td>3 mi. NNE of Block Island, R. I.</td>
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<td>V/27/45</td>
<td>Eleanor</td>
<td>Between Fisher's Island and mouth of Thames River</td>
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<tr>
<td>VI/18/45</td>
<td>Eleanor</td>
<td>2 mi. SE of Watch Hill, R. I.</td>
<td>Only 4 sculpins in catch</td>
</tr>
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<td>1½ mi. SE of Watch Hill, R. I.</td>
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<td>Eleanor</td>
<td>2 mi. SE of Watch Hill, R. I.</td>
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<td>XI/11/45</td>
<td>Eleanor</td>
<td>1 mi. N of North Hill, Fisher's Island</td>
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<td>I/14/46</td>
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<td>Eleanor</td>
<td>2 mi. W of Noyes Pt., R. I.</td>
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<td>III/24/46</td>
<td>Eleanor</td>
<td>1½ mi. W of Hatchett's Reef</td>
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<td>2 mi. NW of Block Island Harbor</td>
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<td>Net was ballooned. Tagged 91 sculpins</td>
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<td>Marise</td>
<td>Quonochontaug to Charlestown, R. I. 2-5 mi. offshore</td>
<td>Net was ballooned. Tagged 343 sculpins</td>
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<td>Tagged 100 sculpins</td>
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<td>Eleanor</td>
<td>1-3 mi. SSE of Watch Hill, R. I.</td>
<td>Tagged 50 sculpins Fishing at night. Tagged 29 sculpins, total catch.</td>
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<td>IV/1-2/47</td>
<td>Betty II</td>
<td>100 yds. to ½ mi. offshore, off Port Jefferson, L. I., N. Y.</td>
<td>Tagged 181 sculpins Tagged 288 sculpins</td>
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<td>Tagged 400 sculpins</td>
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<td>Off Pt. Herod, L. I., about 2 mi. offshore</td>
<td>Tagged 183 sculpins Tagged 110 sculpins</td>
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<td>Betty II</td>
<td>Off Pt. Herod, L. I., near can buoy no. 7</td>
<td>Tagged 224 sculpins</td>
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<td>Betty II</td>
<td>4 mi. off can buoy no. 7</td>
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<td>Watch Hill, R. I. to Charlestown, R. I.</td>
<td>Tagged 228 sculpins</td>
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<td>Between Charlestown, R. I. and Quonochontaug, R. I., 2-4 mi. offshore</td>
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<td>Tagged 304 sculpins</td>
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<td>Tagged 304 sculpins</td>
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<td>VI/1/48</td>
<td>Eleanor</td>
<td>1-2 mi. S of mouth of Thames River</td>
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APPENDIX TABLE B.  PERCENTAGE BY VOLUME OF THE VARIOUS ITEMS IN THE STOMACHS OF 15 SAMPLES OF THE LONGHORN SCULPIN.  LOCALITIES FOR EACH DATE ARE LISTED IN APPENDIX TABLE A.  A PLUS SIGN (+) MEANS THAT THE ITEM WAS LESS THAN ONE PER CENT OF THE TOTAL.  SUCH ITEMS WERE NOT INCLUDED IN CALCULATING THE PERCENTAGES.

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<th>Date of Collection</th>
<th>Number of stomachs</th>
<th>UNIDENTIFIABLE MATERIAL</th>
<th>MISCELLANEOUS</th>
<th>Coelenterata</th>
<th>Annelida</th>
<th>Crustacea</th>
<th>Decapoda</th>
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<th>Coelenterata</th>
<th>Annelida</th>
<th>Crustacea</th>
<th>Decapoda</th>
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#### DATE OF COLLECTION

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**Note:** The table continues with similar entries for other species.