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STUDIES ON THE STRIPED BASS (*Roccus saxatilis*) OF THE ATLANTIC COAST

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By DANIEL MERRIMAN

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ABSTRACT

The results of an investigation of the striped bass (*Roccus saxatilis*) of the Atlantic coast, from April 1, 1936, to June 30, 1938, are discussed and the systematic characters of the species described in detail on the basis of the literature and material afforded by fin-ray, scale, and vertebral counts, and by measurements on more than 350 individuals.

Studies on the fluctuations in abundance of this species over long-term periods show that there has been a sharp decline in numbers. Dominant year-classes have at times raised the level of abundance, but the intensity of the fishery is such that their effects have been short lived. The dominant year-class of 1934 was the largest to be produced in the past half century, although the parental stock was probably as low as it has ever been. There is a good correlation between the production of dominant year-classes of striped bass and below-the-mean temperatures during the periods before, of, and immediately after the main spawning season.

The striped bass is strictly coastal in its distribution from the Gulf of St. Lawrence to the Gulf of Mexico, is anadromous, and spawns in spring. Sex ratios in northern waters show that males seldom make up more than 10 percent of the population, while in waters farther south the sex ratios are not so disproportionate. Females first mature as they become 4 years old, males as they become 2 years old. This difference in age at maturity may account for the small percentage of males in northern waters, for the time of the spawning season in the South coincides with the time of the spring coastal migration to the North, which is made up mainly of immature females. The age and rate of growth have been studied by scale analysis and the average sizes of the different age groups, and the growth has been calculated to the eleventh year.

Striped bass (3,937) have been tagged, and returns have shown that there is a striking migration to the North in spring, and to the South in fall. The population in northern waters in summer remains static. These migrations do not occur until the bass become 2 years old, and have their greatest intensity off the southern New England and Long Island shores. There is little encroachment by the stock in the Middle Atlantic bight on the populations in the North or South.

The available evidence from general observation, tagging, and scale analysis points to the conclusion that the dominant 1934 year-class originated chiefly in the latitude of Cheasapeake and Delaware Bays, and that those fish born as far south as North Carolina contribute directly only a relatively small fraction to the population summering in northern waters.

Stomach-content analyses show that bass are universal in their choice of food, a large variety of fishes and crustacea forming the main diet. It is suggested that the increased bulk and availability of *Menidia menidia notata* in Connecticut waters late in summer and early in fall are responsible for the increase in, or maintenance of the growth rate of striped bass in this region despite the sharp drop in water temperature at this time.

The parasites of the species are discussed and several new host records listed. It is suggested that the bilateral cataracts in a high percentage of individuals bass in the Thames River, Connecticut, are the result of a dietary deficiency.

The decline in abundance of the striped bass of the Atlantic coast over long-term periods and its causes are discussed from a theoretical point of view, and it is pointed out that the present practice of taking a large proportion of the 2-year-olds annually is apparently not an efficient utilization of the supply. It also is pointed out that both the fishery and the stock would probably benefit from the protection of these fish until 3 years old, at which time the average individual length is 41 cm. (16 inches), measured from tip of lower jaw to fork of tail.

STUDIES ON THE STRIPED BASS (*Roccus saxatilis*) OF THE ATLANTIC COAST[1]

By Daniel Merriman, *Osborn Zoological Laboratory, Yale University, formerly Temporary Investigator, Fish and Wildlife Service*[1]

CONTENTS

INTRODUCTION

The following account of the life history and habits of the striped bass (*Roccus saxatilis*) is the result of an investigation originally sponsored by the Connecticut State Board of Fisheries and Game, and undertaken by the author.

The main objectives of this investigation, throughout its entire course, were to obtain information on the life history and habits of the striped bass, to study the fluctuations in abundance of this species and their causes, and to accumulate material on the effect of the fishery—both commercial and sporting—on the present supply.

The striped bass investigation was begun on April 1, 1936, and was concluded on June 30, 1938. Its headquarters have been the Osborn Zoological Laboratory, Yale University, New Haven, Conn., and, during the summer months, the Niantic River, Conn.—an area where this species is more easily available for study than elsewhere in the immediate vicinity. During the first 3 months the work was financed by a group of Connecticut sportsmen. The Connecticut State Board of Fisheries and Game then supported the investigation through December 31, 1937, and also supplied much of the equipment essential to the progress of the work. By that time it had become apparent, as a result of tagging experiments, that the striped bass was a highly migratory species, and that therefore the problem was essentially coastwise in its scope. Clearly the objectives could not be accomplished satisfactorily by studies in one limited area. The American Wildlife Institute generously contributed a substantial sum in March 1937 when a break in the continuity of the work would have been a severe blow to its progress, and thus made it possible for the investigation to extend its scope to include a large portion of the Atlantic coast. On July 1, 1937, the United States Bureau of Fisheries insured the financial backing of the investigation for a full year from that date, and the State Board of Fisheries and Game appropriated a sufficient amount for the continuation of the work within Connecticut.

[1] The Fishery Bulletin of the Fish and Wildlife Service is a continuation of the Bulletin of the Bureau of Fisheries, which ended with vol. 49. The Fish and Wildlife Service was established on June 30, 1940, by consolidation of the Bureau of Fisheries and the Bureau of Biological Survey.

The North Carolina State Department of Conservation and Development also contributed to the striped bass investigation in the fall of 1937, and thus made it possible to accumulate valuable information from the Albemarle Sound region in November 1937 and March, April, and May, 1938.

The author has published a preliminary account of the results of the striped bass investigation through December 1936 (Merriman, 1937a). A review covering much of the same material has also appeared in the Transactions of the Second North American Wildlife Conference (Merriman, 1937b), and a paper given at the New England Game Conference on February 12, 1938, and the Third North American Wildlife Conference on February 14, 1938, was published later (Merriman, 1938). Several progress reports submitted to the Connecticut State Board of Fisheries and Game have been mimeographed and sent out in limited numbers. This bulletin, therefore, incorporates some previously published material as well as the main accomplishments of the investigation from its inception to its conclusion.

ACKNOWLEDGMENTS

Since the author was a graduate student in the Department of Zoology at Yale University during the whole course of this investigation, the facilities of the Osborn Zoological Laboratory were always at his disposal. He especially wishes to acknowledge the help and advice of Prof. A. E. Parr, Director of the Peabody Museum. He is also indebted to Mr. Marshall B. Bishop of the Peabody Museum for his excellent work in the field in North Carolina in the spring of 1938, to Mr. Donald L. Pitcher of the Bingham Oceanographic Laboratory, and to many members of the Osborn Zoological Laboratory and the Peabody Museum for their assistance at various times. Furthermore, the investigation owes much of its progress to Mr. Otto J. Scheer, of New York, who made it possible to tag striped bass at Montauk, L. I., N. Y., in the spring and fall of 1937, to Mr. J. D. Chalk, Commissioner of Game and Inland Fisheries in North Carolina, to Mr. David A. Aylward and Mr. Oliver H. P. Rodman of the Massachusetts Fish and Game Association, and to a number of commercial fishermen and sport fishermen's clubs.

It is also a pleasure to acknowledge the assistance of Mr. Earl E. Sisson, who was employed by the Connecticut State Board of Fisheries and Game to aid in the seining and tagging of striped bass. And finally, the writer wishes to express his sincere thanks to his wife, who has done most of the recording in the field and has given her support in every possible way.

DESCRIPTION OF THE STRIPED BASS

During the past few years the striped bass has been called *Roccus saxatilis* and *Roccus lineatus*. These two specific names have been used about equally in the literature, and with more or less indiscrimination. Jordan, Evermann, and Clark (1930) say:

> This species is usually called *Roccus lineatus* after *Sciaena lineata* Bloch (Ausländische Fische, VI, 1792, 62); but it cannot be the same. The form, serrae of the preopercle, and the stout spines of the fin, as well as the asserted locality 'Mediterranean' indicate that the species concerned is *Dicentrarchus lupus* of Europe. The only resemblance to *Roccus* is found in the striped color; but Bloch says that the stripes on the sides are yellow.

A glance at Bloch's (loc. cit.) illustration substantiates this statement. The name *Roccus saxatilis* (Walbaum) therefore appears to be the more valid, and lately it has come into more widely accepted usage.

Two common names are regularly applied to this species. North of New Jersey "striped bass" is almost universally used, while to the south "rock" or "rockfish" is the generally accepted terminology. Among other names that have been applied in the past, but are seldom if ever heard now, are "green-heads", "squid-hounds" (Goode, 1884), and "missuckeke-kequock" (Jordan, Evermann, and Clark, loc. cit.).

The striped bass, *Roccus saxatilis*, belongs to the family Serranidae, of the order Percomorphi. It has been well described in most of the standard ichthyological references for both the Atlantic and Pacific coasts (e. g., Hildebrand and Schroeder,

1928; Bigelow and Welsh, 1925; and Walford, 1937), and the following account is based on these works and on the material afforded by fin-ray, scale, and vertebral counts, and measurements on over 350 individuals 15 cm. in length or greater studied during the investigation. The majority of these fish were taken in Connecticut waters. The numbers indicate the extremes of variation, while those in parentheses are the approximate averages.

Morphometric description.—Body elongate, moderately compressed; back little arched; greatest depth (at or slightly posterior to origin of spinous dorsal fin) 3.45 to 4.2 (3.7) (young individuals tend to be more slender than old ones), average least depth (at caudal peduncle) 9.6, average depth at anus 3.9—in standard length. Head long and pointed, 2.9 to 3.25 (3.1) in standard length. Dorsal fin rays: IX (VIII in one individual)—I, 10 to 13 (12); fourth and longest dorsal spine 2.2, first and longest dorsal soft ray 2.0 in head. Anal fin rays III, 10 to 12 (11); first and longest soft ray 2.0 in head. Ventral (pelvic) fin rays: I, 5; length of ventrals 1.9 in head. Pectoral fin rays: 15 to 17; length of pectorals 2.0 in head. The two dorsal fins approximately equal in basal length, the first (spinous) being roughly triangular in outline and originating over the posterior half of the pectoral, the second (soft) usually distinctly separate from the first, its soft rays becoming regularly shorter posteriorly. Anal fin of essentially the same shape as second dorsal and slightly smaller; situated below posterior two-thirds of second dorsal. Pectorals and ventrals of moderate size; insertion of ventrals slightly behind that of pectorals. Caudal somewhat forked. Scales: 7 to 9—57 to 67—11 to 15; typically ctenoid (the character "scales on head cycloid" as given by Jordan, 1884, for the genus *Roccus*, does not hold true in the striped bass); extending onto the bases of all the fins except the spinous dorsal. Vertebrae (including hypural): 24 or 25 (almost invariably 12+13=25). Gill-rakers on first arch: 8 to 11+1+12 to 15 (10+1+14). Eye 3 to 4.9 in head (less in smaller individuals). Mouth large, oblique, maxillary extending nearly to middle of eye (except in small individuals) and broad posteriorly (width at tip nearly two-thirds diameter of eye); lower jaw projecting. Teeth small, two parallel patches on base of tongue; also present on jaws, vomer, and palatines. Preopercle margin clearly serrate.

Color in life.—Dark olive-green to steel-blue or almost black above as a rule, but occasionally light green. Paling on the sides to silver, and white on the belly. Sometimes with a bronze luster on the sides. Sides with seven or eight prominent dark stripes, much the same color as the back. Usually the stripes follow scale rows, three or four above the lateral line, one invariably on the lateral line, and three below it. Normally the two above the lateral line, that on the lateral line, and sometimes the first below it, are the longest, reaching or coming close to the base of the caudal. None extend onto the head. All except the lowest are above the level of the pectoral fins. The highest stripes and those below the lateral line tend to decrease in length. The stripes are often variously interrupted and broken. Young of less than 6–7 cm. usually without dark longitudinal stripes, and those of 5–8 cm. often with dusky vertical crossbars ranging from 6–10 in number. Vertical fins dusky green to black, ventrals white or dusky, pectorals greenish.

Distinguishing characters.—There is little danger of confusing striped bass above 10 cm. with any other species either on the Atlantic or Pacific coast. Its prominent dark longitudinal stripes, general outline, and fin structure are sufficient to separate it at a glance from other species. The dorsal fins are usually clearly separate, but sometimes touch. In specimens less than 7 cm. it is often difficult to distinguish striped bass from the white perch (*Morone americana*), whose dorsal fins are continuous—not contiguous, as in the striped bass. The normally separate dorsals of the larger striped bass become an almost useless character here, and the stripes frequently are not present. The general body outlines of the young of these two species are much alike, although the back tends to be somewhat more arched in the white perch. The most valuable differentiating characters are: (1) The second spine of the anal fin, which is almost equal in length to the third spine and more robust in the white perch, and intermediate in length between the first and the third spines and less robust in the striped bass; (2) the relatively thicker and heavier spines in the fins of the white perch; (3) the sharp spines on the margin of the opercle, of which the striped bass has two and the white perch but one; and (4) the soft rays of the anal fin, usually 9 in the white perch and 10–12, normally 11, in the striped bass.

Two fresh-water Serranids bear a superficial resemblance to the striped bass. *Morone interrupta*, the yellow bass of the Mississippi Valley, also has seven longitudinal dark stripes, but is immediately distinguished by its slight connection of the dorsals, greater depth of the body (2.7 in standard length), lesser number of scales in the lateral line (50–54), lack of teeth on the base of tongue, and its robust spines of the dorsal and anal, as well as the more numerous spines of the first dorsal (X). *Lepibema chrysops*, the white bass of the Great Lakes region and Mississippi and Ohio Valleys, also has a number of dark longitudinal narrow stripes. Here the dorsals are separate as in the striped bass, but this species differs in having only a single patch of teeth on the base of the tongue, and in having a much deeper body (over one-third of the length) that is more compressed.

SIZE AND RANGE OF THE STRIPED BASS

The striped bass most commonly taken at present by commercial and sport fishermen on the Atlantic coast vary in size from less than 1 pound to about 10 pounds in weight. Individuals up to 25–30 pounds, however, are by no means rare, and not infrequently striped bass up to 50–60 pounds are caught, although, judging from old records, these larger fish are not as abundant as they have been in the past. Bass above 60 pounds are now decidedly rare. The largest striped bass taken in recent years was the 65-pounder caught on rod and line in Rhode Island in October 1936 and one weighing 73 pounds was taken on rod and line in Vineyard Sound, Mass., in 1913 (Walford, 1937). Authentic records show that a striped bass weighing 112 pounds was taken at Orleans, Mass., many years ago (Bigelow and Welsh, 1925), and Smith (1907) reports several weighing 125 pounds caught in a seine near Edenton, N. C., in 1891.

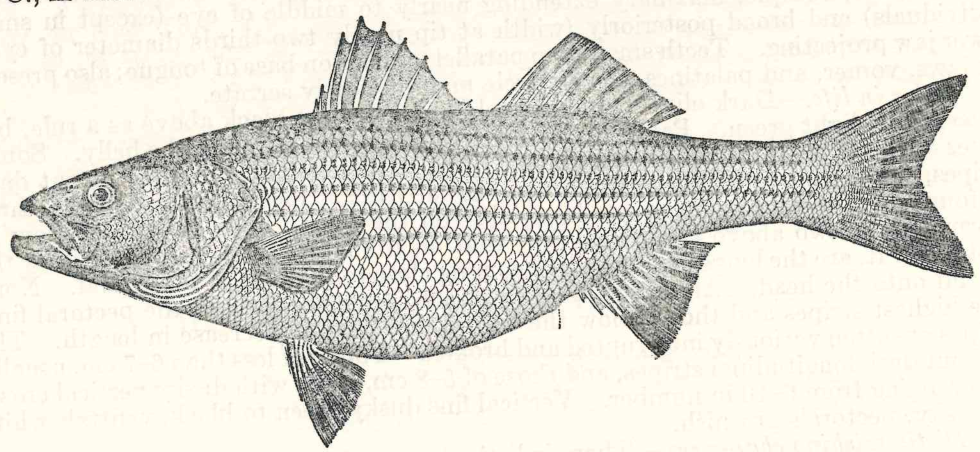

FIGURE 1.—The striped bass (*Roccus saxatilis*).

The striped bass has a range on the Atlantic coast of North America, where it is indigenous, from Florida to the Gulf of St. Lawrence, and is most common from North Carolina to Massachusetts. Jordan and Evermann (1905) state that its southern limit is the Escambia River in western Florida, on the Gulf of Mexico. Jordan (1929), however, states that the striped bass exists as far west as Louisiana. Bean (1884) records the striped bass from the Tangipahoa River, near Osyka, Miss., and this river also flows through Louisiana. Gowanloch (1933) also mentions the striped bass in his "Fishes and fishing in Louisiana."

The striped bass was introduced on the Pacific coast where its present center of abundance is the San Francisco Bay region (Scofield, 1931), and the extreme limits of its distribution are Los Angeles County, Calif., and the Columbia River (Walford, loc. cit.). Walford also states: "There is an indigenous population of bass at Coos Bay, Oreg., about 400 miles north of San Francisco."

This fish is strictly coastwise in its distribution, and records of its being taken more than several miles offshore are extremely rare. It is most commonly taken in salt water, but, since it is anadromous, its capture in brackish and even fresh water is a regular occurrence—particularly during the winter and spring months. It has been taken in the Hudson River as far north as Albany, and is caught in large quantities in the Roanoke River at Weldon, N. C., each spring. Temperature appears to play no little part in its distribution (see p. 42), yet the striped bass can be taken at the extreme limits of its range throughout the year.

REVIEW OF THE LITERATURE ON THE LIFE HISTORY OF THE STRIPED BASS

Mention of the striped bass appears early in American literature. This is undoubtedly because of its great abundance in times past and its coastal distribution—two factors that made it easily available to the early colonists.

Capt. John Smith wrote:

> The Basse is an excellent fish, both fresh & salte . . . They are so large, the head of one will give a good eater a dinner, & for daintinesse of diet they excell the Marybones of Beefe. There are such multitudes that I have seen stopped in the river close adjoining to my house with a sande at one tide as many as will loade a ship of 100 tonnes (Jordan and Evermann, 1905).

And one of Captain Smith's contemporary divines wrote:

> There is a Fish called a Basse, a most sweet & wholesome Fish as ever I did eat . . . . . the season of their coming was begun when we came first to New England in June and so continued about three months space. Of this Fish our Fishers take many hundreds together, which I have seene lying on the shore to my admiration . . . (Jordan and Evermann, 1905).

William Wood in his New England's Prospect (1635) wrote:

> The Basse is one of the best fishes in the country . . . the way to catch them is with hooke and line: the Fisherman taking a great cod-line, to which he fasteneth a peece of Lobster, and throwes it into the sea, the fish biting at it he pulls her to him, and knockes her on the head with a sticke. . . . the English at the top of an high water doe crosse the creekes with long seanes or Basse netts, which stop in the fish; and the water ebbing from them they are left on dry ground, sometimes two or three thousand at a set . . .

Such references to the striped bass became increasingly common in the eighteenth and nineteenth centuries, all of them dealing with record catches or the abundance of this species, and extolling the virtues of the bass as a game and food fish. Probably the earliest observations of any consequence on any phase of the life history are those by S. G. Worth, who published a series of papers from 1881 to 1912 on the spawning habits and artificial propagation of the striped bass in the Roanoke River, N. C. (See under section on spawning habits and early life history.) Turning to more modern times, mention is made of the striped bass frequently, but in all the literature dealing with the fishes of the Atlantic coast there is scant information on the life history of this species. Such standard and well-recognized references as Bigelow and Welsh (1925) and Hildebrand and Schroeder (1928), sum up the available knowledge on the striped bass in a few brief pages. In the past few years, however, the need for further information on this species on the Atlantic coast has resulted in several investigations in different localities, apart from the present work. These have given rise to much interesting material and more general knowledge (e. g., see Vladykov and Wallace, 1937), a great deal of which, however, is yet to be published. Reference to some of this work is made in the following pages.

In the last quarter of the nineteenth century striped bass were introduced on the Pacific coast, where they prospered beyond all expectations and soon became the object of an intensive and prosperous fishery conducted by both commercial and sport fishermen. This fishery has been of great importance ever since. The story of this introduction of the striped bass to the Pacific coast is particularly interesting (Throckmorton, 1882; Scofield, 1931, etc.). In 1879 and 1881 a number of yearling bass were seined in New Jersey, taken across the continent in tanks by train, and planted in San Francisco Bay. A total of only 435 striped bass survived the rigors of these 2 trips. Yet by 1889, 10 years after the first plant, they were caught in gill nets and offered for sale, and in 1899 the commercial net catch alone was 1,234,000 pounds.

In 1915 the greatest catch in the history of the fishery was made, when 1,784,448 pounds of striped bass were delivered to the markets. Since the World War the annual catch has varied between 500,000 and 1,000,000 pounds. The Division of Fish and Game of California has made thorough studies on the life history of the striped bass, as well as the conservation needs of this species. These have been published in a long series of papers from 1907 to the present, of which the outstanding publication is that by Scofield (1931). But, because the conditions of the fishery on the Pacific coast differed so much from those on the Atlantic coast, much of the

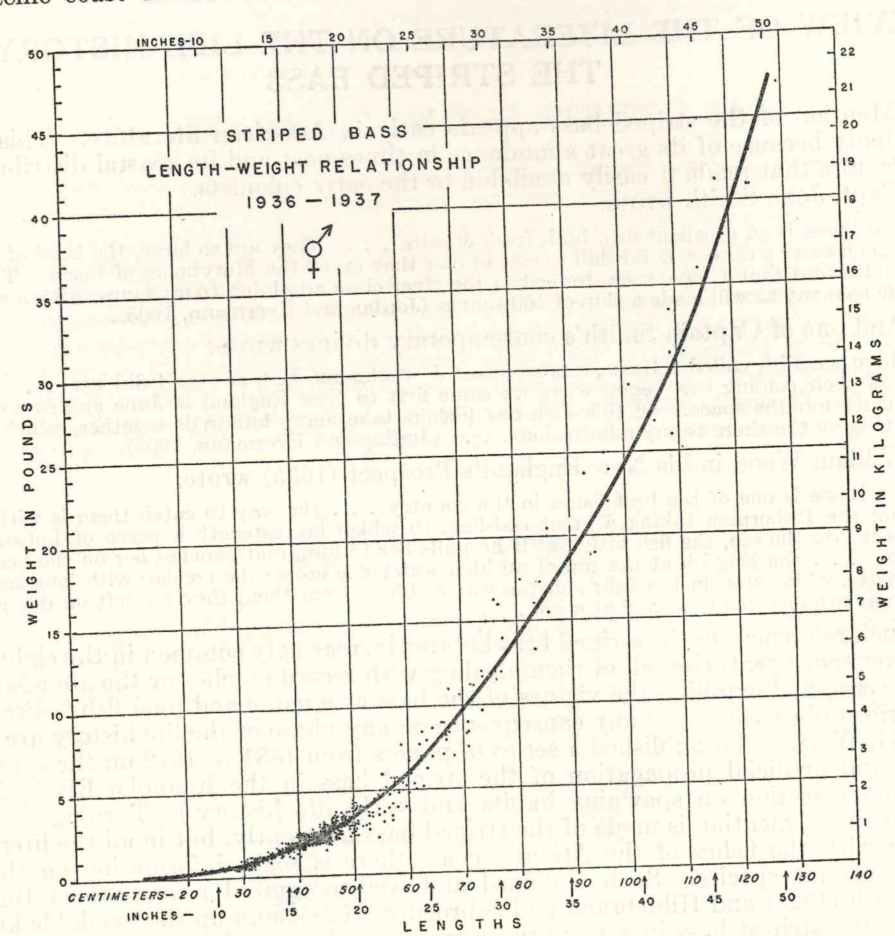

FIGURE 2.—Length-weight relationship of the striped bass, based on 526 fish. Measurements are to the fork of the tail.

information presented by the Division of Fish and Game of California cannot be applied to the striped bass of the Atlantic. On the Pacific coast the main method of capture was by gill net, and it was easy to eliminate the capture of small fish by regulating the mesh size. At the present time commercial fishing for striped bass is prohibited in California. On the Atlantic coast, however, pound-nets, seines, and other methods of capture are used, and striped bass are taken indiscriminately with a great many other species—a situation which would make it highly impractical and most unfair to the commercial fishermen involved if any attempt were made to control the size categories of striped bass taken in these nets by regulating the mesh size.

Length-weight relationship of the striped bass

[Length is stated in centimeters, measured to fork in tail; weight is in pounds]

Length	*Weight*	*Length*	*Weight*	*Length*	*Weight*
20	0. 25	57	5. 25	94	21. 00
21	. 25	58	5. 50	95	21. 25
22	. 25	59	5. 75	96	22. 00
23	. 25	60	6. 00	97	22. 50
24	. 50	61	6. 25	98	23. 00
25	. 50	62	6. 75	99	23. 50
26	. 50	63	7. 00	100	24. 25
27	. 50	64	7. 25	101	25. 00
28	. 75	65	7. 75	102	25. 50
29	. 75	66	8. 00	103	26. 00
30	. 75	67	8. 50	104	26. 75
31	. 75	68	9. 00	105	27. 25
32	1. 00	69	9. 25	106	28. 00
33	1. 00	70	9. 75	107	28. 75
34	1. 00	71	10. 00	108	29. 25
35	1. 25	72	10. 50	109	30. 00
36	1. 25	73	11. 00	110	30. 75
37	1. 50	74	11. 25	111	31. 50
38	1. 50	75	11. 75	112	32. 25
39	1. 75	76	12. 00	113	33. 00
40	1. 75	77	12. 50	114	34. 00
41	2. 00	78	13. 00	115	35. 00
42	2. 00	79	13. 50	116	35. 75
43	2. 25	80	14. 00	117	36. 75
44	2. 25	81	14. 50	118	37. 50
45	2. 50	82	15. 00	119	38. 50
46	2. 50	83	15. 50	120	39. 50
47	2. 75	84	16. 00	121	40. 50
48	3. 00	85	16. 50	122	41. 50
49	3. 25	86	17. 00	123	42. 25
50	3. 50	87	17. 75	124	43. 25
51	3. 75	88	18. 00	125	44. 25
52	4. 00	89	18. 25	126	45. 25
53	4. 25	90	19. 00	127	46. 25
54	4. 50	91	19. 25	128	47. 25
55	4. 75	92	19. 75		
56	5. 00	93	20. 25		

FLUCTUATIONS IN ABUNDANCE OF THE STRIPED BASS

Quotations from early settlers point to the enormous abundance of striped bass in those times. Nor is it difficult to find records of unusual catches in the past century. Thus Caulkins (1852) says in a footnote:

> Four men in one night, (Jan. 5th, 1811), caught near the bridge at the head of the Niantic River with a small seine, 9,900 pounds of bass. They were sent to New York in a smack, and sold for upwards of $300. (New London Gazette.)

A quotation from a letter written by a well-known sportsman to the author, dated August 16, 1937, in which he tells of surf-casting for striped bass in the early 1900's at Montauk, Long Island, N. Y., reads as follows:

> 'As for quantities, almost any time through late summer and into late October, provided one knew the ropes, one could, almost literally, fill a wagon, although I, myself, seldom continued beyond local give-away—that is, until necessity more or less compelled me to become a rod-and-reel market fisherman, and I fished like one: on one occasion to the tune of just under a ton of fish in a single period of seven days.

And even in the last 2 years, when the dominant 1934 year-class of striped bass appeared along the better part of the Atlantic coast, catches reaching extraordinary proportions have been commonplace. As but one example, it is of interest to mention that 90,000 pounds of striped bass were taken by a single trap in 2 weeks in October 1936, at Point Judith, R. I.

Close examination of the available records reveals that the abundance of striped bass on the Atlantic coast has shown tremendous fluctuations over a long period of years. As will be shown below (see p. 13), this is because the striped bass is subject to year-class dominance, a phenomenon which has received increasing attention in the past quarter century, since it has been found to apply to so many different species. Briefly explained, year-class dominance may be said to be the production of such unusually large quantities of any species in a single year that the members of this age-group dominate the population for a considerable period, and are noticeably more abundant than the individuals produced in the preceding and following years. Such dominant year-classes usually make their appearance only at fairly lengthy intervals.

Year-class dominance in any species does not, of course, insure the maintenance of the population at a consistently high level. It is also clear that dominant year-classes are often produced by a comparatively small parental stock (see p. 14), and that therefore—at least down to a certain point—their appearance is not correlated with an unusual abundance of mature and spawning fish. There may even be an inverse correlation between these two factors—that is, a large production in any season by a comparatively small population of mature individuals. Such a correlation has been suggested by Bigelow and Welsh (1925) for the mackerel (*Scomber scombrus*), the "years of great production always falling when fish are both scarce and average very large . . ." This phenomenon is probably most common in particularly prolific species that produce a large number of eggs. Such a species is the striped bass, and such a production of a dominant year-class took place in 1934 (see p. 11).

In the case of the striped bass a study of the size of the stock over short-term periods may, therefore, be most deceptive. Thus the first manifestation of a large year-class might give the impression of increasing abundance, or, if the study started shortly after an exceptionally productive year, a sharp decline in the population would be apparent under the conditions of the existent intensive fishery. To get a true picture of the trend in abundance, it is therefore essential to study the fluctuations over long-term periods.

Accurate catch records, which form the most reliable means of studying the relative size of the population in different periods, are unfortunately not available farther back than the latter half of the nineteenth century. Bigelow and Welsh (1925), however, state: ". . . that a decrease was reported as early as the last half of the eighteenth century." Nor is it surprising that such a decline was noticed so long ago when it is considered that the striped bass is a strictly coastwise species, and one that is easily available throughout the year. If haddock (*Melanogrammus aeglefinus*) (Herrington, 1935), halibut (*Hippoglossus hippoglossus*) (Thompson and Herrington, 1930), and other offshore fishes have become scarcer through the intensity of fishing, and this is admitted, it is much more likely that a purely coastal species such as the striped bass, which is far more accessible and therefore unceasingly the object of fishermen's attention, should soon have shown a marked decrease in numbers. Also, the availability of the striped bass and the resultant heavy drain on the stock is not the only factor involved. Since this fish is anadromous, there has been every chance for civilization to do irreparable damage to valuable spawning areas. There is abundant evidence to show that such destruction has often occurred (see p. 16). In view of these facts it was not an unreasonable expectation that the supply should soon have diminished, and that in spite of the production of dominant year-classes the stock could not be maintained at its original high level.

Even in the absence of catch records or figures to prove the point, there can be no question but that the numbers of striped bass along the Atlantic coast have decreased during at least the past 2 centuries. There have undoubtedly been periods when the population showed sudden and pronounced increases, presumably due to the presence of unusually good year-classes. But these peaks have probably been short-lived, and the general trend over long periods has been downwards.

Two series of accurate catch records going back to the latter half of the nineteenth century have been made available to the author. Both of these bear out the above contention and substantiate such a hypothesis. The first record is that of the numbers of striped bass taken annually from 1865 to 1907, on rod and line, by the members of the Cuttyhunk Club at Cuttyhunk, Mass.[2] A graph of this material is shown in figure 3. (For the annual average poundage of the fish caught and the weight of the largest bass in each year, see table 3.) The most striking fact about this curve is its rapid decline from fairly large numbers to extremely low numbers in the 43-year period that it covers. Unfortunately a rod-and-line fishery such as this one cannot be considered a strictly reliable index of abundance—especially since the members of the club confined themselves to fishing for large bass. Moreover, there is no indication of the intensity of fishing, so that the low numbers in the twentieth century might represent the catch of only a few individuals, while the high numbers before 1880 may be the catch of a much larger group. Therefore, the annual fluctuations in this graph are perhaps not real indications of varying abundance, and the rate of decline may be too steep. Nevertheless, it is difficult to imagine from this evidence that a serious depletion did not take place. Even though such a record, lacking as it does information on the effort expended, cannot represent changes in abundance in detail, there can be little doubt that its downward trend indicates the general decline in abundance over the period it covers.

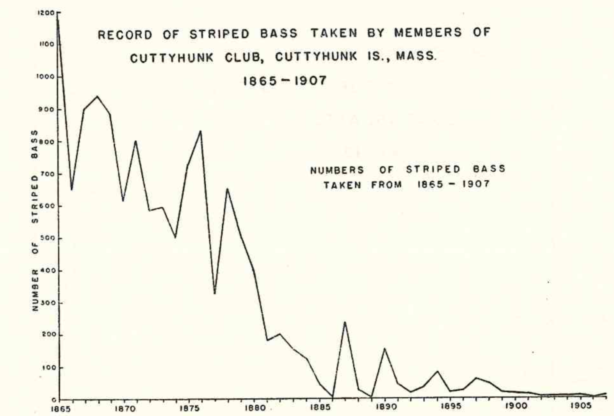

FIGURE 3.—Record of the numbers of striped bass taken by the members of the Cuttyhunk Club from 1865 to 1907 (see Table 3).

Another record of considerable interest and significance is that of the numbers of striped bass taken in pound-net catches from 1884 to 1937 at Fort Pond Bay, Long Island, N. Y. (see fig. 4 and table 4). From 1884 to 1928 these pound-nets were owned by members of the Vail family, who kept accurate records of the numbers of striped bass caught at each haul.[3] They also indicate the number of traps in operation each year. These varied from 6 to 10, and the catches shown in this graph up to 1928 have been weighted to make them equivalent to a fishing intensity of 10 pound-nets throughout. In 1928 the ownership of these nets changed hands, but the author has been able to complete the records up to the present.[4] Unfortunately no record of the number of pound-nets in operation from 1928 to 1937 had been kept, and although this number is known to have varied only from 8 to 12, a small error is thus introduced. The magnitude of the catches is such, however, that this part of the graph—indicated by the dotted line—may be properly considered a reasonably accurate continuation of that before 1929. It is of further interest that these pound-nets have occupied essentially the same position each year over the entire period covered by this record.

It is impossible to test the validity of this record as a method of sampling the total population, and thus accurately record fluctuations in abundance that occurred. However, it is probable that it gives a fair indication of the decrease in abundance from 1884 to 1935, and that the 1936 and 1937 peaks give a correct picture of the

[2] This record was placed at the author's disposal through the courtesy of Mr. Bruce Crane, Dalton, Mass.
[3] These records were made available by the U. S. Fish and Wildlife Service and the Bingham Oceanographic Foundation.
[4] These records were made available through the cooperation of Capt. Daniel D. Parsons, Montauk, Long Island, N. Y., the present owner.

magnitude of the increased abundance resulting from the 1934 dominant year-class. The peaks at 1894 and 1895, 1906, and 1922 perhaps also represent good year-classes that bolstered the stock temporarily, but there is no adequate means of checking this, since practically no other records covering the same period are available. Striped bass tend to school heavily, and the presence of several schools might easily form the main part of such a peak as the ones shown at 1906 or 1922 in figure 4. Consequently, it may have been that in these years striped bass were not more numerous, but that one or more large schools hit the traps while on migration and gave a false impression of abundance. In another year the reverse situation might have taken place—that is, that the population was unusually high, but that comparatively few bass happened to strike the pound-nets, thus producing a low point on the curve that is not a true indication of abundance. It is, therefore, best not to assume that these fluctuations represent actual changes in the size of the population—at least not until there is further evidence on this score.

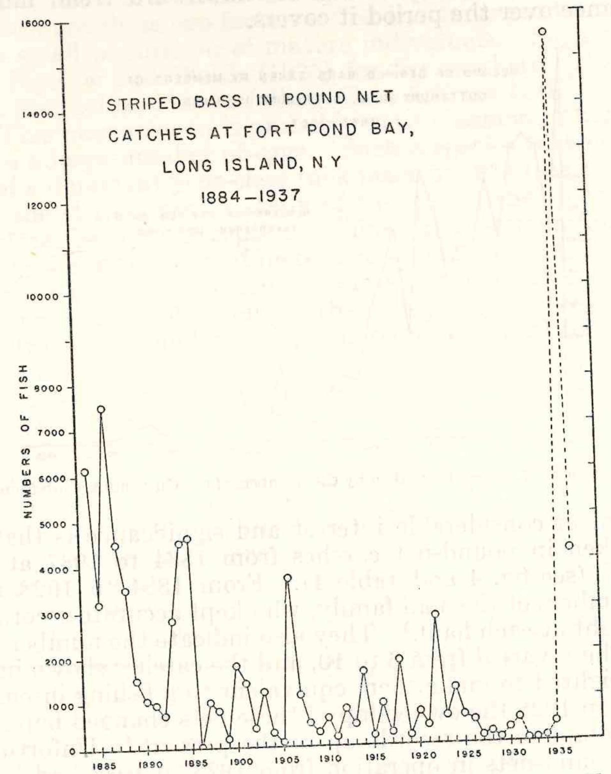

FIGURE 4.—Numbers of striped bass taken each year in the pound nets at Fort Pond Bay, L. I., N. Y., from 1884 to 1937. The fishing intensity has been equalized throughout (see Table 4).

The peak years mentioned by Bigelow and Welsh (1925) for the catches from Boston to Monomoy, Mass., from 1896 to 1921, show some discrepancy with those in figure 4. In this area 1897 and 1921 were years in which exceptional catches were made. It will be noticed, however, that these years are close to the peaks at 1895 and 1922 shown in figure 4. It may therefore be true that dominant year-classes were present from 1895 to 1897, and in 1921 and 1922, but that they made their presence felt in successive years in somewhat different areas.

The peaks at 1936 and 1937, however, are no doubt reasonably accurate indications of the increased abundance in those years. In 1936 the enormous numbers of striped bass that appeared along the Atlantic coast were mainly made up of fish 2 years old, the age at which this species first makes its appearance in the commercial and sport fishermen's catch in Long Island and New England waters. In 1937 a large proportion of the population along the Atlantic coast was composed of 3-year-olds.

The increased abundance in these 2 years was due, therefore, entirely to the 1934 year-class. This group of fish is treated in some detail in the section on age and rate of growth (p. 26), but a glance at figure 5 will sufficiently emphasize the relative abundance of the 3-year-olds in 1937. This figure is composed of three length-frequency curves made up from a random sampling of the commercial catch at different localities. Since striped bass 3 years old ranged in size roughly from 35 to 55 cm. (peak at 40 to 45 cm.) during the period these samplings were made, it is evident that the great majority of the catch was made up of 3-year-olds.

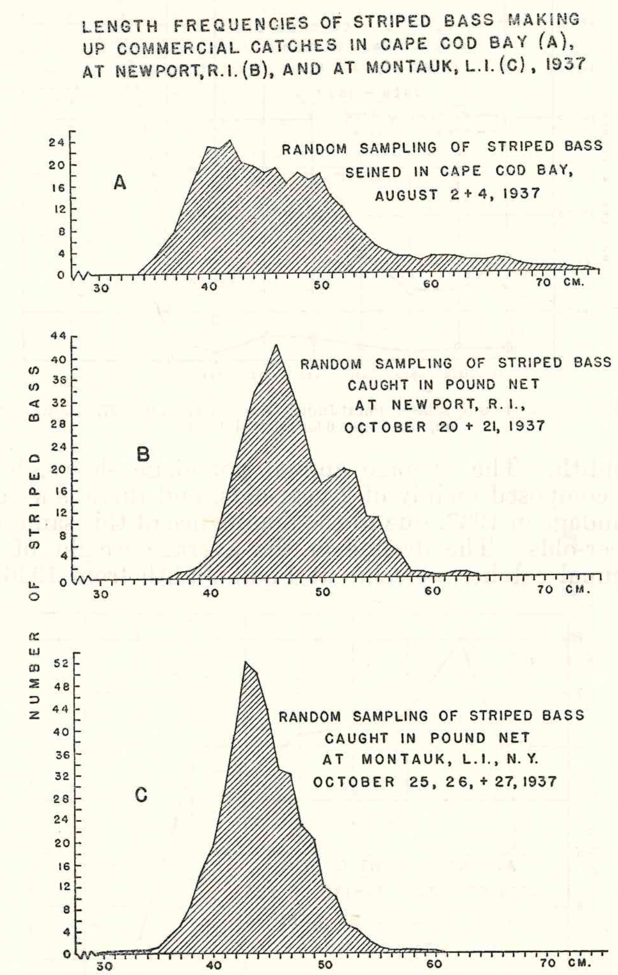

FIGURE 5.—Length-frequency curves made up from random samplings of the commercial catch in different localities in 1937. Data smoothed by threes in all cases (see Table 5 for original measurements).

Additional information on the 1934 year-class is seen in the catch records of a haule-seine fisherman at Point Judith, R. I., from 1928 to 1937.[5] (See figs. 6, 7, and 8.) Not only were the numbers and approximate poundage of the fish taken at each haul recorded, but also the date of each haul and the number of hauls annually, thus making it possible to equalize the fishing intensity throughout the entire period. The same areas were fished over this 10-year period. The annual catch in numbers of fish and total poundage are shown in figure 6, and the average weight of the striped bass taken each year is plotted in figure 7. The small proportions of the catch from 1928 to 1935 correspond well with that shown in figure 4, and the tremendous increase

[5] These records were provided through the courtesy of Mr. Chester Whaley, Wakefield, R. I.

in 1936 and 1937 is added evidence on the size of the 1934 year-class. It will be noticed, however, that the decline in the catch in 1937 is not as sharp as that shown in figure 4, probably due to the fact that this seine fishery at Point Judith took a goodly number of 2-year-olds (members of the 1935 year-class) in the spring of 1937. These fish did not make up as large a proportion of the catch at Fort Pond Bay, Long Island, N. Y., during the 1937 season. The records are not sufficiently accurate to permit an exact analysis of the relative numbers of 2- and 3-year-olds in the 1937

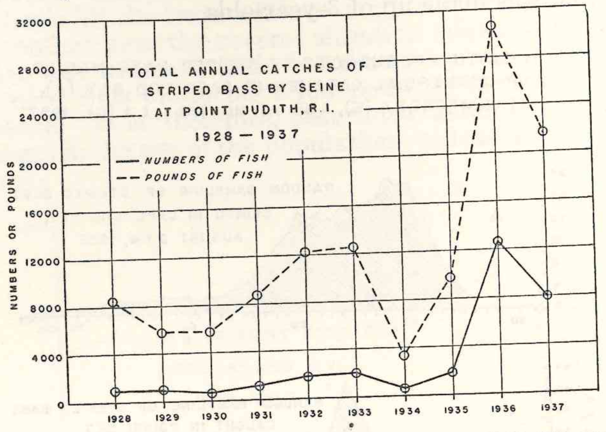

FIGURE 6.—Annual total catch of striped bass by seine at Point Judith, Rhode Island, 1928–37. Fishing intensity equalized throughout (see Table 6 for original data).

catch at Point Judith. The average annual poundage shows, however, that the catch in 1936 was composed mainly of 2-year-olds, and there is a noticeable increase in the average poundage in 1937, due to the dominance of this same 1934 age-group—at that time 3-year-olds. The decline in the average weight of the striped bass making up the annual catches by seine at Point Judith from 1930 to 1936 is quite

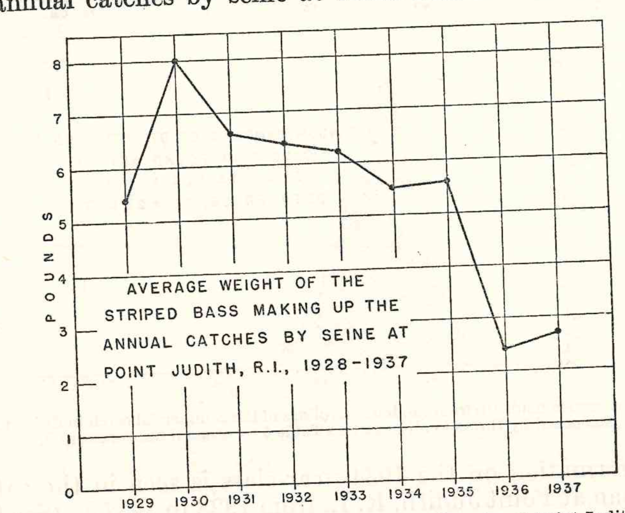

FIGURE 7.—Average weight of the striped bass making up the annual catches by seine at Point Judith, R. I., 1928–37 (see Table 6 for original data).

striking, the drop in this period being from an 8-pound average to a 2-pound average (see fig. 7). European investigators have shown a similar decline in the average annual weight making up the catch following man's intervention on a virgin stock. Thus after the World War, when the North Sea fisheries began to operate again, the larger size-categories were removed first, and in each succeeding year the catch was made up of fish of a smaller average size. In the case of the striped bass, however, the general decline in the average weight from 1930 to 1936 cannot be explained

in the same manner. This is so because although this particular seine fishery at Point Judith was a new one, it was not operating on a virgin stock, for the striped bass is a highly migratory species and is the object of intensive fisheries of different types along the entire Atlantic coast. A more logical explanation is that this downward trend in annual average weight over this period was brought about by the decreasing numbers of large fish that formed the remnant of a dominant year-class produced some years before. That there was a definite decrease in the proportion of large fish making up the catch from 1930 to 1936 is evident from figure 31, in which the percentages of small, medium, and large fish taken in each year are shown. The peak in the annual average weights at 1930 (fig. 7) was caused by the comparatively great numbers of large fish that made up the catch. Thereafter the composition of the yearly catch showed a decreasing percentage of fish from the larger size-categories (except in 1935). It seems logical, therefore, that a fairly good remnant of a dominant year-class, whose members had attained a large size, existed in 1930, and that in each successive year this remnant became increasingly smaller, thus producing the downward trend in the annual average weight of bass making up the catch in these years. The sharp drop in average weight in 1936 was primarily due to the appearance of the 1934 dominant year-class in the commercial catch.

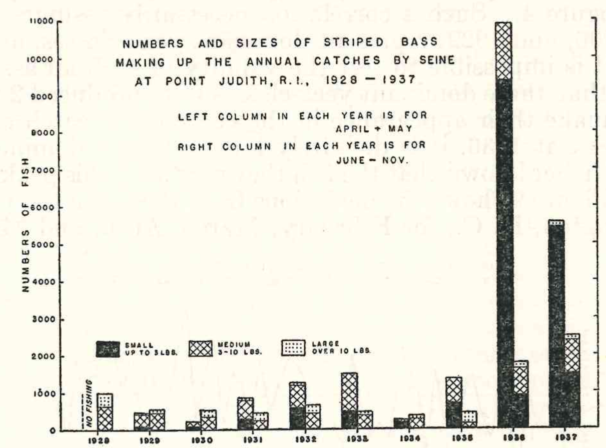

FIGURE 8.—Numbers and sizes of striped bass making up the annual catches by seine at Point Judith, R. I., 1928–37. The left column in each year is for April and May, and the right column for June to November. The fishing intensity has been equalized throughout.

The tremendous numbers of 2-year-olds in this year is well shown in fig. 8. It will also be noticed that there was an exceedingly small percentage of large fish in this year. The increase in annual average weight in 1937 was due to the increase in size of the members of the 1934 dominant year-class—at this time 3-year-olds. If no other dominant year-class comes along for a considerable period of years, it is to be expected that the annual average weight of the striped bass making up the yearly catch will climb steadily to a certain limit, i. e., until the numbers and larger size of the striped bass born in 1934 become insufficient to increase the average weight of the individuals making up the entire catch. If the production of young then continues at a low level, the annual average weight should show a steady decline until the members of another dominant year-class attain sufficient size to start it on an upward trend again. It seems likely that it is the latter part of this cycle that is shown in figures 6 and 7.

The question of precisely what caused the appearance of the dominant year-class of 1934 is of especial interest. Judging from the catch records shown in figures 4, 6, 7 and 8, there can be little doubt that this year-class represents the largest production of striped bass on the Atlantic coast in the past half century or more. Yet it is apparent, as has been pointed out, that the parental stock in 1934 was probably as small as it ever as been (see figs. 4, 6, and 8) (the catch in northern waters can be used as an indication of the size of the stock from Massachusetts to Virginia since this species is highly migratory within these limits). It would seem, therefore, that the production of a dominant year-class of striped bass is in no way dependent on the presence of a great number of mature individuals. It is thus necessary to look to other factors for the explanation of this phenomenon. Russell (1932) has pointed out that especially large dominant year-classes were produced in the North Sea in 1904 simultaneously by three different species—herring (*Clupea harengus*), cod (*Gadus morhua* [6]), and haddock (*Melanogrammus aeglefinus*). It would seem from this evidence that environmental factors apparently play some part in producing these exceptional year-classes. Russell (loc. cit.) has also mentioned the fact that ". . . there is no necessary connection between the number of eggs produced in a particular spawning season and the amount of fry which survives," and it is apparent that environmental factors are most effective in determining the percentage of survival. This is probably especially true in a species with pelagic eggs, a category to which the striped bass essentially belongs (see p. 18). Since the striped bass is anadromous, anything that might affect the rivers in which this species spawns, and the areas in which the eggs hatch and the larvae develop, is worthy of consideration. Unfortunately, the only records that are available are meteorological. Attempts have been made to correlate both temperature and precipitation, since either is capable of seriously influencing the regions where spawning and early development take place, with the prominent peaks shown in the catch records in figure 4. Such a correlation necessarily assumes that the peaks at 1894 and 1895, 1906, and 1922, represent dominant year-classes, and, as has already been mentioned, it is impossible to test the validity of such an assumption. It also takes for granted that these dominant year-classes were produced 2 years before, since striped bass first make their appearance in the commercial catch as 2-year-olds. In the case of the peak at 1936, it is definitely known that a dominant year-class was present, and it is further known that the fish that produced this peak were born 2 years before, in 1934. Figure 9 shows the deviations from the mean temperature from 1880 to 1935 at Washington, D. C., for February, March, April, and May. Washington

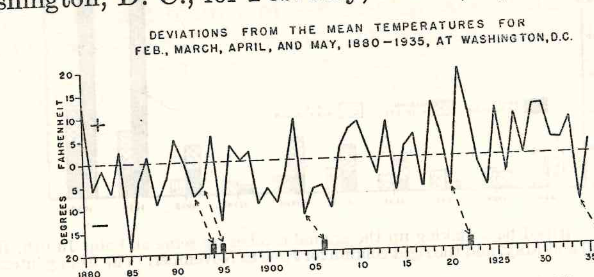

FIGURE 9.—The deviations from the mean temperature for February, March, April, and May, 1880-1935, at Washington, D. C. The black columns on the base line indicate the years when exceptionally good catches of striped bass were made, and the arrows connect them with the temperatures 2 years before, when in all probability, dominant year-classes were produced.

D. C., was chosen because it is in the general latitude of the majority of the important spawning areas for striped bass. The 4 months from February to May were chosen because May is the main spawning season (see below), and because temperatures over this period may well affect the river temperatures as late as May and thereafter. It will be seen from figure 9 that the peak years in the catch record in figure 4 invariably correspond with a below-the-mean temperature 2 years before. It seems likely, therefore, that dominant year-classes in the striped bass are produced only on a subnormal temperature. On the other hand, a low temperature during the late winter and spring months does not necessarily cause the production of a dominant year-class. There are undoubtedly other factors which must concatenate with a subnormal temperature to bring about such a production. It is impossible to state what these factors are, but examination of the precipitation records shows that there is no correlation between rainfall and the dates 2 years before the peaks at 1884 and 1885, 1906, and 1922, shown in figure 4. The inverse correlation between temperature and this catch record, however, is good. The coefficient of correlation for the entire catch record (1884–1937) and the temperature over this whole period is −.354, which is significant to the 1-percent level. It is thus highly probable that the production of dominant year-classes in the striped bass is quite closely associated with low temperatures.

[6] The spelling "*morhua*," instead of "*morrhua*" as used by most recent authors, is in keeping with Schultz and Welander (1935).

In conclusion, it may be said that there is every evidence that over a long-term period the abundance of the striped bass of the Atlantic coast has shown a sharp decline. Dominant year-classes have at times temporarily raised the level of abundance, but the intensity of the fishery is such that their effects have been short-lived. This is well shown in figure 4, where it will be noticed that the return to a state approaching the normal low abundance usually follows immediately after the appearance of a dominant year-class in the commercial catch. In the 1934 year-class, however, the numbers of striped bass reached such enormous proportions that not only did the 2-year-olds of 1936 dominate the fishery, but the 3-year-olds of 1937 also formed the main part of the catch. None the less, the sharp decline in numbers of bass taken in 1937, as compared with those caught in 1936, is clearly evident, and there can be little doubt that the members of this dominant year-class will be reduced within a few years—under the conditions of the present intensive fishery—to a point where they are negligible. The rate of removal of the different age-groups of the striped bass by the fishery is shown in some measure by the percentage of returns of tagged fish. These percentages are shown in tables 17–20, and 22. It is of interest that the extreme in percentage of recapture is seen in the case of 303 fish (predominantly 3-year-olds) tagged and released at Montauk, Long Island, N. Y., in late October 1937. Six months later over 30 percent of these tagged fish had been recaptured. Furthermore, it is not reasonable to expect that the percentage of tag returns gives a sufficiently great valuation of the rate of removal of the fish of different ages, for, among other reasons, no reward was offered for the return of tags, and it is undoubtedly true that many of the marked fish that were captured were never reported. It is roughly estimated that about 40 percent of the 2-year-olds of 1936 were taken during their first year in the fishery, and that at least 25–30 percent of the remaining 3-year-olds were caught in 1937. This means that a minimum of 50 percent of the 2-year-olds entering the fishery in the spring of 1936 had been removed by the spring of 1938, neglecting the effect of natural mortality. It thus becomes clear why dominant year-classes only raise the level of abundance over short periods, and why, in spite of the occasional increases in number, the general trend of the annual catch of striped bass has been downward. Looking to the future, there is no reason to suppose that the increased abundance caused by the 1934 dominant year-class—huge as it was—will produce any lasting effect on the stock. It is more probable that the return to the normally low level of abundance, so characteristic of the years before 1936, will soon take place, and that only the production of another dominant year-class will raise the population of striped bass to such unusually high numbers.

SPAWNING HABITS AND EARLY LIFE HISTORY OF THE STRIPED BASS

It is commonly stated in the standard ichthyological references for the Atlantic coast that striped bass are anadromous, spawning in the spring of the year from April through June, the exact time depending on the latitude and temperature (Smith, 1907, and Hildebrand and Schroeder, 1928). Most of the statements on the spawning of this species have been based on a series of papers in which S. G. Worth (1903 to 1912) discussed the problem of artificial propagation and presented many interesting sidelights on the various phases of spawning and early life history from his studies at Weldon, on the Roanoke River, N. C. Although most of the information in Worth's work is fragmentary, his observations are of value because there has been so little work on any part of the Atlantic coast to corroborate and amplify his statements. The work of Coleman and Scofield (1910) and Scofield (1931) on the Pacific coast indicates that striped bass spawn from April through June in the low-lying delta country adjacent to Suisun Bay, Calif., where the water borders between brackish and fresh.

The presence of young fry and small striped bass in the brackish waters of large rivers of the Atlantic coast offers proof that this is an anadromous species, and the absence of juvenile and yearling bass along the outer coast indicates that this species does not undertake coastal migrations until they are close to 2 years old. Thus

Mason (1882), Throckmorton (1882), Norny (1882), and Bigelow and Welsh (1925) present interesting accounts of baby bass being taken in various rivers along the coast in the past (Navesink River, N. J.; Wilmington Creek, Del.; Kennebec River, Maine). Hildebrand and Schroeder (1928) record them as being taken in Chesapeake Bay during the summer months, and Dr. Vadim D. Vladykov, while working on the survey of anadromous fishes for the State of Maryland, also took many juvenile striped bass 5–10 cm. in length on the eastern shore of Chesapeake Bay during the summer of 1936. More recently juvenile bass have been taken in the Hudson River by the New York State Conservation Department, and in the Parker River, Mass., by the author (p. 17). There is also some evidence, from the reported capture of baby bass, that isolated spawning areas still exist as far north as Nova Scotia.

There can be little doubt that striped bass in early times entered and spawned in every river of any size, where the proper conditions existed, along the greater part of the Atlantic coast, and that as cities were built and dams and pollution spoiled one area after another, the number of rivers that were suitable for spawning became fewer and fewer. At the present time there is every indication that by far the greater part of the production of striped bass along the Atlantic coast takes place from New Jersey to North Carolina, and that the addition to the stock from areas to the north is so small as to be almost insignificant and of little consequence. Thus in Connecticut, where there is much evidence—from the statements of old-time fishermen—that striped bass used to spawn, there is now every reason to believe that spawning seldom if ever occurs. During the entire course of this investigation the author has tried innumerable times in different localities to find juvenile striped bass in Connecticut waters, for since the juveniles are found close to or in areas where the adults are known to spawn, their presence in Connecticut waters would have indicated the probability of spawning occurring nearby. These efforts never met with any success. Most attention was centered on the Niantic and Thames Rivers, especially the latter, because accounts of baby bass having been caught there within the last 50 years are more numerous than for other regions. Areas similar to those where small bass were taken in the Hudson River in the summers of 1936 and 1937, as well as many other likely localities, have been worked with minnow seines and small-meshed trawls that were efficient enough to catch large numbers of young fish of many other species and occasionally even adult striped bass. However, the smallest striped bass taken in Connecticut waters was a small 2-year-old which measured 23 cm. (9 inches). If spawning occurred to any great extent, small fish 3–8 cm. long, comparable to those caught in other areas in the summer, would most certainly have been found. Plankton and bottom hauls taken at weekly intervals in the Niantic River in an area where bass were known to be present from April through November 1936, have failed to reveal the existence of anything that might be construed as evidence that striped bass spawn there. Further than this, not a single ripe fish of this species has been taken by the author in the course of this investigation in Connecticut waters, although many thousands of bass have been handled at all times of year save the winter months. Inquiries among commercial fishermen in New England and Long Island waters show that ripe striped bass have been caught so rarely and at such irregular times in recent years that their presence can be considered nothing more than abnormal. The fact that large fish that showed no signs of even approaching ripeness were commonly taken in the Niantic River during the spring and early summer months, when bass are known to be spawning in other areas, suggests that this species is not necessarily an annual spawner. The impression from the available information is that spawning does not occur in the region investigated, although it is possible that other Connecticut waters provide proper breeding grounds.

Despite the fact that there is no evidence that striped bass spawn in Connecticut waters at the present time, studies in recent years have disclosed two probable spawning areas in other northern waters. In 1936 the New York State Conservation Department took large numbers of juvenile striped bass in various localities on the Hudson River from Beacon downstream. A length-frequency curve of these fish is

shown in figure 10.[7] Curran and Ries (1937) in describing the capture of juvenile striped bass in the Hudson River, say:

> During the survey few adults but many juvenile striped bass were taken throughout the stretch of river from the city of Hudson to New York. Collections of young for the year were taken first on July 20 in Newburgh Bay. At this time they were 2 inches in length and later study of their scales proved that they were 1936 fish. From Newburgh to Yonkers, about 35 miles downstream, they were found in considerable numbers. Gravelly beaches seemed to be the preferred habitat as few were taken over other types of bottom. In night seining over the gravel they were found to be associated with herring and white perch while daytime hauls showed the herring replaced by shad. Nearly every seine haul in which young striped bass were caught brought in white perch as well.

The chlorine as chlorides ranged from 10.0–8,560.0 parts per million (water of low salinity) over this stretch of the Hudson River (Biological Survey (1936), 1937). Larger individuals—up to 2 pounds— have been taken in the Hudson as far up as Albany. There can be little doubt, therefore, that the Hudson River is a spawning area for striped bass. Their capture by commercial fishermen in April and May in this region, and the not uncommon reports of ripe individuals at this time of year, is added evidence that spawning takes place in the spring in water that is at least brackish and perhaps entirely fresh.

On August 4, 1937, the author took three small striped bass in the Parker River, near Newburyport, Mass. These fish were 7.1, 7.6, and 8.5 cm. long, and subsequent

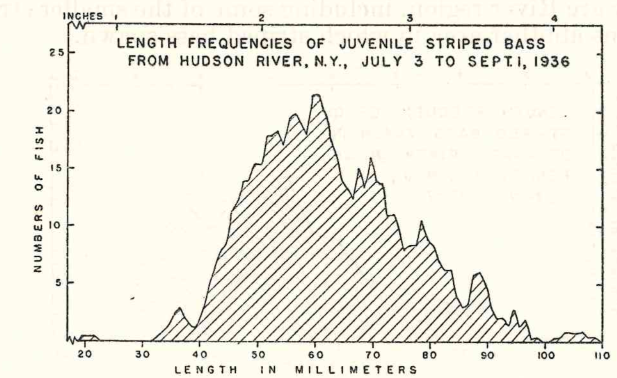

FIGURE 10.—Length-frequency curve of juvenile striped bass from the Hudson River, July 3 to Sept. 1, 1936. The number of fish making up this curve is 628. The data have been smoothed by threes. The great majority of these fish were taken in late August (see Table 7 for original measurements).

examination of their scales showed them to be juveniles. They were taken about 6 miles from the mouth of the river and about 2 miles below the Byfield Woolen Mills, where a dam prevents anadromous fishes from going further upstream. The bottom, on which these fish were seined was mostly mud and sand, with little gravel and a few scattered rocks. The salinity at this point was 10.23 parts per 1,000, and the water temperature at the surface was 25.5° C. and at the bottom 24.8° C. (ebb tide, one-third out). The depth of the river in this area at this time was 8 feet, and the width 40–50 feet. Other fish found in association with these juvenile striped bass were juvenile white perch (*Morone americana*), and various Clupeoid species; snapper bluefish (*Pomatomus saltatrix*) were also included in seine hauls in this region. The Parker River is free from pollution and is strongly tidal all the way to the Byfield Woolen Mills, where a large amount of fresh water empties into it, particularly in the spring. From this point down, the river winds through the Rowley marshes and eventually empties into Plum Island Sound. It has steep sides, and the rise and fall of the tide along the better part of its length is 5–6 feet. The failure to catch more small striped bass in this river, despite several attempts, is probably best explained by the great difficulty of seining in such an area. The steep sides of the banks and the fast tidal current both make it next to impossible to handle a seine efficiently along

[7] The entire collection of striped bass made by the members of the Biological Survey in 1936 was placed at the author's disposal in February 1938 by Dr. Dayton Stoner, State Zoologist of the New York State Museum at Albany, N. Y. Further than this, Dr. Moore, Chief Aquatic Biologist of the New York Conservation Department, and other members of the staff, gave the author much information regarding the capture of small bass in the Hudson River, before the results of the Biological Survey of 1936 were published.

this river. The capture of only three juvenile striped bass, however, is significant, and probably indicates that striped bass spawn in the Parker River. Added evidence that this is a spawning area is seen in the fact that striped bass are known to winter in this river, as is shown by their capture through the ice by bow-net fishermen. It is considered likely that this is an example of an isolated spawning area in northern waters, supported at least in part by a resident population, and possibly added to by migrants from the south in exceptional years. Although this is the northernmost point from which juveniles have been definitely reported in recent years, there can be no doubt that they were commonly taken in the coastal rivers of the Gulf of Maine in old times (Bigelow and Welsh, 1925), and there is good reason to believe that other isolated spawning areas still exist north of Cape Cod.

Another area in which juvenile striped bass were taken was in the Delaware River, near Pennsville, N. J. On November 8, 1937, the author was present when the game protectors for the State of New Jersey Board of Fish and Game Commissioners took 104 small striped bass from the intake wells of a large power plant on the Delaware River, where fish of all sorts are regularly trapped against the screens by the strong flow of water, and are removed and liberated in other regions. A length-frequency curve of this material is shown in figure 11. The examination of scales from these fish showed that the bulk of this sampling was composed of yearlings, and that only a few juveniles from about 9.0–12.5 cm. long were present. It is considered probable, therefore, that the Delaware River region, including some of the smaller streams that enter Delaware Bay, forms another area in which striped bass spawn.

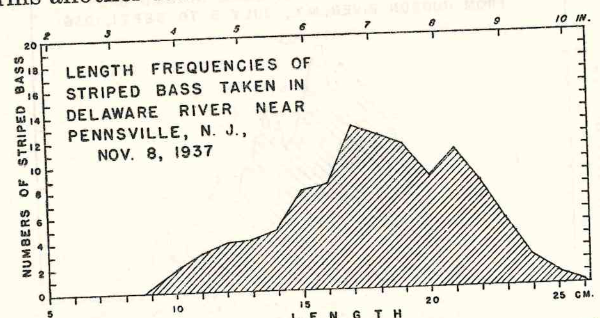

FIGURE 11.—Length-frequency curve of juvenile and yearling striped bass taken in the Delaware River, near Pennsville, N. J., on Nov. 8, 1937. The number of fish included in this graph is 104. The data have been smoothed by threes (see Table 9 for original measurements).

It has long been known from the observations of Worth (1903 to 1912) at Weldon, N. C., that striped bass spawn in the Roanoke River. The main observations on the eggs and larvae of the striped bass that are recorded in the literature for the Atlantic coast are taken from Worth's papers, and were made during the time that he conducted a hatchery at this point. Bigelow and Welsh (1925) sum up the available information as follows:

> The eggs (about 3.6 mm. in diameter) are semi-buoyant—that is, they sink but are swept up from the bottom by the slightest disturbance of the water—and this is so prolific a fish that a female of only 12 pounds weight has been known to yield 1,280,000 eggs, while a 75-pound fish probably would produce as many as 10,000,000. The eggs hatch in about 74 hours at a temperature of 58°; in 48 hours at 67°.

In recent years the hatchery at Weldon has again resumed operations, thus affording an excellent chance for the study of the eggs and larvae of the striped bass. Others have already accumulated detailed information on this subject (Pearson, 1938), and the following material (from data collected in 1937 and 1938) included herewith, is therefore nothing more than a brief account of some of the more interesting highlights of the spawning and early life history of the striped bass.

Spawning in the Roanoke River normally occurs in April and May, although occasionally there are a few stragglers that appear as late as June. It is probable that spawning takes place over a good stretch of the river from Weldon down. (Weldon is over 75 miles by river from Albemarle Sound.) At Weldon the river flows about 4 miles an hour, and is approximately 100 yards wide. Water samples taken on March 29, 1937, showed the chlorinity to be less than 5 parts per million (fresh water), the pH 7.7, and the alkalinity 53.1 estimated as milligrams of bicarbonate per liter.

In 1938 the first spawning striped bass were taken at Weldon on April 11, and by May 10 spawning was apparently completed and the fish had left this locality. This was an unusually early and short spawning season, probably due to the abnormally high temperatures during this time. From April 29 to May 11 the water temperature averaged well over 70° F. (21.11° C.) and at one time reached 77° F. (25.0° C.). During the spawning season it is a quite common occurrence to see the so-called "rock-fights" described by Worth (1903), and well known to local fishermen on the Roanoke River. These consist of a great number of small males, 1–3 pounds in weight, and apparently only a single female, appearing on the surface and causing a tremendous commotion by splashing about and creating general confusion. The activity is said to be so great that the fish often injure one another quite seriously, and fishermen who catch striped bass when they are "in fight" attest to this fact and to the number of small males, 10–50 as a rule, that take part in such a display with a single female of from 4–50 pounds. Whether or not this is actually part of the spawning act or a form of courtship does not seem to be definitely established, but general opinion favors the former view. There can be little doubt that the spawning fish at Weldon are composed mainly of males, the females probably never making up as much as 10 percent of the population. In May 1938 the examination of 127 individuals taken at Weldon showed but 6 of them to be females, and much the same sex ratio was found to obtain farther down the Roanoke River at Jamesville, N. C., at the same time.

There is no reason to doubt the accuracy of Worth's estimates of the number of eggs produced by a single female striped bass. Records kept at the hatchery at Weldon during 1928, 1929, 1931, 1932, 1937, and 1938, show that the number of eggs per female varied from 11,000 to 1,215,000 in a total of 111 individuals examined in this time. The majority of these fish yielded from 100,000 to 700,000 eggs each. Unfortunately the weights of the individual fish on which these counts were made were not taken, but a single female weighing 4½ pounds, taken at Weldon on May 4, 1938, produced 265,000 eggs.

The eggs of the striped bass average about 1.10–1.35 mm. in diameter when they become fully ripe, and at the time that they are extruded into the water. During the first hour after fertilization the vitelline membrane expands tremendously, thus creating a large perivitelline space. Measurements on a series of 50 eggs that were preserved 1 hour after fertilization in a solution of 7 percent formaldehyde gave an average measurement of 3.63 mm. in diameter, the extremes being 3.24 and 3.95 mm. Eggs similarly preserved at longer time-intervals after fertilization showed the same general measurements. So far as one can judge from preserved specimens, the description given by Bigelow and Welsh (loc. cit.) of the eggs as being semibuoyant fits perfectly. These eggs are undoubtedly swept far downstream by the strong current, and the protection against injury by jarring afforded by the large perivitelline space is probably of no small consequence in the survival of the developing embryos. The speed of development and the time to hatching is of course dependent on temperature. At 71°–72° F. (21.7°–22.2° C.) hatching occurs in about 30 hours, while at 58°–60° F. (14.4°–15.6° C.) hatching normally takes place in about 70–74 hours. In view of the fast current in the Roanoke River, and the rate at which the developing eggs are carried downstream, it is reasonable to assume that hatching probably does not take place until they are close to the mouth of the river or even in Albemarle Sound. Figure 12 shows the different stages of development of striped bass eggs and larvae that were reared in the hatchery at Weldon, N. C. These eggs were fertilized artificially and held at a temperature of 70°–72° F. (21.1°–22.2° C.). The photographs of the eggs were taken from above looking down. A side view would in reality show that the yolk, with the developing embryo and oil globule, lies at the lower pole of the whole egg as it floats normally in the water. The single large oil globule which is imbedded in the surface of the yolk always lies uppermost, and the blastodisc appears on the side of the yolk in an area that is approximately at a 90° angle with the oil globule—not just opposite the oil globule on the lower pole as Wilson (1891) has shown for the sea bass ("*Serranus atrarius*"—Wilson, loc. cit., now called *Centropistes striatus*). Hatching occurred in 30 hours in the lot under observation, and it will be seen in figure 12 (F) that 6½ days later the yolk sac was almost completely absorbed.

To the author's knowledge, the smallest striped bass that have ever been taken in their natural habitat were seined along the shore of Albemarle Sound from Mackeys to Rea's Beach, N. C., on May 11, 1938. Since the first spawning fish were taken on April 11 in this year at Weldon, it is likely that these individuals were not more than 1 month old. A length-frequency curve of the 85 juveniles taken at this time is shown in figure 14, and it will be seen that they ranged in size from 1.9–3.1 cm., the peak falling at 2.7 cm. The growth of the striped bass from this age on is further discussed in a later section.

In general, then, it may be said that all the evidence points to the fact that the striped bass is anadromous, spawning in the spring of the year, the exact time probably depending on temperature and latitude. It is not definitely established, however, how high a salinity the eggs and larvae of bass will tolerate. Considering the wide variation in the type of river in which bass are known to reproduce, it does not seem unlikely that spawning may at times take place successfully in areas where the water is at least strongly brackish and perhaps even strongly saline. Worth (loc. cit.) first noticed that in raising artificially fertilized eggs of striped bass, an apparatus similar to MacDonald jars—in which the eggs are kept in a strong circulation of water—was necessary in order to get a high percentage of normal development. It would seem, therefore, that a fairly strong current is probably essential for the development of the eggs, but that this may be either tidal, such as that in the Parker River, Mass., or mainly fresh water, as in the Roanoke River. Some possible evidence that spawning does not necessarily always take place in waters of extremely low salinity is provided by the irregular and inconstant manifestation of what appear to be distinct spawning marks on the scales of mature striped bass (see p. 24), for it is generally assumed that such marks are only found on fish that enter fresh water. It would be logical to expect that if all striped bass entered fresh water for spawning purposes, spawning marks on the scales would be more common than they actually are. Such spawning marks are, of course, particularly well-known on scales from salmon (*Salmo salar*), which do not feed to any great extent during their sojourn in fresh water for spawning purposes, and whose scales are probably partially resorbed during this period, thus forming the characteristic spawning mark. It should be pointed out, however, that striped bass undoubtedly do not stop feeding to the same extent or for a similar length of time during spawning.

SEX AND AGE AT MATURITY

It is impracticable to get large quantities of striped bass for sex determinations and stomach-content analyses anywhere along the Atlantic coast. This is so because this fish is almost universally shipped to market, and frequently even sold to the individual customers, without being cleaned; hence it was not possible to examine the body cavities in large numbers in the wholesale markets. Since there is no valid method of determining sex without inspecting the gonads, the collection of quantitative data on this phase of the work was necessarily limited to the study of fish caught on rod and line by sportsmen and cleaned by the author, to a number of small random samplings of bass that were seined during tagging operations, and to a few fish that were examined on different markets as they were being sold.

A total of 676 striped bass caught in northern waters (Long Island and New England) from April to November 1936 and 1937 were examined for sex. These fish ranged in size from 25 to over 110 cm., and in age from 2 years old to over 12 years old. Of these 676 fish, only 9.7 percent were males. One hundred and eighty-three of them were 3 years old or more, and only 4.4 percent of these were males. No males above 4 years old have been found in northern waters. The remaining 493 fish examined were 2-year-olds, 11.8 percent of which were males. Although the number of fish examined for sex is too small to permit any final conclusions, there is little doubt that the number of males in northern waters seldom reaches much over 10 percent of the entire population. And the evidence so far is that the percentage of males is greatest among the 2-year-olds—that age at which this species first undertakes the migration from further south (see p. 44), and appears in large quantities in northern waters; the percentage of males apparently decreases in the age categories above the 2-year-olds.

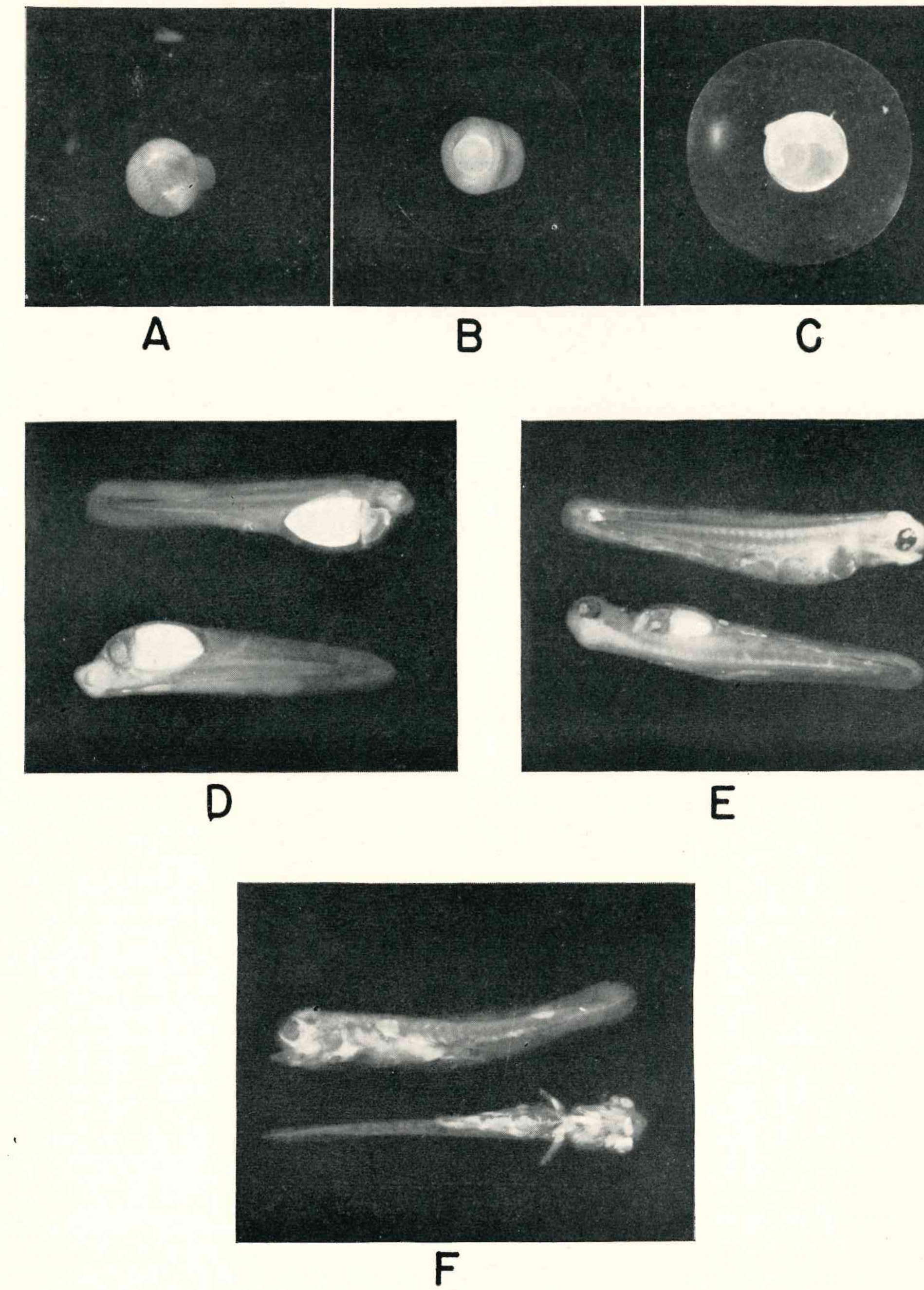

FIGURE 12.—Six developmental stages of striped bass eggs and larvae raised at the hatchery at Weldon, N. C., at a temperature of 70–72° F. Hatching occurred at 30 hours. Magnification equals ×8.2 throughout. A. 1 hour after fertilization. B. 17 hours after fertilization. C. 29 hours after fertilization. D. 20 hours after hatching. E. 60 hours after hatching. F. 6½ days after hatching.

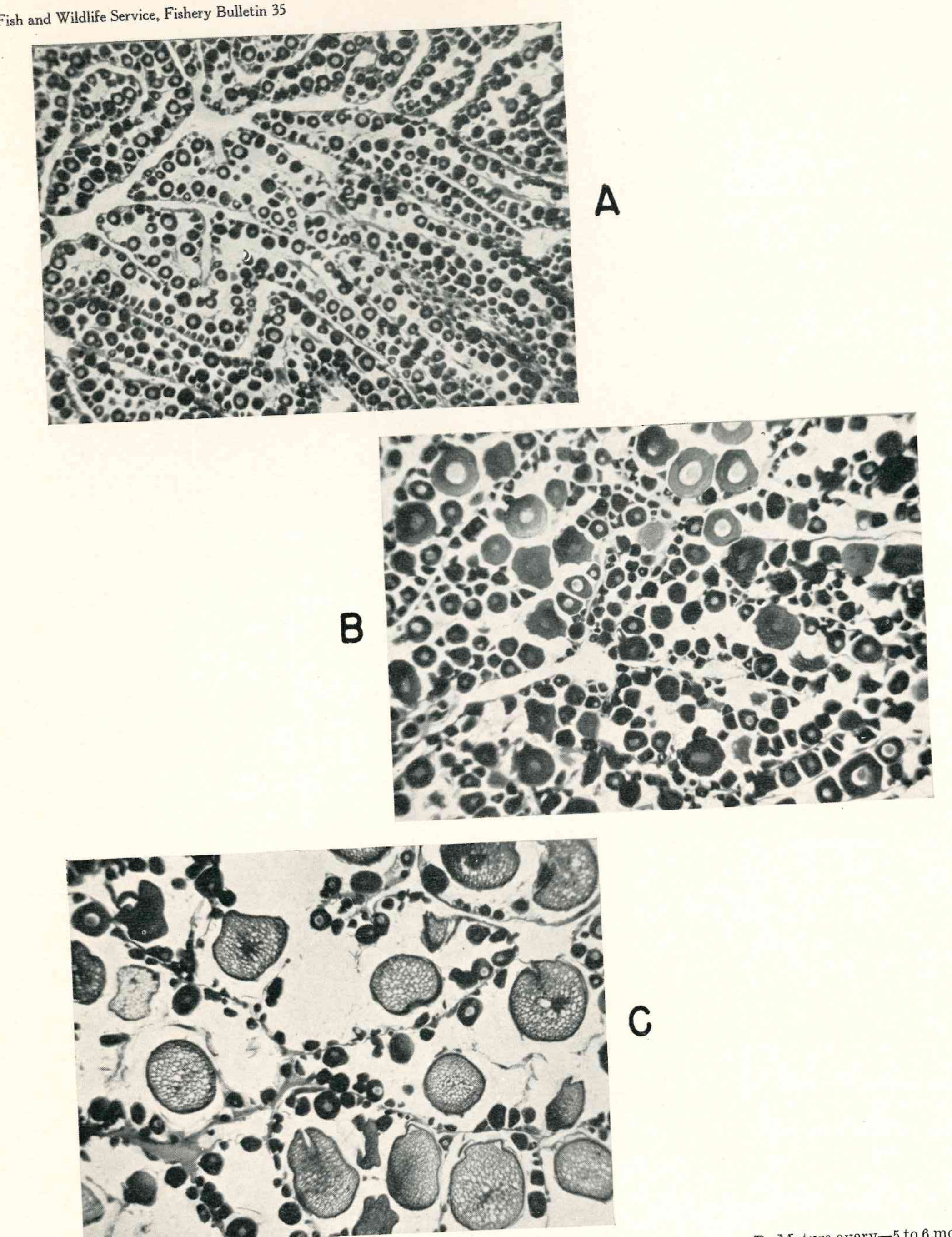

FIGURE 13.—Sections through immature and mature striped bass ovaries. A. Immature ovary. B. Mature ovary—5 to 6 months before the spawning season. C. Mature ovary—approaching full maturity. Magnification throughout ×36.

Such a disproportionate number of females to males is of course most unusual, and it seems unlikely that this condition prevails among the total population of the Atlantic coast. The examination of 29 small bass from Delaware Bay in November 1937 showed approximately 45 percent were males. A sample of 126 bass ranging in size from 21 to 42½ cm., from Albemarle Sound, N. C., in March and April 1938 was composed of 31.7 percent male fish. There is also evidence that the composition of the spawning populations of striped bass is predominantly male (p. 19). A theoretical explanation of the strikingly low percentage of males in northern waters is included in the section under migrations (p. 44).

In studies of the age at maturity, miscroscopic examination of the gonads presented the most plausible method of procedure in northern waters. The fact that ripe [8] individuals were not available in Connecticut precluded the possibility of studying the age groups making up a spawning population. Gonads from 109 female striped bass ranging in size from 32 to 110 cm. were collected at various intervals from April through November 1936 and 1937. Of these, 46 were fixed in Bouin's fluid and slices from the anterior, middle, and posterior region of each one were cleared in toluene.[9] These were sectioned, stained with Delafield's hematoxylin and eosin, and mounted. Samples of up to 50 ova from each of the three regions of the gonads from which slices were taken were then measured by means of an ocular micrometer. It was soon found that samples from the anterior, middle, and posterior parts of each ovary contained eggs of the same general sizes, and that there was no significant difference between the ova of these regions, no matter at what stage of development the gonads were. Thereafter only sections from the middle of each ovary were studied. The remaining 63 ovaries from striped bass collected from April through November 1936 and 1937 were preserved in a solution of 10 percent commercial formalin and water. Slices from the middle of each one of these gonads were then macerated mechanically, until the eggs either floated free or could be easily teased from the surrounding epithelium. Samples of up to 50 ova from each ovary were then measured under a dissecting microscope by means of an ocular micrometer. The measurements on the eggs from 109 ovaries by these 2 methods gave comparable results throughout.

A study of the measurements of the eggs from striped bass of different sizes almost immediately revealed that there were two easily distinguishable types of ovaries. (See fig. 13.) The first type had eggs whose diameters consistently averaged 0.07 mm. There were occasionally eggs as large as 0.18 mm. in diameter, but more commonly the largest eggs measured 0.11 mm. The second type contained eggs of two definite size categories; there were small eggs of the same size as all those that were seen in the first type of ovary, averaging 0.07 mm. in diameter, and there were large eggs averaging 0.216 mm. in diameter or greater, the extreme size that has been encountered being 0.576 mm. It is a reasonable assumption, especially in view of Scofield's (1931) work, that those ovaries containing only small eggs represent immature fish, and that those ovaries having eggs of both small and large size come from fish that are mature, in the sense that the large eggs are those that will be produced the following spawning season. A possible criticism of this assumption is that part of the material examined might have been composed of ovaries from fish that had just completed spawning, and that such ovaries might, therefore, contain only eggs of the small size. On the basis of the distinction between mature and immature individuals proposed above, these fish would then be considered immature, a conclusion that would be entirely erroneous. There is no evidence, however, that ovaries from fish that had completed spawning immediately before were included in the material. It has already been pointed out that spawning individuals were not found in the waters from which this material was collected, and it is most unlikely that any freshly spawned bass were studied for the purpose of determining the age of maturity. Moreover, by far the greater part of the collection of gonads of striped bass of different sizes took place in the summer and fall, by which time spawning is known to be long since past. Another possible criticism of this method of determining the age at maturity of striped bass is that some of the material may have come from fish that were not spawning the following year, for this species is not necessarily an annual

[8] The word "ripe" is used throughout to connote flowing milt or eggs.
[9] Oil of wintergreen and other clearing agents were also used at first, but in general toluene gave the most satisfactory results.

spawner (see p. 16), and might therefore not have contained eggs of the larger size although the fish were mature. It is considered unlikely, however, that any serious error in the results is introduced by this means.

The results from this method of studying the age at maturity indicate that approximately 25 percent of the female striped bass first spawn just as they are becoming 4 years old, that about 75 percent are mature as they reach 5 years of age, and that 95 percent have attained maturity by the time they are 6 years old. The average lengths of individuals of these sizes are discussed in the following section (p. 30), and table 10 gives the results of determining the age at maturity of 109 female striped bass of known length by measurements of the diameters of the ova.

The examination of spawning individuals in North Carolina in the spring of 1938 gives added evidence on the age at which female striped bass first spawn. Scale samples from 25 fully ripe females of measured length (43 to 78½ cm.) were collected in late April and early May. The smallest of these fish was 43 cm.—a bass that was just becoming 4 years old, but was somewhat smaller than the average individual of this age. There were also 5 other individuals from this lot of 25 mature females that were the same age as this smallest fish. Of the remaining 19 fish, 16 were just reaching 5, 6, or 7 years of age, while the other 3 were 8 or 9 years old. During the period when these mature females were encountered, a great many hundreds of smaller females

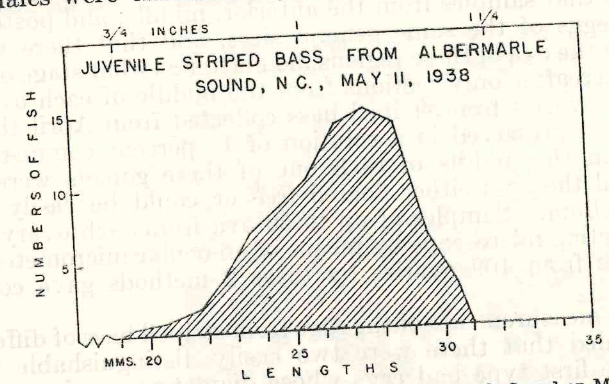

FIGURE 14.—A length-frequency curve of 85 juvenile striped bass taken in Albemarle Sound on May 11, 1938. Data smoothed by threes (see Table 9 for original measurements).

from 1 to 3 years old were handled, but none were ever found to be ripe, thus offering further proof that female striped bass do not arrive at maturity until they reach at least 4 years of age.

Male striped bass, on the other hand, become mature and first spawn at a much earlier age. A total of 303 ripe males were encountered in late April and early May in the Albemarle Sound region in 1938. The smallest of these was 21.5 cm. long and was just becoming 2 years old, although it was unusually small for a fish of this age. The largest was 51.5 cm. long, and was just becoming 5 years old. Of the 303 ripe males examined, 150 were just becoming 2 years old, and all the remainder, except the largest individual mentioned above, were becoming either 3 or 4 years old. It thus becomes apparent that a large percentage of male striped bass are mature at the time they become 2 years old, and it is probably true that close to 100 percent are mature by the time they become 3 years old. (See Vladykov and Wallace, 1937.)

AGE AND RATE OF GROWTH

It has been well established in an ever increasing number of species of fish that scales, since they present more or less concentric rings or annuli, may be used for age determinations. It is generally assumed that the formation of a true annulus is caused by the slowing down or almost complete cessation of growth in the winter, resulting in the arrangement of the circuli so that an annulus appears. Actually, in the striped bass, the annulus does not appear in the winter and only becomes evident by April or May. Further than the determination of age, scale analysis has other vitally important applications in studies on the life histories of fishes. It can be used for growth calculations, is often a method for determining the geographical

point of origin of individual fish, and provides a means of studying migrations—e.g., in salmon, *Salmo salar* (Masterman, 1913), and herring, *Clupea harengus* (Dahl, 1907)—age at maturity, and the number of times spawning occurs in different individuals.

In the case of the striped bass, there had been no previous work on the Atlantic coast to determine the validity of the scale method for age and rate of growth studies, although Scofield (1931) had applied it successfully on striped bass in California. The preliminary examination of scales immediately disclosed the presence of distinct annuli, which were increasingly numerous, the larger the fish from which the scales were taken. Moreover, the number of annuli were normally constant on different scales taken from a single individual. Also the scales taken from 17 fish that were tagged in 1936 and recaptured from May to September of 1937 invariably showed that the formation of an added annulus had taken place in the winter intervening between the dates of release and recapture. In view of this and much other evidence, it seemed that the scale method was definitely applicable to the striped bass.

During the course of the investigation scale samples were taken from approximately 7,000 striped bass of measured length. Over 5,000 of these samples have been mounted and studied. It is essential that all scales be taken from the same area on the different fish if they are to be used for growth-rate studies, for the shape and size of scales from different regions of the body vary to a marked extent and thus scale measurements can only be considered comparable if the samples are homologous.

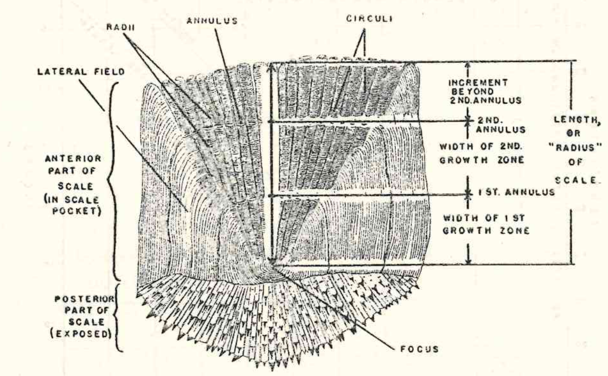

FIGURE 15.—Diagrammatic sketch of a striped bass scale to show parts and method of measurement.

Hence all scales were taken from the first or second white stripe above the lateral line in the mid-region of the body directly below the gap between the spinous and soft dorsal fins, for it was found that scales from this area were more consistently suitable for study than those from any other place. A single sample generally consisted of 4 or 5 scales.

Length measurements of all striped bass were made from the tip of the lower jaw to the fork in the center of the caudal fin, for it became evident in handling live fish which were being tagged that measurements of this type were the easiest to make and the least subject to error. All lengths given in this bulletin are to the fork in the tail, unless otherwise specified. Figure 16 is a graph for the conversion of different types of length measurements. A flat measuring board with vertical head-piece was always used, and measurements were made to the nearest half centimeter.

Scale samples were prepared for study by two different methods. The first 600 were mounted on standard 3- by 1-inch slides with ⅞-inch cover-slips, the mounting medium being corn sirup. All the remaining samples were prepared by taking the impressions of the finely sculptured outer surfaces of the scales on transparent celluloid. Lea (1918) first showed with herring scales:

> . . . that all details which are subjected to observation when the scales are used for the purpose of age determination and growth calculations, arise from the play of light on the delicately moulded relief forming the outer surface of the scales (Lea and Went, 1936).

Lea produced casts, or imprints of the outer surfaces of scales in thin celloidin films and found them ideal for study. Nesbit (1934a) devised an efficient method of producing scale impressions that was fast and at the same time gave accurate results. This method has been applied with complete success to striped bass scales. Transparent celluloid, acetate base, was obtained in sheets 20 by 50 inches and 0.050 inch thick. It was cut into pieces 1 by 2½ inches so that over 100 fitted in an ordinary wooden slide-box of 25-slide capacity. The scale-sample numbers were written on each slide with Volger's Opaque Quick-Drying Ink. The surface of a slide was then softened slightly by spreading a thin film of acetone over it with a glass slide, and the scales making up that particular sample were placed outer surface downward on the area that had been moistened with acetone. The slide and scales were next subjected to pressure under a reinforced seal press having a die approximately 1¼ inches in diameter. The scales were then removed and the impressions of their outer surfaces were left clearly imprinted on the slide. Measurements on 50 scales from striped bass of all sizes were made before they had been subjected to pressure, and then the impressions of these same scales on transparent celluloid were measured; there was no significant difference in the two measurements. Thus it is clear that no stretching takes place in the scale impression method described above. The advantages of this method are threefold: (1) The cast of the outer surface is easier to

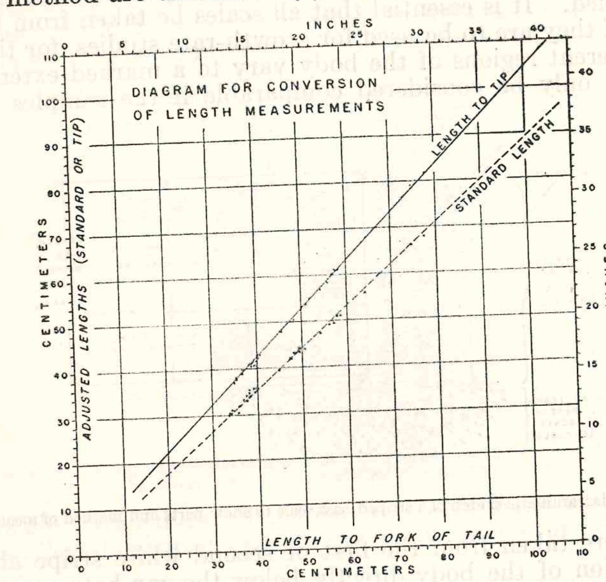

FIGURE 16.—Diagram for the conversion of different types of length measurements.

study than the scale itself because the light does not have to penetrate the fibrillar layers of the scale to show the desired marking; it is also better for photographic purposes. (2) The method is much faster. (3) The cost is far less.

All scales, or scale impressions that were studied for age determinations, or on which measurements were made, were first examined under a dissecting microscope, a magnification of about 20 times being satisfactory for most purposes. Those that were measured were then placed in a micro-projection apparatus and the necessary measurements were made on the image, which was magnified 13.75 times.

The problem of interpreting annuli correctly at all times in scales from striped bass is somewhat complicated by the occasional presence of accessory, or false annuli. Usually, however, these false annuli are different in structure, so that they are quite often easily recognizable. The false annuli are mainly of two types. The first is a broad accessory annulus that is scarlike in its appearance and is frequently seen on scales from larger fish, extremely rarely on those from smaller individuals 2 or 3 years old. This type of mark invariably appears just outside a true annulus or in close conjunction with it. It seems likely that these are spawning marks, since striped bass are anadromous and spawning occurs in the spring near the time of the formation of a true annulus (pp. 20 and 22). The second type of false annulus has much the same appearance as a true annulus, but is distinguishable on close examination by the

character of the circuli that border it. This type occurs most commonly on scales that overlap a regenerated scale. It appears that the process of regeneration in a scale modifies the growth of adjacent scales sufficiently to form false annuli on the latter. This type was observed frequently, particularly on scale samples from tagged fish that had been recaptured and had regenerated scales in the area from which a sample was taken at the time of their original release. Regenerated scales were common in all samples, often forming at least 10 percent of those examined. Sometimes entire samples had to be discarded because there were no scales that were not regenerated. Up to 15 percent of the samples have been rejected on rare occasions because of false annuli, regenerated scales, and other factors which made the age determinations and scale measurements subject to serious errors. Scales from larger striped bass were found to be much more difficult to read for age than those from smaller individuals. Not only did the first annuli become indistinct, but there were likely to be more false annuli so that age determinations were confusing. For this reason growth calculations by the scale-measurement method have been confined to fish less than 5 years old. Particularly on scales from fish over 8 years old it was almost impossible to be sure that the age reading was correct, and on fish of this size or larger it was only feasible to make approximations as to the age of each individual. As a check on age determinations of striped bass of all sizes the growth rings on otoliths have frequently been counted, and it was found that on individuals up to 3 years old this method was satisfactory. The opercular and subopercular bones have also been examined for annular markings, which were best seen after these bones had been cleared in a half-and-half mixture of 5 percent glycerine and potassium hydroxide. On the whole such markings were found to be indistinct and irregular, and did not constitute an adequate means of making age determinations.

Since the youngest striped bass taken in Connecticut waters during the course of the investigation were 2 years old, age determinations and rate of growth studies on juvenile and yearling fish were necessarily confined to material from elsewhere. The growth of the larvae has already been discussed under spawning habits and early life history (p. 19). The smallest juveniles that have been taken in their natural habitat have also been described, and, as is shown in figure 14, these fish, which were not more than 1 month old at the time they were seined in Albemarle Sound, averaged about 2.7 cm. in length. Figures 10 and 11 show the range in size of juvenile bass from the Hudson River, and of juvenile and yearling bass from Delaware Bay. It is apparent that juvenile striped bass in the Hudson averaged 5–7 cm. in length by the middle of the summer (see fig. 10). The juvenile bass taken in Delaware Bay in November 1937 formed only a small part of the curve shown in figure 11, the bulk of this sample being made up of yearling fish. The juveniles at this time, however, were from 9.5–12.5 cm. long. Growth practically ceases in the winter, and when striped bass become 1 year old in the spring they average 11–12 cm. long. Six yearling individuals taken in the Hudson River in July and August, 1936 and 1937, averaged 14.3 cm. (extremes 12.0–15.9 cm.). The yearlings in the Delaware Bay region (see fig. 11) averaged approximately 19 cm. in November 1937. By the time they become 2 years old striped bass are about 20–23 cm. in length, and it is at this age that this species probably first takes any large part in the coastal migrations. It should be mentioned at this time, however, that even in juvenile and yearling striped bass there is a tremendous variation about the mean in the measurements of any age group at any one time, as can be seen from figure 11. The subject is further complicated since the populations under consideration were from different areas where in all probability slightly different growth rates occur. Thus the lengths given for striped bass of different ages throughout can only be rough approximations.

Fish 2 years old and older were sufficiently abundant to give ample material for growth-rate studies in Long Island and New England waters, particularly on the members of the dominant 1934 year-class. Figure 17 shows length-frequency curves of all striped bass measured in Connecticut waters from April through October 1936 and 1937. The prominent peaks that characterize these two curves are mainly made up of the 2-year-olds in 1936 and the 2- and 3-year-olds in 1937, and they give some idea of the relative abundance of the members of the 1934 year-class. The measurements that make up these graphs come mainly from seined individuals, but they also come from fish that were caught on rod and line and in pound-nets. Although this method of sampling the total population cannot be entirely free from error, it is probable that these curves represent the relative proportions of the different size- or age-groups to one another fairly accurately for the general region of the Niantic and Thames Rivers, Conn. The tendency of this species to school heavily, particularly among the smaller size-categories, thus making them more available and easier to catch, may have resulted in an over-emphasis on the relative numbers of the members of the 1934 year-class. And the fact that the larger fish tend to lie among the rocks in or near the surf, in places where they cannot be reached by seining, perhaps provides reason to suppose that these larger fish are not proportionately represented in these graphs. On the other hand, evidence from samplings of the striped bass population from commercial fishermen's nets in northern waters indicates that the 2-year-

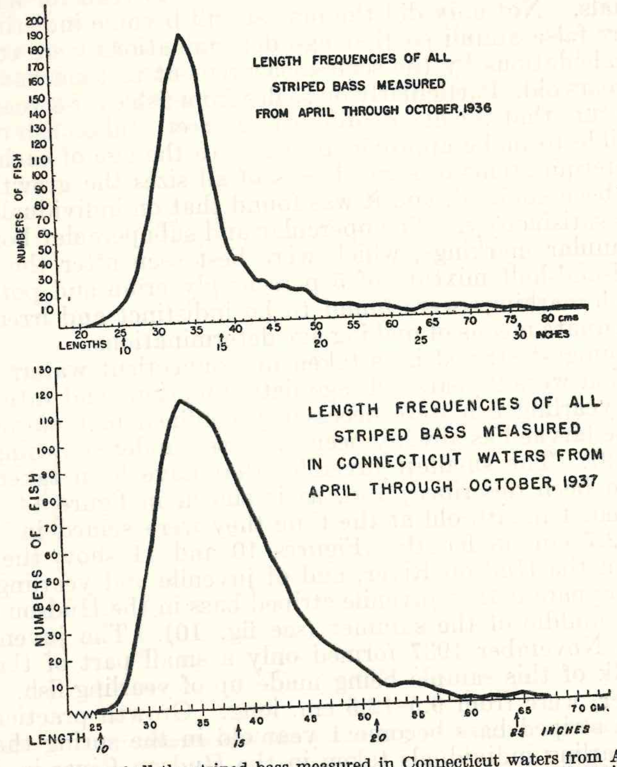

FIGURE 17.—Length-frequency curves of all the striped bass measured in Connecticut waters from April through October, 1936 and 1937. The data have been smoothed by threes throughout. See text for further discussion. See Table 11.

olds in 1936 comprised over 85 percent of the stock available at this time (see fig. 8) and that the members of this year-class continued to dominate the population in 1937 in spite of the fast rate of depletion of fish of this age due to the highly intensive fishery (see figs. 5, 6, 7, and 8). Evidence from other samplings of the stock in northern waters in the summer of 1937 shows that the 2-year-olds of 1937 are apparently represented too strongly in the length-frequency curve for this year (see fig. 17). It is difficult to account for the large proportion of 2-year-olds in the lower graph in figure 17, but it is clear that they were not relatively as abundant in 1937 in all northern waters (see fig. 5). It seems probable that the Niantic and Thames Rivers, where most of the fish that make up the length-frequencies in figure 17 were taken, are especially favorable for the smaller sized (2-year-old) bass.

The growth by months of the 2- and 3-year-olds seined in Connecticut waters from June through October for 1936 and 1937 is shown in figure 18. It will be seen that the 2-year-olds in June 1936 averaged about 29 cm., and that there was a steady progression in the monthly modes through to October 1936 where the 2-year-olds were roughly 37–38 cm. long. The 3-year-olds in 1936 showed much the same type of growth, the modes of the monthly length-frequency curves for this age-group progressing from 40–41 cm. in June to 48–49 cm. by October 1936. The 2-year-olds of

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1937 exhibited approximately the same amount of growth (8–9 cm.) from June through October as fish of the same age in 1936, but it will be noticed that they consistently averaged at least 2 cm. larger over this entire period. Thus the modes of the length-frequency curves of the 2-year-olds of 1937 moved from 31 cm. in June to 39 cm. in October. However, the 3-year-olds of 1937, although growing the same amount as fish of the same age in 1936 over an equivalent period of time, averaged 2 cm. smaller throughout, the modes moving from approximately 38 cm. in June to 46 cm. in October. The comparison of any of the monthly length-frequency curves in 1936 with its counterpart in 1937 clearly shows that the 2-year-olds in 1937 were distinctly larger than those of 1936, while the 3-year-olds of 1937 were definitely smaller than fish of the same age in 1936. The members of the dominant year-class of 1934 (2 years old in 1936 and 3 years old in 1937) therefore appear to have been below average size.

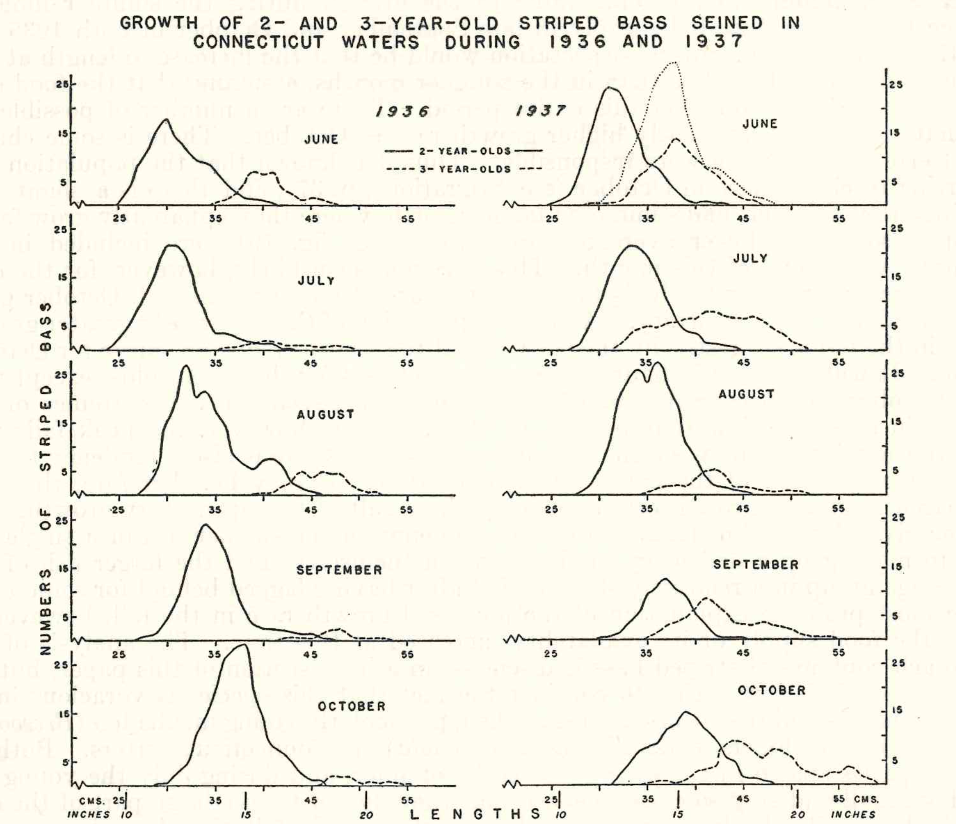

FIGURE 18.—The growth of the 2- and 3-year-old striped bass seined in Connecticut waters during 1936 and 1937. The curves are smoothed in every case by a moving average of threes. The numbers of fish making up each curve have not been equalized except in that for September 1936, where the total number of fish was divided by three. The dotted line in the June 1937, length-frequency curves is a repetition of curve for the 2-year-olds in October 1936, and is included for the purpose of comparing the 2-year-olds of October 1936, with the 3-year-olds of June 1937 (members of the same year-class) (see Table 12 for original measurements).

They were consistently smaller than the fish which were born in 1933 or 1935 were at equivalent ages; both the 1933 and 1935 year-classes were few in numbers by comparison to the dominant 1934 year-class. It is quite clear that this lesser average length of the members of the dominant 1934 year-class developed before the individuals became 2 years old. The smaller sizes of the individuals making up this dominant age-group agree well with Jensen's (1932) studies on plaice (*Pleuronectes platessa*) in the North Sea, where it was shown that a strong year-class checks the growth of the fish in this age-group. Jensen (loc. cit.) also points out that the principle of the smaller-than-average size of the individuals making up a dominant year-class, at least in plaice, also appears true from Thursby-Pelham's work, where it is shown that the rich year-class of 1922 was distinguished by a small average length. This is explained by Jensen on the basis of increased competition for food among the members of the same size category. Other European investigators, however, have not found that the same phenomenon applies in other species of fish in the North Sea. It is possible that environmental factors, such as low temperatures in the spring and early summer of 1934, played some part in the smaller-than-average size of the members of the 1934 dominant year-class of striped bass.

It will be noted in figure 18 that the growth rate of the 2- and 3-year-olds in 1936 and 1937 was fairly steady over the period from June through October. In general, the modes of the length-frequency curves for the 2-year-olds progressed about 2 cm. each month. In October 1936, however, the 2-year-olds appear to have shown an increased growth rate, the mode for this curve having progressed 3–4 cm. beyond that for September. In October 1937 the fish of this age did not exhibit a similarly increased growth rate, but the mode for this length-frequency curve progressed about 2 cm.—an amount about comparable to the growth during the summer months. Since the temperature fell sharply in late September and October in both 1936 and 1937 (see fig. 30), the normal expectation would be that the increase in length at this time would have been less than in the summer months, assuming that the food supply remained constant over this entire period. There are a number of possible explanations of this apparently higher growth rate in October. There is some chance that errors in sampling were responsible. Thus it is known that the population was starting to change late in October (see Migrations, p. 37), and there is a slight possibility that fish that had summered farther north, where they apparently grow faster despite somewhat lower average temperatures (see fig. 19) were included in the samples at the end of this month. This does not seem likely, however, for the consistent recapture of individuals tagged in this area from June through October gives good evidence to the contrary. Another explanation of the apparently greater growth rate in the fall is suggested by the skewness of the length-frequency curve for October 1936. It will be noted in figure 18 that in all curves for the 2-year-olds, except that for October 1936 the peaks come about midway between the two extremes of the range in size, or below that point. In October 1936, however, the peak falls well above the midpoint between the extremes of size, and there is also a tendency toward the same situation in the curve for October 1937. It may be, therefore, that this apparently greater growth rate is possibly the result of "compensatory growth," the name given by Watkin (1927) to the phenomenon of the smaller fish of a single age group making up a deficiency in size between themselves and the larger fish of the same age group in a relatively short period after having lagged behind for some time. The most probable explanation of the increased growth rate in the fall, however, is that the food supply or its availability increased at this time. The analysis of the stomach contents of striped bass is discussed in a later section of this paper, but for the present it is interesting to consider the fact that this species is voracious in its feeding habits and that it preys on small fish, particularly young menhaden (*Brevoortia tyrannus*) and shiners (*Menidia menidia notata*) in Connecticut waters. Both of these species spawn in the spring and early summer, and during July the young are still so small and stay so close to shore that they do not form a large part of the diet of the bass. But by late summer, and particularly early fall, they have increased in size to such an extent that they have added enormously to the available food supply. (For information on the growth rate of *Menidia*, see Food of the striped bass, p. 53, and fig. 36.) The analysis of stomach contents during September showed that striped bass continually gorged themselves on these small fish to the virtual exclusion of other types of food. Furthermore, judging from the relative numbers taken in seine hauls in 1936 and 1937, and from the statements of local fishermen, young menhaden were unusually abundant in Connecticut waters in the latter part of 1936. It is likely that these juvenile menhaden were responsible for the greater growth rate of the striped bass in the fall of 1936, and that the increased availability of the food supply in the late summer each year accounts for the maintenance of or increase in the growth rate through October despite the sharp drop in temperature at this time.

As will be shown subsequently, there is evidence that the growth rate of the striped bass varies considerably in different localities along the coast. It has already been pointed out, however, that there was a great variation about the mean in measure-

ments of fish from any one region at any one time, and that the samples from different areas may have been composed of stocks from widely separated localities which showed different growth rates. Nevertheless, scale analysis (see Origin of the dominant 1934 year-class, pp. 46–52) points to the fact that the striped bass on which studies were made in northern waters in the summer of 1936 and 1937, were mainly of essentially the same origin and with similar growth rates in their first and second years. Figure 19 shows length-frequency curves for 2- and 3-year-old striped bass taken north and south of Cape Cod in 1937. Those taken north of Cape Cod were from Massachusetts, and those south of Cape Cod from Connecticut. The striking difference in the striped bass of the same ages from these two areas is at once apparent. The 2-year-olds north of Cape Cod show a peak at approximately 40 cm., while those south of Cape Cod have a peak near 34 cm. The 3-year-olds from the same areas present peaks at 45 and 40 cm., respectively. It is almost certain that all these fish were of southern origin (see Origin of the dominant 1934 year-class, p. 51), and that they first migrated to northern waters as 2-year-olds in the spring (see Migrations, p. 44). It is possible that the difference in size can be accounted for by differential

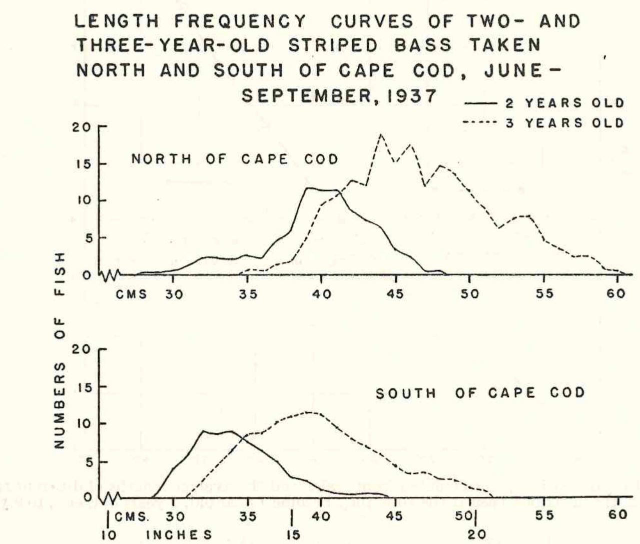

FIGURE 19.—Length-frequency curves of 2- and 3-year-old striped bass taken north and south of Cape Cod from June through September 1937. Data smoothed by a moving average of threes throughout (see Table 13 for original measurements).

migration—that is, that the larger fish of the age-categories concerned migrated farther north than the smaller individuals. This is unlikely, however, and the difference in size is probably best explained by differential growth rates in the spring, summer, and early fall in the areas under consideration. The samples from these areas are perhaps poor, in that they are composed of rod-and-line caught fish in order that they might be comparable, for it was impossible to get samplings of the population north of Cape Cod over this entire period by any other method. The differences in size may be slightly exaggerated, owing to the fact that the sampling in the early summer south of Cape Cod was somewhat more intensive than that of the middle and late summer, while the sampling north of Cape Cod was evenly distributed throughout the entire period from June through September 1937. There can be little doubt, however, that in 1937 the 2- and 3-year-old striped bass north of Cape Cod grew much faster than those in Connecticut waters from June through September.

The average length attained by striped bass each year from the first to the tenth year has been calculated by two different methods, and is shown in figure 20. It is of some interest that these lengths of striped bass at different ages compare almost exactly with those given by Scofield (1931) and Clark (1938) for striped bass on the Pacific coast. Since bass 2 years old and older were available in Connecticut waters in large numbers, it was possible to calculate the average lengths of the different age groups simply by making age determinations from the scale samples of fish of measured length. This has been done on 2,500 fish, and the results are shown by the solid line in figure 20. The average lengths of striped bass from 1 to 4 years old have been calculated from the scales of 4-year-old bass of measured length (see below). This is indicated in figure 20 by the dot-and-dash line. There is every reason to believe from the available samplings of fish of the ages covered by this part of the graph that the lengths derived by this method are accurate estimates. Further than this, it will be noticed that in the center part of the growth curve in figure 20, where the lengths at different ages calculated by both the above-mentioned methods overlap, there is an almost perfect correspondence in the estimated lengths as derived by the two different procedures. It should be emphasized again, in connection

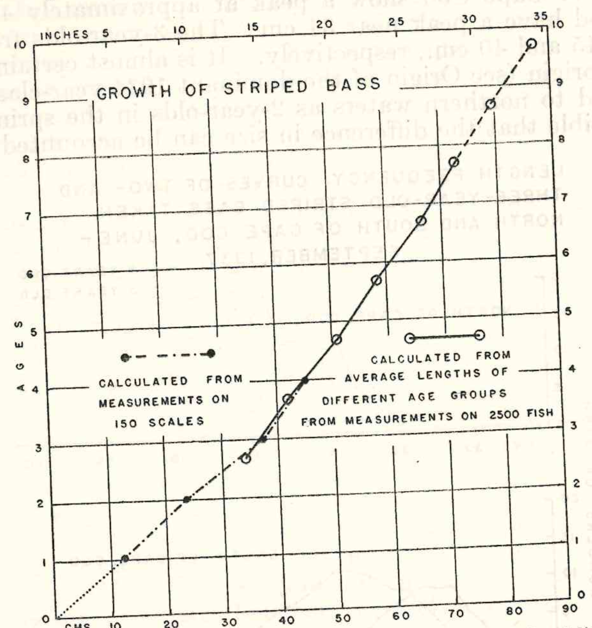

FIGURE 20.—The growth of the striped bass, as calculated from scales and the average lengths of different age groups. See Table 14 for average lengths of striped bass at the time they become 1 year old, 2 years old, etc., to 9 years old.

with figure 20, that the lengths represented on this graph are averages, and that there is a wide variation about the mean in the lengths at any age. This is of course particularly true among the larger sizes, as is indicated by the broken line at the upper end of the growth curve. In general, fish 100 cm. (nearly 40 inches) long average about 25 pounds and are about 11 or 12 years old; those 125 cm. (nearly 50 inches) long weigh approximately 50 pounds and are roughly 20 to 25 years old. The largest striped bass taken in recent years (caught in Rhode Island on rod and line in October 1936) weighed 65 pounds and measured 137 cm. (54 inches); examination of several scales leads the author to believe that this fish was 29, 30, or 31 years old.[10]

In calculating the growth of striped bass up to 4 years old by the scale method, the following formula was used:

$$L_1 = C + \frac{V_1}{V}(L - C)$$

L_1 equals the length of the fish at the end of year "x," V_1 the length of the scale included in the annulus of year "x," V the total length of the scale, L the length of the fish from which the scale is taken, and C the length of the fish when scales first appear. (The use of the factor C has various limitations, see pp. 31–32). The measurements on striped bass scales were made from the focus to the anterior edge of the scale and to the annuli along a line that bisected the angle formed by the junction of the two

[10] In connection with the age of striped bass, Bigelow and Welsh (1925) write, ". . . they are certainly long-lived, for one kept in the New York Aquarium lived to an age of about twenty-three years."

lateral fields at the focus. (See fig. 15.) Scales from striped bass that were beyond their fifth year were not used, since the annuli were often indistinct and it was therefore difficult to make precise measurements. Van Oosten (1929), Creaser (1926), and others have pointed out that the validity of the scale method of determining the length of a fish at different years in its life depends on 3 main factors: (1) That the scales remain constant in number and identity throughout the life of the fish; (2) that scale growth is proportional to the growth of the fish; and (3) that the annuli are formed yearly and at the same time of the year. Since it has been proved in many other species that scales do maintain their identity throughout the life of the fish, and because there is no evidence to the contrary in the striped bass, it has been assumed that the first requirement holds true. In testing the relation of scale growth to the growth of the fish, the radii of scales from 153 bass of measured length

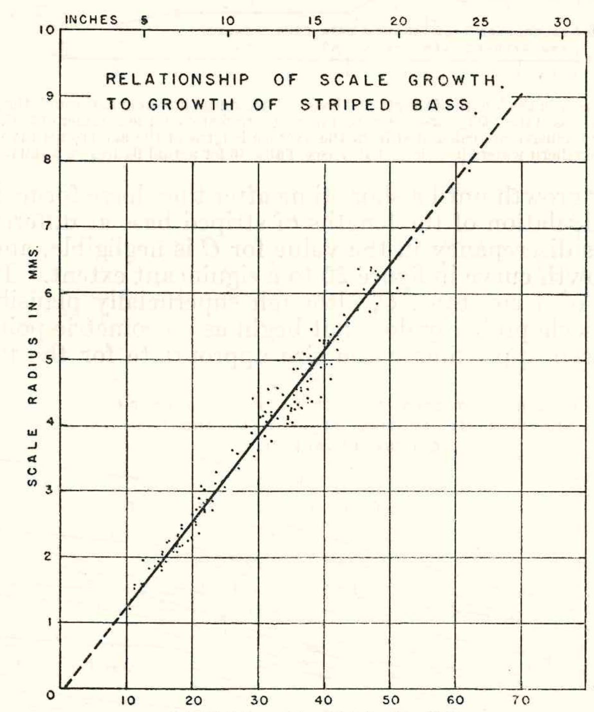

FIGURE 21.—The relationship of scale growth to body growth in the striped bass (see Table 15 for original data).

from 10.5 to 67 cm. were plotted against the lengths of the fish. (See fig. 21.) It will be noted that there is a good straight-line relationship, and that therefore the scale growth may be considered proportional to the growth of the fish within the limits studied. There is no proof, however, that scale and body growth are proportional in the smaller sizes below 11 cm., or in the extreme larger sizes above 67 cm. The formation of annuli has already been discussed, and there can be no doubt that they are formed yearly and at the same time of year—during the winter.

Since all the larval stages of development of the striped bass were not available, it was impossible to determine the factor C (that length at which scales first appear on the fish) by careful examination of preserved material. Bass down to 2.0 cm. were collected in the field, and these all showed prominent scales. Individuals up to 0.5–0.6 cm. (approximately 8 days after fertilization of the eggs and 6 days after hatching) were preserved from the hatchery at Edenton, N. C., and these did not show any signs of scale formation. It was therefore necessary to estimate at what length scales first appear on striped bass between 0.6 and 2.0 cm. by other means. The material that forms the basis of figure 21 was used for this purpose. A regression equation expressing the body-scale growth relationship of the striped bass was obtained by means of the product moments method, and it was found that the line intersected the abscissa at 0.6 cm. This value for the length at which scales first appear seems to be too low in view of the evidence mentioned above, but it has been used for the factor *C* in the scale formula for lack of any other means of determining it more accurately. There is no evidence, as shown before, that scale growth and body growth in the striped bass are proportional in individuals below 11 cm., and an error in the value of 0.6 cm. for *C* may thus be introduced, since the method applied above necessarily assumes such a relationship. It is considered likely that scales do not first appear until the bass are about 1.0 cm. long, and that scale growth is not directly

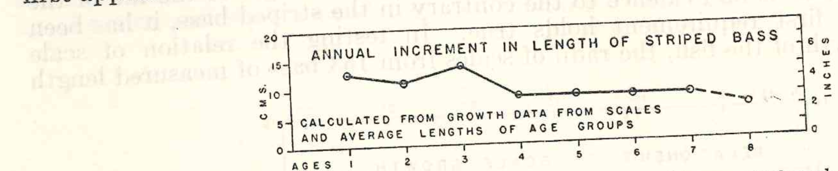

FIGURE 22.—The annual increment in the length of the striped bass. The annual increments through the fourth year are calculated from the scales from striped bass of the 1933 year-class caught in northern waters in the summer of 1937. The annual increments in the fifth to eighth years inclusive are calculated from the average lengths of the age groups involved, these lengths being taken from fish caught in northern waters in 1936 and 1937 (see Table 16 for actual figures on annual increment).

proportional to body growth until a short time after they have formed. But the error introduced in the calculation of the lengths of striped bass at different ages from the scale formula by this discrepancy in the value for *C* is negligible, and does not affect the points on the growth curve in figure 20 to a significant extent. It should be mentioned that the use of a constant, *C*, although superficially plausible, is not sound theoretically. The scale probably does not begin as a geometric point, but as a plate whose radius may well approximate the size appropriate for the fish at that time.

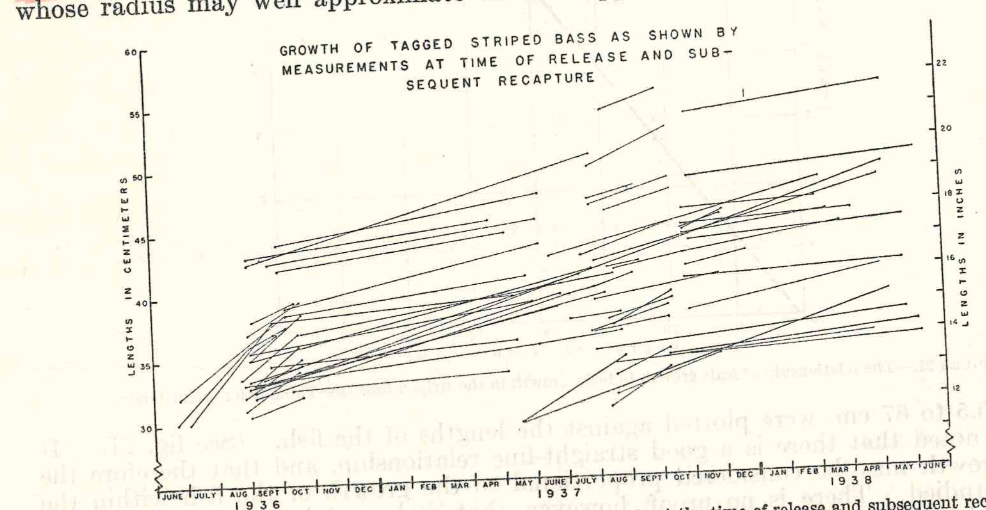

FIGURE 23.—The growth of tagged striped bass as shown by measurements at the time of release and subsequent recapture.

Thus, in the weakfish (*Cynoscion regalis*) a negative *C* would be needed to correct for the negative Lee's phenomenon observed (Nesbit, unpublished material).

The annual increment in the length of the striped bass is shown in figure 22. It is apparent that the greatest growth occurs in the third year, that age at which this species first undertakes coastal migrations to any great extent. Thereafter the increment in growth falls off sharply, particularly in the fourth year, and from then on maintains an average of about 6.5–8.0 cm. each year at least up to the eighth year. There is some evidence from the available material that the growth rate decreases still more in the eighth and succeeding years.

The growth of tagged individuals that were measured at the times of release and subsequent recapture provides a good means of checking on the calculated growth rate of the striped bass as shown in figure 20. This material is shown in figure 23.

Only measurements which came from reliable sources were included in this graph, and the great majority were on fish that were taken at or near the point of release by the author; hence the growth rates refer mainly to fish in Connecticut waters. The lines connecting any two points in this figure of course only represent the total growth in the period intervening between release and recapture. The growths of these individual tagged fish over different lengths of time and in different seasons of the year check well with the growth rates calculated from other material, and in general substantiate the previously discussed information on the growth of the striped bass. It will be noted that the fastest growths occurred in the small fish (2 years old) in the late summer and early fall of 1936, that the growth rates were slow during the winter of 1936–37 (these measurements were in all probability mainly on individuals that wintered in the north), that the growth rates picked up again in the summer of 1937, and that they slowed down once more during the winter of 1937–38. The normally faster growth rate of the 2-year-olds is also indicated by the relative steepness of the lines in the smaller size categories.

MIGRATIONS

There have been no accounts in the literature of the migrations of the striped bass on the Atlantic coast until the present investigation,[11] with the exception of Pearson's (1933) brief paper which was limited to the movements of bass within Chesapeake Bay. There was, however, much evidence to show that this species makes seasonal movements of considerable magnitude. Thus the examination of catch records of commercial fishermen over a period of years at Montauk, Long Island, N. Y., and Newport and Point Judith, R. I., shows that striped bass are caught in large quantities as a general rule only in the spring and fall of the year. This is shown in figure 24, where the bulk of the pound-net catches at Fort Pond Bay, Long Island, N. Y., from 1884 to 1928, were made either in May or October and November. It is also generally known that the date of capture of striped bass along the coast of the Middle and North Atlantic States by pound-nets and seines in great numbers in the spring is progressively later the farther north these catches are made. Moreover, the reverse is true in the fall; for example, the main catch at Point Judith, R. I., regularly precedes the time that the fishermen on the south side of Long Island make their biggest hauls. It therefore appeared logical to suppose that striped bass undertake definite coastal migrations to the north and east in the spring, and to the south and west in the fall. Various tagging experiments to demonstrate the time and extent of these migrations have been carried out during the entire course of the investigation. The results of these taggings are summarized in tables 17, 18, 19, 20, and 22.

Two methods of tagging have been carried on. External disc tags have been used the greater part of the time, and internal belly tags have also been tried on juvenile and yearling striped bass. Both of these tags were used at the suggestion of Mr. Robert A. Nesbit, of the United States Bureau of Fisheries. The external disc tag is actually a modification of the Scottish Plaice Label, the main changes consisting of reduced dimensions, the use of celluloid instead of hard rubber, the addition of printing, and the substitution of nickel pins for silver wire as the method of attachment. Sketches illustrating these methods of tagging are shown in figure 25. Scale samples were taken in most cases, and lengths and the dates and localities of release were always recorded on all striped bass that were tagged.

The external disc tag proved to be a fairly efficient and practical means of marking striped bass. A single tag of this type consisted of two discs of bright red (DuPont No. 6671) celluloid, each 0.025 inch in thickness and one-half inch in diameter, with a center hole ³⁄₃₂-inch in diameter. Each pair of discs bore the same number in black print across the middle, and the necessary instructions to insure their return were printed in black around the circumference. The discs were made by printing on 0.020-inch opaque celluloid and cementing onto the side bearing the printing a

[11] In California, however, tagging experiments on the striped bass have shown that there were " . . . no definite migrations, simply a diffusion from the locality in which the bass were tagged" (Clark, 1936).

0.005-inch transparent celluloid, so that the numbers and legends were covered and protected. The first 1,500 tags bore the words, RETURN TO FISH & GAME, HARTFORD, CONN. In the remaining tags this inscription was changed to, RETURN TAG, etc., etc., since it was found that a certain number of returns were being lost because the original wording was sufficiently misleading so that some individuals thought the whole fish should be sent in and were unwilling to part with their catch. Each tag was attached to the fish by means of a pin. This pin was put through the center hole in one disc and pushed through the flesh of the back between the two dorsal fins—one-fourth to one-half inch below the dorsal contour of the body—in a horizontal plane. The matching disc was then put on that part of the pin that

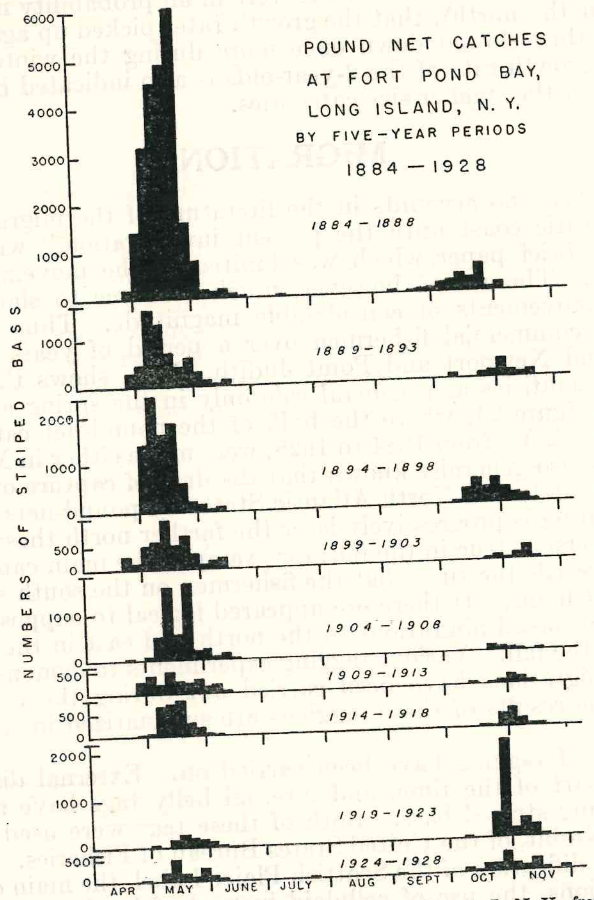

FIGURE 24.—Numbers of striped bass caught in the pound nets at Fort Pond Bay, L. I., N. Y., from 1884 to 1928, for each 5 days during the fishing season, by 5-year periods. The catches have been weighted to make them equivalent to a fishing intensity of 10 pound-nets throughout (see figure 4, table 4). Note that the catches are made only in the spring and fall of the year It is of interest to note that the size of the spring catches has shown a sharp decline over the period covered by this record, while the size of the fall catches has remained about the same during this time.

had come through the flesh on the other side of the body, and the pin was crimped over with a pair of finely pointed pliers in such a way that both discs fitted closely against the back of the fish. The printing on the tags was faced out so that it was immediately evident. It sometimes happened, however, that over periods of more than several months Bryozoans and other forms attached themselves to the tags and obscured the printing and even the color of the discs, so that it was necessary to scrape the entire surface with a sharp knife before the inscription became legible. Mussels (*Mytilus edulis*) over 1 cm. long have been found on the tags at times, and barnacles (*Balanus balanoides*) covering the entire disc were by no means uncommon. It became evident from the recapture of tagged individuals that it was best to crimp the pin to such a degree that there was less than one-sixteenth of an inch of free space

between the discs and the sides of the fish. If more space was left to allow for growth, sores were created where the edges of the discs rubbed against the body, and weeds were more likely to catch on the tags and cause added irritation. Moreover, since there have been only a few recaptures of fish marked by this method more than a year after the date of release—the longest recovery of a tag of this type was from a fish that was tagged September 7, 1936, in the Niantic River, Conn., and recovered May 2, 1938, in the Hudson River, off Nyack, N. Y.—there is little point in allowing for much growth. In an attempt to preclude any possibility of chafing, both flat and saucer-shaped discs were used. The flat discs showed far less tendency to cause irritation and to pick up weeds and debris, and were in general more satisfactory, although there is some evidence from recaptures in the summer of 1938 that the saucer-shaped discs stay on longer. Two types of pins were used for attaching

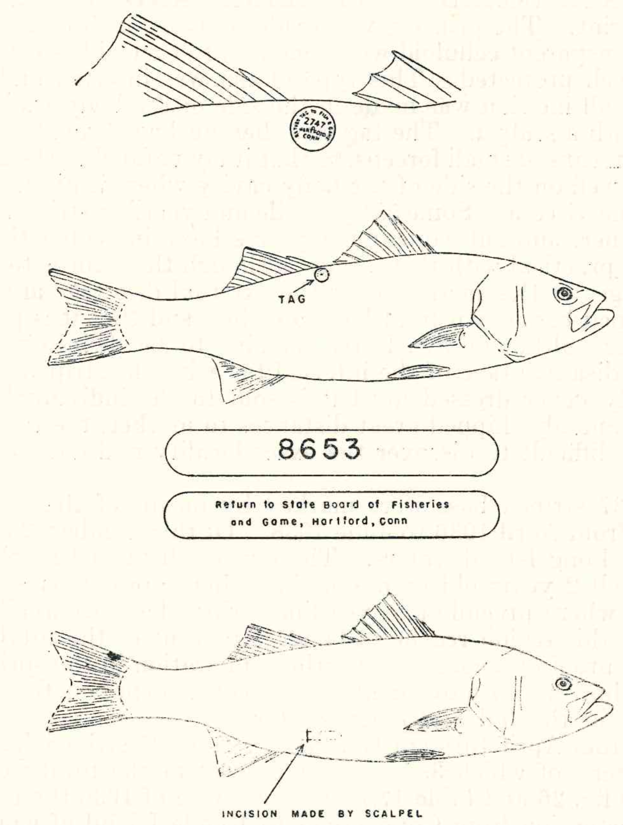

FIGURE 25.—Sketches to illustrate the external disc and internal belly tag methods of marking striped bass.

the external tags. Those tried with the first 500 bass were stainless steel insect pins. There was abundant evidence in the early work from the subsequent recapture of fish that still showed a scar in the area where they had been tagged with this type of pin, but had lost the tag, that these pins were not adequate in salt water. Not only did they become brittle and fragile after a short time (no fish marked by means of this pin was recaptured more than 2 months after its release), but their slender shafts showed a distinct tendency to cut through the flesh, thus allowing more room for the movement of the tags and causing sores. All these difficultues were fairly well obviated by the use of heavier noncorrosive nickel pins. The nickel pins were made of No. 20 B. & S. pure nickel wire. The diameter of the head of each pin was not less than 0.080 inch in diameter. The pins were ordered in two lengths, 1⅜ and 1¾ inches, for use in tagging different sizes of striped bass. These pins never showed any tendency to corrode in salt water.

The external disc tag method of marking striped bass, however, has two definite
disadvantages. These are that the evidence from the recapture of fish tagged by
this means shows that the discs do not usually stay on for periods much over 1 year;
probably because the pins "migrate" toward the dorsal contour of the fish and are
eventually sloughed off, and that it is impractical to tag bass less than 8 inches long
with discs and pins of the sizes given above. The internal belly tag devised by Nesbit
(1934b) has therefore been used on small striped bass (see fig. 25). Since this type
of tag has been used successfully over long-term periods with small weakfish (*Cynoscion*
regalis), herring (*Clupea pallasii*), and other species, it seemed logical to expect that
it was applicable to juvenile and yearling striped bass. This tag consisted of a piece
of bright red celluloid 0.030 inch thick, 1⅝ inches long, and ¼ inch wide, with well-
rounded ends. One side of the tag bore the number, and the other side the words
RETURN TO STATE BOARD OF FISHERIES AND GAME, HARTFORD,
CONN., in black print. The printing was made on 0.020-inch opaque red celluloid,
and a 0.005-inch transparent celluloid was cemented to each side so that the numbers
and legends were well protected. This type of tag was inserted and carried in the
body cavity. A small incision was made in the side of the body wall, ½ to 1 inch in
front of the anus with a scalpel. The tag was then pushed through this incision into
the body cavity by means of small forceps, so that it lay parallel to the antero-posterior
axis of the fish but well on the side of the body cavity where it did not interfere with
or displace any of the viscera. Some 581 juvenile and yearling striped bass have been
tagged in this manner, and subsequent recaptures have indicated that this method
is both feasible and practical with this species, although the returns to date have been
few. The advantages of this method over the external disc tags are that it enables
the marking of striped bass down to at least 5 inches, and that it is probably a much
better long-time tag—although this latter remains to be definitely proven in this
species. The only disadvantage of the internal tag with the striped bass is that this
species is practically never dressed until it is sold to the individual customer, and
since this fish is commonly shipped great distances to market, the tag is likely not to
be found until it is difficult to discover the exact locality and date of capture of the
fish that bore it.

A total of 3,937 striped bass were marked by means of the external disc and
internal belly tags from April 1936 to June 1938. Of this number, 2,573 were tagged
in Connecticut and Long Island waters. These were all tagged by the external disc
method, and were all 2 years old or more, since there are comparatively few areas
in northern waters where juvenile and yearling striped bass are available. Returns
from fish tagged in this region reached 544 (21.1 percent of the total) by July 1938
and gave abundant proof of a coastwise northern migration in the spring, a relatively
stable population showing no movement of any consequence in the summer, and a
southern migration in the fall and early winter.

In the period from April through October 1936, 1,397 striped bass were tagged
in Connecticut waters, of which 337, or 24.1 percent of the total were returned by
July 1, 1938. (See fig. 26 and table 17.) In the spring of 1936 these returns showed
that an eastward extension from Connecticut to Rhode Island of what undoubtedly
was a mass migration to the north, reaching its peak during May in southern New
England waters, definitely took place. During late April and May only a few striped
bass were tagged, yet returns from the Thames River, Conn., and Point Judith and
Newport, R. I., proved that many of these fish were taking part in what the spring
catch records of the seines and pound-nets had suggested was a tremendous mass
movement to the north. Fish tagged in the Niantic River, Conn., in May were
returned from Point Judith and Newport, a distance of 40 to 50 miles in a straight line,
5 to 7 days after their release. The recapture of tagged fish in the summer and early
fall showed that the striped bass population in the Niantic and Thames Rivers remained
static. Only minor migrations and movements up to 10 miles from the original
point of release were recorded from June to October, and it is significant that during
the spring, summer, and early fall, there was not a single recapture of a marked bass to
the south or west of the areas in which they were tagged. The stability of the popula-
tion through the summer and up to the latter part of October was shown by the con-
sistent recapture of tagged fish at or near the localities where they were released. An

extreme example of this is that of a bass that bore tag No. 197, which was seined, tagged, and released in June in the Niantic River. This bass was caught in a trap in Niantic Harbor in July and released, caught on a rod and line in the Niantic River in September by the author and released, and caught and released again while seining for tagging purposes in the Niantic River in early October. Returns from tagged striped bass first indicated that a migration to the south was starting in late October,

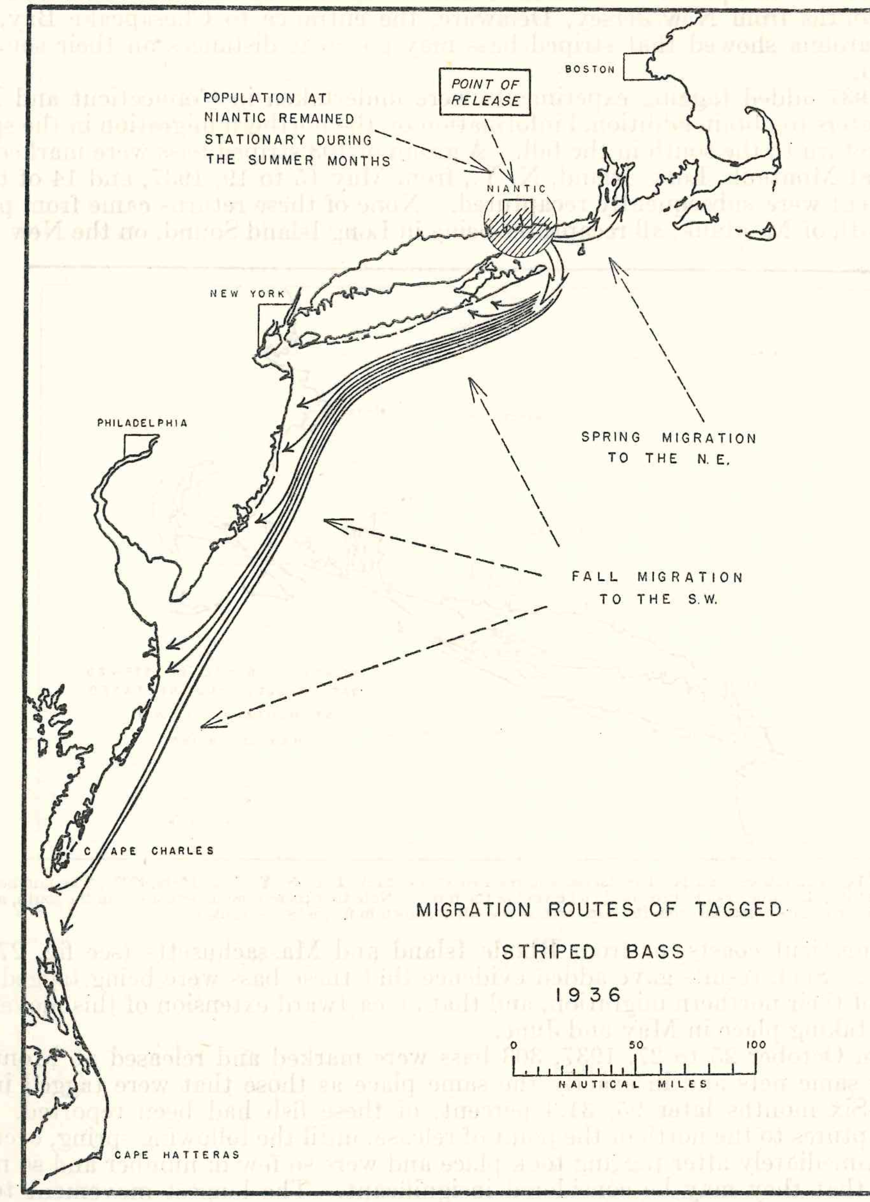

FIGURE 26.—Chart of the Atlantic coast showing the migrations of striped bass as determined by the returns from 1,397 individuals tagged from April through October 1936 (see table 17).

when two fish tagged in the Thames River were recovered in the Niantic. Although these fish had only moved about 10 miles, they were the first that had ever been taken to the south or west of the original point or release. Almost immediately thereafter bass that had been tagged in Connecticut waters during the summer began to be caught in large quantities in the pound-nets at Montauk, Long Island, N. Y., and in seines and on hook and line on the south side of Long Island. The number of returns from Montauk reached a peak during the first 10 days of November. Thereafter tags were sent in from bass caught progressively farther south as time went on. No marked fish were caught north and east of the original point of release during the fall and winter, and it was plainly evident from the examination of commercial fishermen's catch records, as well as from tag returns, that an intensive migration to the south had taken place. Scattered returns of tags throughout the winter and early spring months from New Jersey, Delaware, the entrance to Chesapeake Bay, and North Carolina showed that striped bass may go great distances on their southern migration.

In 1937 added tagging experiments were undertaken in Connecticut and Long Island waters to obtain additional information on the northern migration in the spring and the return to the south in the fall. A group of 103 striped bass were marked and released at Montauk, Long Island, N. Y., from May 15 to 19, 1937, and 14 of these, 13.6 percent were subsequently recaptured. None of these returns came from points to the south of Montauk, all recaptures being in Long Island Sound, on the New York and Connecticut coasts, or from Rhode Island and Massachusetts (see fig. 27 and table 18). Such results gave added evidence that these bass were being tagged near the end of their northern migration, and that an eastward extension of this movement was still taking place in May and June.

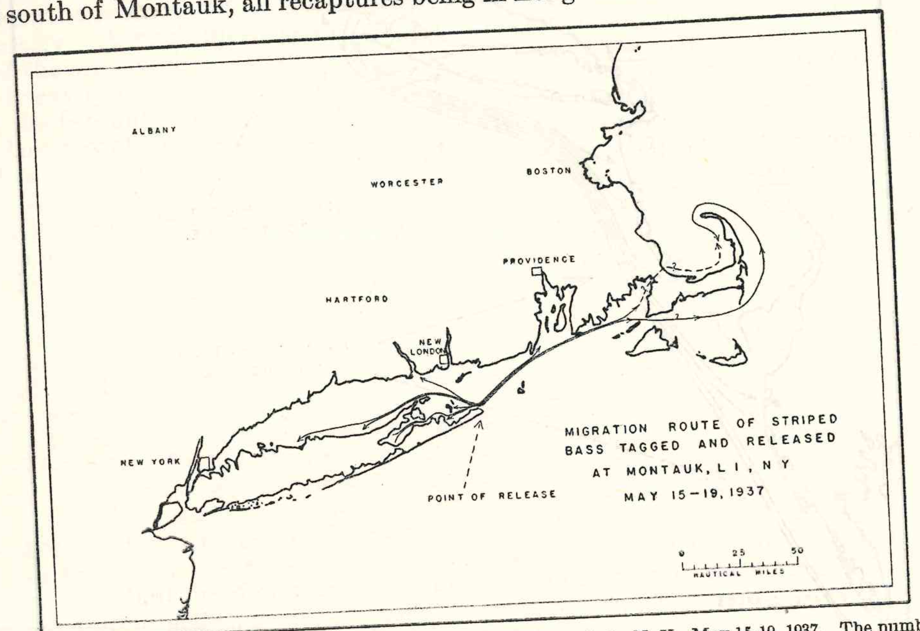

FIGURE 27.—Migration routes of striped bass tagged and released at Montauk, L. I., N. Y., May 15-19, 1937. The number of fish tagged was 103, the number of returns 14 (13.6 percent of the total). Note that there were no returns from the south, and contrast with the results of tagging from the same area in the fall as shown in figure 28 (see table 18).

From October 25 to 27, 1937, 303 bass were marked and released at Montauk, from the same nets and in exactly the same place as those that were tagged in the spring. Six months later 95, 31.3 percent, of these fish had been reported. The only recaptures to the north of the point of release, until the following spring, occurred almost immediately after tagging took place and were so few in number and so minor in scope that they may be considered insignificant. The longest movement to the north that was recorded in the fall was less than 10 miles. On the other hand, recaptures to the south and west of the area where the tagged fish were released were so numerous as to make it certain that these fish were taking part in an intensive southern migration at that time of year (see fig. 28 and table 19). Many returns in the fall, winter, and early spring months from the south side of Long Island, New Jersey, Delaware, Chesapeake Bay, and North Carolina as far south as Pamlico Sound, indicated the approximate extent and speed of the migration, and further amplified

the results of 1936. The rate at which striped bass may travel south in the fall is shown by the recapture of several fish tagged at Montauk, 450–500 miles away from the point of release, 35–40 days after the date of tagging—an average of 12 miles per day. This distance was measured in a straight line along the coast, which the fish undoubtedly did not travel. Moreover, there is no proof that the fish left the moment they were tagged or were caught at the other end of their migration as soon as they arrived. It seems likely, therefore, that they averaged far more than 12 miles per day. It is of interest that a considerable number of recaptures in the winter and early spring months were from well up large coastal rivers, where spawning occurs in May, thus indicating that some bass probably winter in or near the spawning areas. It is probable that the majority of the spawning individuals in any year do not move into these areas until the late spring,[12] particularly in southern rivers.

A total of 770 striped bass were also tagged from April to October in 1937 in the Niantic and Thames Rivers, Conn., and the returns from these further corroborated the results obtained from other marking experiments in northern waters. (See table 20.) There were an insufficient number of fish tagged in April and May to expect

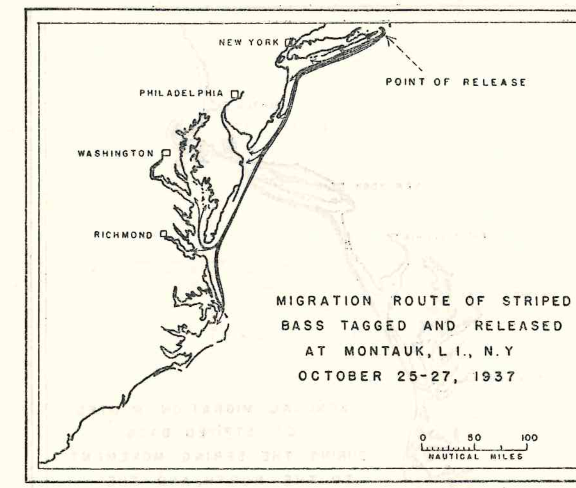

FIGURE 28.—Migration route of striped bass tagged and released at Montauk, L. I., N. Y., Oct. 25–27, 1937. The number of fish tagged was 303, the number of returns 100 (33 percent of the total). Note that there were no returns of any significance to the north of the point of release, and contrast with the results of tagging from the same area in the spring as shown in Figure 27 (see table 19).

any returns showing the northern migration at that time of year. Consistent recaptures at or near the point of release during the summer and early fall months, however, again demonstrated the stability of the population in Connecticut waters from June to October. The returns from the south in the fall and winter months offered additional proof of the migration south from northern waters in late October and November, recaptures on the south side of Long Island, in New Jersey, Delaware, and Chesapeake Bay being not infrequent. The total number of returns from the 770 striped bass that were tagged was 93, 12.1 percent, by July 1, 1938. By comparison with other tagging experiments on striped bass carried on in these waters, this was a strikingly low percentage of recapture. This may be accounted for by the fact that excessively high temperatures in the latter part of August 1937, apparently drove the bass out of the Niantic and Thames Rivers, where they are normally subject to a highly intensive fishery, to the cooler coastal waters where they were not so easily available, and because a large number of the fish tagged in 1937 were released in areas that are not so well known to local fishermen.

Thus the evidence accumulated from tagging experiments on striped bass in Connecticut and Long Island waters in 1936 and 1937, and from the examination of commercial catch records, leaves little room for doubt that there is a mass migra-

[12] In this connection, Mr. Robert A. Nesbit tagged 64 striped bass in Sandy Hook Bay, N. J., April 22–25, 1938, and recaptures in late April and May showed that many of these fish went up the Hudson River. Recaptures in the summer showed a movement to the east and north.

tion to the north in the spring and to the south in the late fall, and that the summer populations in New England waters are essentially stable. The impression created by the information derived from tagging in these waters is that the migrations of the striped bass have their maximum size and intensity along the southern New England and Long Island shores, and that the farther south the fall movement goes the smaller it becomes, as individuals and groups split off from the main lot to winter in different localities. Conversely, starting from the south in the spring, the numbers making up the mass migration northward become greater and greater as the movement proceeds up the coast, being augmented as it progresses by the fish that have wintered farther north (see fig. 29). Having once reached northern waters an increasing number of striped bass stop along the coast to summer, and the migration dwindles in size and intensity as it progresses up the New England shore line. In the fall the migration south probably starts with many of the individuals that went farthest north in the spring, and increases in size and intensity at least until it reaches southern New England and Long Island. In years directly preceding 1936, when the level of abundance was consistently low, it is probable that the northern limit of

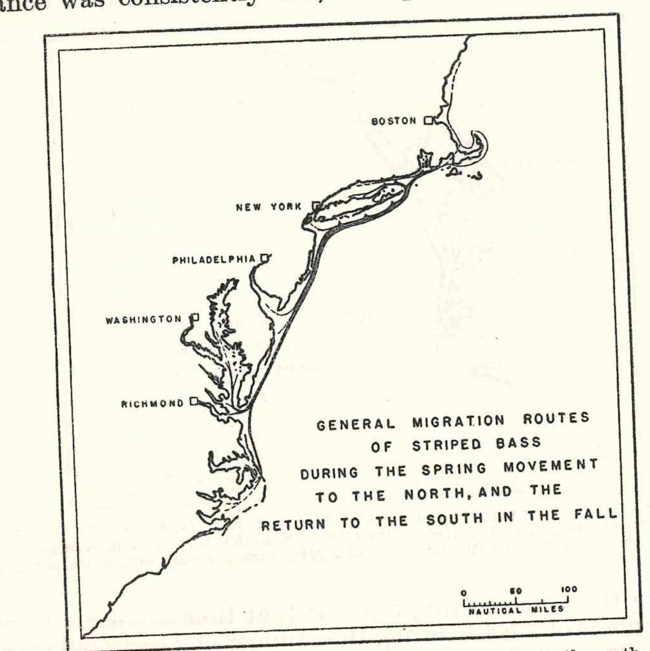

FIGURE 29.—The general migration routes of striped bass during the spring movement to the north, and the return to the south in the fall.

the striped bass migration from the south in the spring was Cape Cod, for north of this point this species was comparatively rare save in a few isolated localities that probably contained self-supporting permanently resident populations. Moreover, there is no commercial fishery for striped bass on the outer coast of Cape Cod comparable in size to those in Rhode Island and Long Island—a fact which indicates that there is no annual migration around Cape Cod of sufficient intensity to support such a fishery. In 1936 and 1937, however, when the members of the dominant 1934 year-class first reached northern waters, striped bass not only appeared in great numbers in Massachusetts north of Cape Cod, but were also commonly taken in New Hampshire and Maine. Three mackerel seiners caught 29,000 pounds of striped bass on August 2 and 4, 1937, in Cape Cod Bay. These fish were landed at the Boston Fish Pier, where it was the first time that this species had been handled in over 30 years. The study of scale samples of fish from these areas in 1937 showed them to be predominantly 3-year-olds of apparently the same origin as those taken off southern New England shores at the same time—evidence is presented later in this paper to show that the bulk of the dominant 1934 year-class was produced in the Middle Atlantic States (see p. 46). The dominant year-class of 1934 was of such

tremendous size that in 1936 and 1937 its members either spread or were crowded farther north than in recent times. It is also the case that the widening and enlargement of the Cape Cod canal in the past few years has undoubtedly provided an easy means for fish to reach northern New England waters, and reliable witnesses attest to the fact that striped bass passed through the canal in large quantities in the summer of 1937.[13]

The most northerly return of a striped bass tagged in southern New England or Long Island waters was from Cape Cod Bay. But there can be little doubt from the

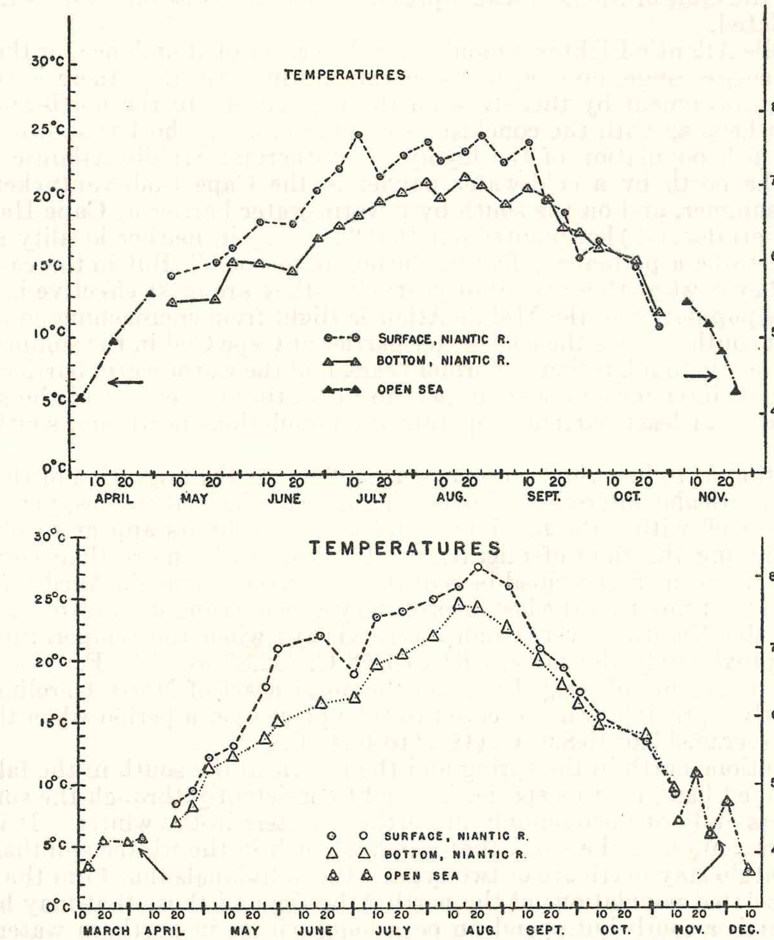

FIGURE 30.—Water temperatures in the Niantic River, Conn. The surface and bottom temperatures were taken in an area where striped bass were caught throughout the season. The open sea temperatures were taken at the mouth of the Niantic River, where the water passes through a narrow gut on the incoming tide with such force that the surface and bottom temperatures are the same. The open sea temperatures were taken during the spring and fall migrations of the striped bass. Arrows indicate when the first and last bass of the season were caught. Upper graph is for 1936, lower for 1937.

catch records and the examination of scale samples that the migration north in 1936 and 1937 at least reached Maine, and that north of Cape Cod the migrants from further south mingled with resident populations that probably had been isolated for some years past. In the summer of 1937 striped bass were taken in large quantities in Nova Scotia, but it is almost certain that there are self-supporting resident populations in various localities along the Canadian coast, and in the absence of length measurements and scale samples it is impossible to be sure of the origin of these fish. Two alternative possibilities suggest themselves in explanation of the presence of striped bass in Nova Scotia; first, that these fish are of northern origin and are completely separate from the

[13] Part of a letter to the author from Mr. John R. Webster, of the U. S. Bureau of Fisheries, dated March 8, 1938, reads, ". . . it now seems almost certain that these fish passed through the Canal. Mr. Churbuck told me the water around State Pier was loaded with bass and that people fished for them all along the banks of the Canal with great success."

populations farther south, and second, that they are made up of individuals of mixed origin—that is, that the northern stocks are added to by the migrants from the south.

The southernmost return of a striped bass tagged in Connecticut and Long Island waters was from the northern tip of Pamlico Sound, N. C. It is probable that the striped bass of the Southern Atlantic Bight—that part of the coast of United States south of Cape Hatteras—are a completely separate population, that may possibly be added to under rare circumstances by the stock from the Middle Atlantic Bight—Cape Hatteras to Cape Cod—and it seems reasonable to expect that the striped bass population of the Gulf of Mexico, which presumably extends as far west as Louisiana is entirely isolated.

The Middle Atlantic Bight is undoubtedly the center of abundance for the striped bass over its entire range, and tagging experiments indicate that there is comparatively little encroachment by this stock on the populations to the north and south. This is well in keeping with the conclusions of Parr (1933), who has shown that the shallow-water fish population of the highly heterothermal Middle Atlantic Bight is bounded on the north by a cold-water barrier in the Cape Cod-Nantucket Shoals region in the summer, and on the south by a warm-water barrier at Cape Hatteras in the winter. Parr (loc. cit.) has pointed out that ". . . in neither locality are such barriers found to be a permanent feature during all seasons." But in the case of the striped bass they exist at those times of year when they are most effective in keeping the bulk of the population of the Middle Atlantic Bight from encroaching on the areas to the north or south. Thus the cold-water barrier at Cape Cod in the summer marks the end of the northern migration in normal years, and the warm-water barrier at Cape Hatteras in the winter may play some part in delimiting the extent of the southern migration, and so at least partially separate the populations north and south of this boundary.

The question as to how much temperature influences the migration of the striped bass is one of particular interest. This is a highly eurythermal species, yet temperature variations well within the maximum and minimum limits appear to play some part in determining the time of migration. It seems to be more than coincidence that the times when the first striped bass of the year were taken—in April 1936, 1937, and 1938—and the times that the last ones of the year were caught—in November 1936 and 1937—in the Niantic River, Conn., were always when the temperature of the water was approximately the same, 6.0° to 7.5° C. (42.8° to 45.5° F.) (see fig. 30). Moreover, the migration of striped bass on the outer coast of North Carolina in late March and early April 1938 was observed to take place over a period when the water temperatures averaged 7.0° to 8.0° C. (44.6° to 46.4° F.).

The migrations north in the spring and the return to the south in the fall do not include all striped bass, for this species is caught consistently through the summer in southern waters and not uncommonly in northern waters in the winter. It is a relatively small percentage of the stock that remains north in the winter months. However, those that do stay north are of two types—the individuals that form the resident more or less isolated populations of the north Atlantic, and those that may have had their origin farther south but spend an occasional winter in northern waters. The latter may possibly bolster the northern spawning stocks, but are often composed of individuals that are not spawning in that particular year, for this species is not necessarily an annual spawner (see p. 16). Striped bass that do remain in the north through the winter months apparently become dormant and inactive in many cases and actually hibernate to much the same extent that has been described for the black bass (*Micropterus dolomieu*) in the northern part of its range by Hubbs and Bailey (1938). Their easy capture through the ice by scoop nets and by gigging testifies to their sluggish state in cold water, and the outward appearance of individuals taken in the winter and extremely early spring often shows that they are in poor condition. Striped bass certainly undergo partial hibernation as far south as New Jersey, the extent of this southern limit undoubtedly being determined by the prevailing temperatures. Dormant individuals are most commonly taken in northern waters during the winter in shallow bays and in the brackish waters of estuaries. Thus it appears that although temperatures from 6.5° to 8.0° C. play some part in causing the migrations of this species, their effect is not universal. It may be that the first and last fish of the

season in such a place as the Niantic River, where striped bass are caught so consistently at approximately the same temperature in the spring and fall, are mainly winter residents, but it is also known that migratory individuals are present at the times of the earliest and latest catches. It is of interest to note that during October and November 1936, a time which was characterized by sudden drops in temperature, it was plainly indicated that with each cold snap, and resultant decline in temperature of the water, some of the striped bass in the Niantic River moved out and their place was almost immediately taken by fish that presumably came from farther up the coast. Such changes in the population were definitely observed on at least two occasions, both immediately following sharp drops in temperature. Strong winds and storms in the fall also play a part in causing the fish to undertake their migrations.

The maximum temperatures for this species appear to be in the neignborhood of 25°–27° C. (77.0°–80.6° F.), for in New England waters in the latter part of August and early September 1937 when there was a protracted period of exceptionally warm weather (see fig. 30), dead bass in considerable numbers were reported simultaneously in Connecticut and Massachusetts. Such mortality occurred chiefly in shallow-water estuaries where the water temperatures reached especially high levels. A number of dead bass were observed by the author in the Niantic and Thames Rivers at this time, and an examination of them disclosed no parasites or injuries that might possibly have been fatal. The water analyses of the Connecticut State Water Commission taken at various intervals in the Thames River near New London, Conn.—an area where many dead bass were found—showed nothing unusual nor the presence of any toxic substances during this period (see table 21). There also was a marked migration of bass that normally spend the entire summer in the Niantic and Thames Rivers out to the cooler coastal waters at the time the water temperatures were so high. This was shown by the recapture of tagged fish outside, and by the almost complete absence of bass in the rivers where they are usually found at this time of year. In view of such facts, the evidence is strong that a temperature of 25°–27° C. (77.0°–80.6° F.) marks the maximum tolerance limit. This is a water temperature which is seldom exceeded over the entire range of the striped bass.

It is of some interest to note that although a considerable number of striped bass weighing from 5 to 25 pounds were marked by external disc tags, there have been no returns from these fish save in the immediate locality at which they were released and within a short time after marking took place. Returns of tagged fish from any other area then the general point of release have been confined to individuals not more than 4 years old. It is difficult to account for this circumstance, and, although it may be that the larger bass did not take such a great part in the migrations as the younger individuals, information as to the size-categories appearing in commercial catches in previous years does not make it seem likely that this is an adequate explanation. By the same token, it is improbable that the larger fish migrate in waters farther offshore, thus reducing the chances of their being caught along the coast. It is possible that the larger individuals do not carry the external disc tags as well as the smaller fish, and that the tags are not retained for more than a short while. It is true that the larger the bass the nearer the top of the back the pin bearing the tags must be inserted, because the breadth of the fish makes it impossible for pins only 1¾ inches long to penetrate to the other side far below the dorsal contour. Other reasons for the lack of returns of the larger tagged fish are, first, the overwhelming abundance of the members of the dominant 1934 year-class, and second, the tendency of the smaller size-categories—2- and 3-year-olds—to school heavily. This schooling instinct, or schooling "synaprokrisis" (Parr, 1937), tends to make them much more available to commercial fishermen than the larger individuals which are not so strongly inclined to congregate together. The heavy schooling of the smaller fish of definite size-categories was observed countless times in the course of seining for tagging purposes in 1936 and 1937. That these schools tend to travel considerable distances without breaking up is suggested by the recapture in several instances at the same time and in the same area some distance away from the original point of release of two or three fish that had previously been tagged in a single seine haul in the Niantic River.

The recapture of tagged fish as well as observations on the commercial and sports fisheries for striped bass along the Atlantic coast from Maine to North Carolina gives abundant proof that this species is preeminently coastal in its distribution. But studies of the migrations by tagging experiments give convincing evidence that bass do at times cross open bodies of water of considerable size. Thus the spring migration route north apparently takes striped bass from the tip of Long Island straight across to Connecticut and Rhode Island shores, and in the fall the reverse appears to be true—that bass travel from Rhode Island and Connecticut to Montauk and do not follow all the way around the shore line of Long Island Sound. This is shown by the recapture of tagged fish at Montauk shortly after their release in Connecticut waters in the fall, and by the almost complete absence of tag returns at any time from the western half of Long Island Sound. A few fish do round Montauk Point and go west along the north shore of Long Island in the spring (see fig. 27), but the majority go to the north and east. Commercial fishermen of long experience in Rhode Island are convinced that in the fall migration to the south a heavy offshore wind causes the main body of fish to go straight from a point at least as far east as Newport to the tip of Long Island, and that a storm from the south causes the bass to follow down the coast of Rhode Island and part of Connecticut before crossing to Montauk. The evidence from the catch records of pound-nets under different conditions in the fall tends to confirm this view. It also is probable that striped bass often cross the mouths of Delaware and Chesapeake Bays in much the same way that they cross the tip of Long Island Sound.

It has been pointed out (see p. 20) that approximately 90 percent of the individuals examined for sex in Long Island and New England waters in 1936 and 1937 were females, and it also appears that there is an increasingly smaller percentage of males in northern waters among the large size-categories. On the other hand, this strikingly abnormal sex ratio does not exist in waters farther south, and the following theoretical explanation of this condition is offered. The spring coastal migration to the north in April and May coincides with the spawning season in the south, and is mainly composed of small immature fish and a relatively small number of individuals that are not spawners in that particular year. Because of the discrepancy in the age at maturity of the males and females, the males spawning for the first time at the end of their second year while the females do not become mature at least until the end of their fourth year, many of the males do not take part in the spring migration but stay behind to spawn with the larger females. Thus the migration northward at this time of year is largely made up of immature females 2 and 3 years old. The examination of the size-categories making up the catch in northern waters at different seasons indicates that there is a less intensive migration along the coast in June, which is composed of fish of a much larger average size. In all probability these are mainly females which have completed spawning farther south and have moved up along the coast singly or in small groups. This is demonstrated in figure 31, where the different sizes of striped bass making up the annual catch of a haul-seine fisherman at Point Judith, R. I., before and after June are shown. It is apparent that the small fish make up the bulk of the catch before June each year, but that thereafter bass of the larger size-categories comprise a far greater part of the catch. In 1936 and 1937 an unusually large percentage of the total were small fish, due to the dominance of the 1934 year-class.

There is no evidence that striped bass younger than 2 years old undertake the coastal migrations discussed above. The complete absence of juvenile and yearling individuals anywhere along the coast, save in or close to areas that have been established as being places where striped bass spawn, is proof that the coastal migrations do not occur until this species becomes 2 years old. In northern coastal waters, where the author handled many thousands of striped bass, individuals less than 2 years old were only encountered on the rarest of occasions.

Two interesting tagging experiments were conducted in North Carolina during March, April, and May, 1938. These were carried on for the purpose of determining to what extent the bass from this region take part in the spring migration to the north, and how much they contribute to the population in northern waters during the spring, summer, and fall. This whole question is discussed in some detail under the section on the origin of the dominant 1934 year-class, where evidence is presented

which supports the conclusion that North Carolina does not contribute directly more than a small percentage to the supply summering in the north. In general the results of these experiments substantiate this view as far as they go. In one of the experiments a total of 506 juvenile and small yearlings—fish that were just becoming 1- and 2-year-olds—were tagged internally in the general region of the Sutton Beach haul-seine fishery, between the mouths of the Chowan and Roanoke Rivers in the western end of Albemarle Sound, N. C., with the idea that subsequent recaptures of these fish would demonstrate to what extent bass from this region contribute to the populations farther north. These fish were tagged from April 18 to 28, 1938, and 47 were recaptured in the same area before the fishery closed in May. Several others were taken within a short distance of the point of release in the spring, thus indicating that this method of tagging striped bass is satisfactory, at least for short-time returns. It is hoped that the internal tags will also prove satisfactory for long-time returns, as they have in some other species, so that it will be possible to prove the amount of North Carolina's contribution to northern waters over a period of years. The other tagging experiment in North Carolina during March and April 1938, was conducted partially at the extreme eastern end of Albemarle Sound and mostly on the outer coast in the general region of Kitty Hawk and Nags Head. In this experiment, 600 2-, 3-, and 4-year-old striped bass, of which the great majority were 2-year-olds, were marked with the external disc tags. Of these, 62 were caught in the same general

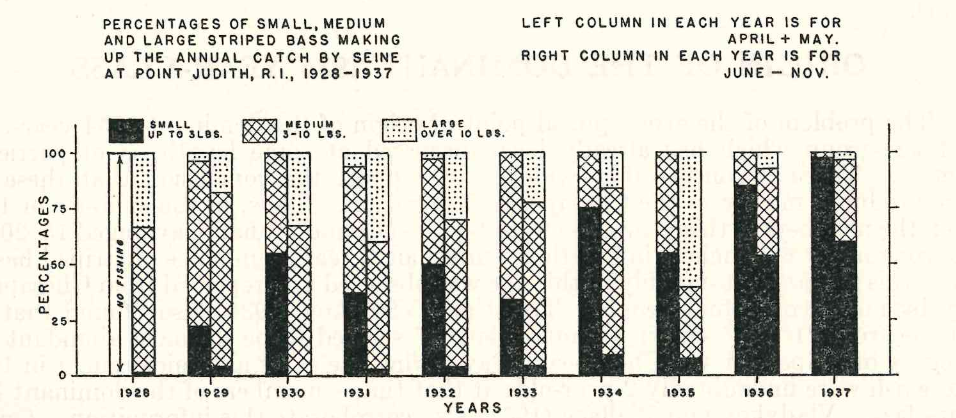

FIGURE 31.—The percentages of small, medium, and large striped bass making up the annual catch by seine before and after June at Point Judith, R. I., from 1928 to 1937. The left-hand column is for April and May, and the right-hand column for June to November in each year. See Figure 8 for the same material graphed in terms of actual numbers instead of percentages.

area within a short time after they had been tagged, and 46 were again released. By June 15, 1938, there had been 45 returns from these 600 tagged fish from areas some distance away from the point of release. Despite the fact that these fish were tagged at the time of the spring migration to the north, they did not show an intensive one-way movement such as has been proven to take place, for example, in northern waters by tagging in the fall. Thus 24 of the 45 returns were from Pamlico, Croatan, and Albemarle Sounds, indicating that many of the fish tagged on the outer coast moved south and west, some of them being taken in the extreme western tip of Albemarle Sound. The remaining 21 returns came from areas to the north of the point of release; 9 came from the Virginia Beach region; 8 from well into Chesapeake Bay (mainly from the James River and Rappahannock River sections); and 4 from more northern waters—2 from New Jersey, 1 from Wainscott, Long Island, N. Y., and the other from Point Judith, R. I. Had there been a heavy migration to the north at this time from this area, it seems reasonable to expect that in view of the highly intensive fishery for this species as shown by the percentage of recapture from other tagging experiments, there would have been a far greater number of returns from more northern waters. That this tagging experiment was not conducted at a time that was too late to coincide with the bulk of the spring migration to the north seems virtually certain, in view of the fact that tagging was started as soon as the outer-coast fishermen began to catch striped bass and was not concluded until the catches had dwindled so that few bass were being taken. Further evidence along this line appears in tables 22A, 22B, and 22C, which show that there were no returns from outside the State of North Carolina from the small number of striped bass that were released there in March and April, 1937. It does not appear, therefore, from the preliminary results of this work that the North Carolina stock contributes more than a small percentage directly to the summer population in the north. Rather, it seems that the bulk of the northern migration of the striped bass in the spring, and the corresponding return to the south in the fall, takes place between the Chesapeake Bay area and Cape Cod, and that only a relatively small number of migrants from the north and south of these regions take part in these movements.

In this connection the author is grateful to Mr. David H. Wallace, of the Chesapeake Biological Laboratory of the University of Maryland, for giving him the results of a tagging experiment conducted in conjunction with Dr. Vadim D. Vladykov's investigation of anadromous species for the State of Maryland. Of 483 bass tagged from November 15 to 19, 1937, in the east end of Albemarle Sound, in Croatan Sound, and on the outer coast of North Carolina, most of which were yearling and 2- and 3-year-old fish, only 2 had been recovered from northern waters by June 1, 1938, these coming from New Jersey. This is added evidence that North Carolina contributes only a small amount directly to the population summering in northern waters. It is of interest that 1 of these fish tagged on November 15, 1937, was caught in New Jersey on January 16, 1938, showing that some fish migrate north before the spring months.

ORIGIN OF THE DOMINANT 1934 YEAR-CLASS

The problem of the geographical point of origin of the dominant 1934 year-class, that age-group which has already been discussed at some length, is of particular interest. There is considerable evidence to support the conclusion that these fish were produced mainly in the Chesapeake Bay region. Thus, in the summer of 1935, when the members of this year-class were 1-year-olds and probably averaged 15–20 cm. (approximately 6–8 inches) in length, an unusually great abundance of striped bass of about this size and presumably of this age was observed and reported from Chesapeake Bay by many competent people. Truitt and Vladykov (1936) also "found that fish ranging from 21 to 25 cm. in standard length" seemed to be the most abundant age-category of striped bass in Chesapeake Bay during the early and midsummer in 1936. These fish were undoubtedly 2-year-olds at that time—members of the dominant 1934 year-class. Vladykov and Wallace (1937) also corroborate this information. On the other hand, diligent inquiry elicited no reports of yearling bass in 1935 from waters farther north. In the light of these observations it therefore seems logical to suppose that this large group of fish that were 2-year-olds in the summer of 1936, and first appeared in north Atlantic waters in that year, came in the majority from the Chesapeake Bay area and that general latitude. (See below for evidence that the dominant 1934 year-class did not come from farther south, p. 49.) From what is now known of the paucity of the spawning areas in the north, it is most unlikely that those regions north of the latitude covered by Delaware Bay contributed more than a small fraction to this dominant year-class—or for that matter, that they ever play more than a small and unimportant role in contributing to the total stock along the Atlantic coast under present conditions. Thus it becomes apparent that the striped bass fishery from New Jersey northward is almost entirely dependent for its existence on the stock of bass produced to the south, and on the migrations from the south to the north in the spring, which do not occur until bass become 2 years old or older.

Granting that the major portion of the production of striped bass takes place from the northern part of Delaware Bay south, it is of interest to determine how far south the stock contributes to the supply in northern waters, and to what extent different areas contribute to this supply. It is known that the Chesapeake Bay area is an important spawning center, and the work of V. D. Vladykov and D. H. Wallace (as yet unpublished) on tagging striped bass in connection with the survey of anadromous fishes for the State of Maryland has shown that the migration of bass out of Chesapeake Bay to the north in the spring is not an uncommon occurrence. Thus it seems well established that this general region contributes to the supply in the north and is an important center of production.

The question of how much the areas to the south of Chesapeake Bay contribute to the population in the north, and whether or not the dominant year-class of 1934 was produced simultaneously in Albemarle and Pamlico Sounds as well as in Chesapeake Bay, is of further interest. The author has found no evidence from talking with commercial fishermen in the Albemarle Sound region in 1937 and 1938 that there was an unusually large quantity of yearling bass in 1935 in these waters, as was the case in Chesapeake Bay. Further than this, tagging experiments in March and April in 1938 on the outer coast of North Carolina and in the eastern end of Albemarle Sound tend to show that the bass from this area do not undertake such an intensive migration to the north in the spring, and that they do not contribute a large amount to the summer population in northern waters. It has been pointed out that these tagged fish did not show an intensive one-way migration at this time, but rather a diffusion from the point of release with only a small percentage of the fish making definite movements of considerable distance to the north. This was in spite of the fact that these fish were released at exactly the time they would be expected to undertake the spring migration northward, and was in direct contrast to the one-way mass migration southward as shown by tagging in the north in the fall (see pp. 36–39 and 44–46). It is clear from this information that the stock in North Carolina waters probably contributes only a relatively small percentage directly to the populations summering in the north.

There is further evidence from the results of scale analysis that the main source of supply for the summer populations in northern waters is in the Chesapeake Bay area—or at least that general latitude (which includes Delaware Bay), and not from farther south. Unfortunately vertebral counts are of no value in showing the general point of origin of individual striped bass or for racial analysis, for this is a species with a virtually constant number (25) of vertebrae (see p. 3), and therefore the counts show no variation with latitude such as has been shown to occur in other forms (e. g., Hubbs, 1922). Scale and fin-ray counts may possibly be of some use in this respect, but they have not been used in this study because of the impracticality of making such counts, especially where the material was limited and it was desirable to tag a large proportion of the fish that were taken in northern waters. But whereas scale and fin-ray counts were not feasible in conjunction with tagging work, it was perfectly practicable to take scale samples from live fish. For these reasons, and because the scale method has given such successful results in determining points of origin in other species, scale analysis was used throughout for this purpose.

The assumption on which such a method rests in a species that spawns over a considerable latitude is that since there are likely to be different environmental factors over the entire range of spawning, there are also likely to be different growth rates which should be reflected in the scales. The problem is, then, to detect these differences in the scales from fish of different latitudes, and to establish that they are constant and therefore good criteria for determining the points of origin of the individuals from which the samples are taken. The striped bass is known to spawn over a wide latitude, and apparently does not migrate along the coast until it becomes approximately 2 years old. Thus, if there are any differences in the growth rate of this species in various localities along the coast, those that are to be used in determining points of origin must be found within that part of the scale bounded by the second annulus. With this in mind, as well as the fact that scale growth is proportional to body growth (see p. 31), the widths of the first and second growth zones of scales from striped bass of known and unknown origin were measured by the method described in the section on age and rate of growth (see fig. 15).

Figure 32 shows the length-frequencies of the widths of the growth zones in millimeters on scales from striped bass taken in different localities along the Atlantic coast in 1937. The top three series of length-frequency curves (those from scales from fish taken at (1) Cape Cod Bay, Mass., (2) Harkness Point, Conn., and (3) Montauk, Long Island, N. Y.) are from members of the 1934 dominant year-class—that group of fish whose origin is of especial interest. The samplings of fish from which these three sets of curves come, were made in the summer and fall of 1937 in northern waters. In the three sets of measurements, the widths of the first and of the second growth zones are strikingly alike throughout—a fact which at least suggests

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that the members of the dominant 1934 year-class that visited northern waters in 1937 were of much the same origin. It should be mentioned that measurements of the first and second growth zones on the scales from 2-year-old bass in Connecticut waters in 1936 (members of the 1934 dominant year-class) also gave length-frequency curves that were exactly comparable to those shown in the top three sets of curves in figure 32. Had they been of different origin—from areas scattered along the entire length of the Atlantic coast—it would be expected that the distribution of the length-frequencies of the widths of the first and second growth zones in these cases would have been much wider and not nearly as constant in the range of measurement as they actually are.

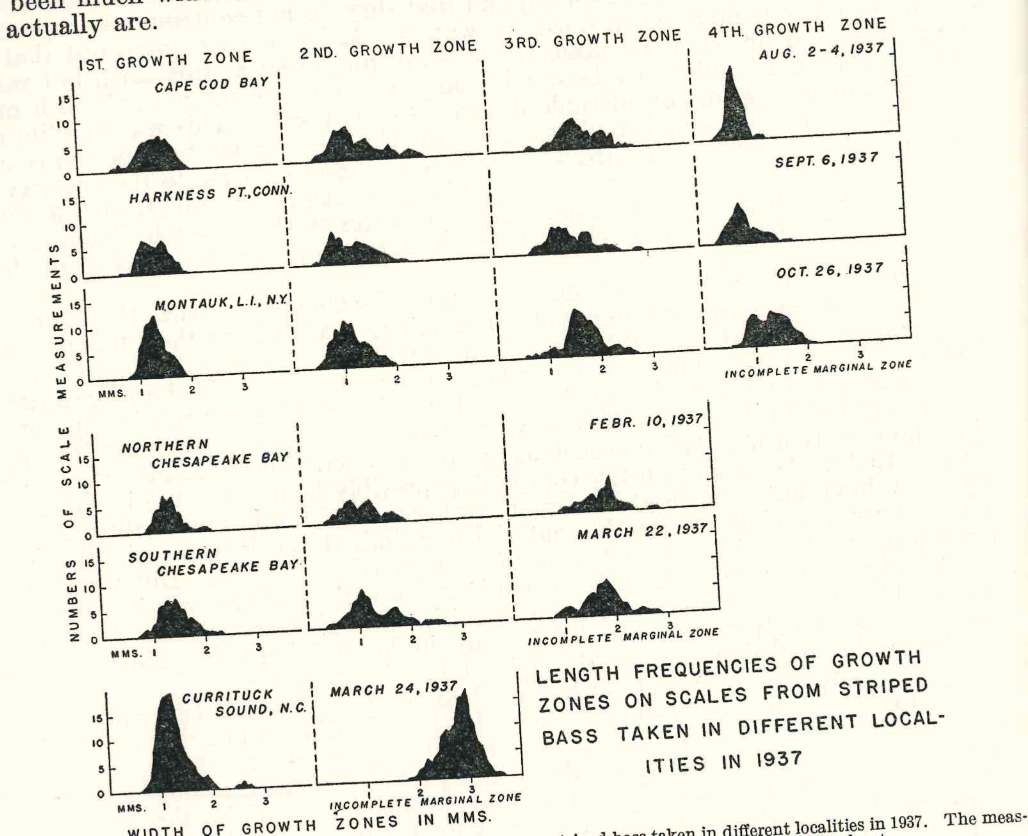

FIGURE 32.—The length-frequencies of the growth zones on scales from striped bass taken in different localities in 1937. The measurements making up each curve have been smoothed by a moving average of threes throughout.

One other point is of interest in the length-frequencies of the growth zones on the scales from these fish taken in northern waters in 1937. This is the comparison of the fourth growth zones (incomplete marginal zones) of the samples from Cape Cod Bay and Harkness Point. It has been pointed out in the section on age and rate of growth that there is much evidence that striped bass north of Cape Cod grew much faster than those south of Cape Cod during the summer of 1937 (see fig. 19 and p. 29). Since scale growth is proportional to body growth (see fig. 21), this phenomenon should be reflected in the scales, and a glance at the length frequencies of the incomplete marginal zones mentioned above (see fig. 32) shows this to be true. Thus the measurements of the fourth growth zones of the scales from fish from Cape Cod Bay present a peak slightly in advance of the similar peak for the Harkness Point sample, despite the fact that the sample from Cape Cod Bay was taken more than 1 month earlier than the one from Harkness Point. This is probably best explained by the faster growth rate of the fish summering north of Cape Cod, for if the growth rates were the same, the peak for the Harkness Point sample would have been far in advance of the one for the Cape Cod sample, since it was taken so much later in the summer.

Turning now to the two middle sets of length-frequencies in figure 32, those from scale measurements from fish taken in northern and southern Chesapeake Bay in February and March 1937, it is apparent that these are also from samples of the dominant 1934 year-class at the time its members were just becoming 3 years old, and when the third annulus was in the process of formation on the anterior margin of the scale. Looking at the widths of the first two growth zones, it is immediately apparent that the general distribution of the length frequencies and the peaks of the first growth zones and the second growth zones are similar throughout. Furthermore, they coincide almost exactly with the same growth zones of the scales from fish born in the same year but collected at a later date in northern waters—see the top three sets of curves in figure 32. It cannot be assumed, however, although it may well be true, that these samples from Chesapeake Bay are from fish that were produced in that region and had remained there, since it is known that this species often undertakes coastal migrations after it becomes 2 years old. Thus these fish might have moved into Chesapeake Bay in 1936, and might, therefore, not have had their origin in this region. On this account, it is not possible to assert that the similarity in the widths of the first growth zones and those of the second growth zones in the top five sets of curves in figure 32 is proof that the dominant year-class of 1934 originated in Chesapeake Bay. These similarities do, however, suggest that this is so.

Looking at the bottom set of curves in figure 32, those from scales from fish taken in Currituck Sound, N. C., it is again apparent that the widths of the first growth zones are much the same as those for all the other samples in this figure, although they do tend to be slightly less. The widths of the second growth zones of scales of the fish from this area, however, are strikingly different from any that precede it in figure 32. Whereas the widths of the second growth zones of the scales from fish from northern waters and from Chesapeake Bay in 1937 all range from approximately 0.5 mm. to or slightly over 2.0 mm. (with peaks at 1.0 mm.), the widths of the second growth zones of scales from fish from Currituck Sound range from about 2.0 to 3.6 mm. (with a peak at 2.9 mm.). These second growth zones of the scales from fish from Currituck Sound are labelled incomplete marginal zones in figure 32 because the second annuli, although in the process of formation on the anterior margins of the scales, were still indistinct. Therefore, the measurements of the marginal zones are to all intents and purposes equivalent to what those on the second growth zones would have been had the second annuli been completely formed. It should not be necessary to point out that if there were any differences from this factor, the widths of the second growth zones would have been even greater.

There is no doubt that these completely different and exceptionally wide second growth zones on the scales from fish from Currituck Sound are characteristic of the bass born in that general region in 1935, for these scales were taken from fish that were slightly less than 2 years old, and therefore had not undertaken any coastal migration. Thus the wide second growth zones on scales from fish born in the general Albemarle Sound region in 1935 give promise of being a means of distinguishing fish from this area from those born farther north. And since these wide growth zones are so different from the other growth zones in figure 32, they provide added evidence that the dominant 1934 year-class arose in the general latitude of Chesapeake Bay. They also tend to show that those bass born in North Carolina do not contribute a large proportion of the population that summers in northern waters. On the other hand, the fish that make up the top five sets of curves in figure 32 were all born in 1934, while those that make up the bottom set of curves (Currituck Sound) were born in 1935; and it should be pointed out that the comparison of the widths of the second growth zones of scales from fish born in different years may be fallacious. Thus there is no evidence from the single sampling in Currituck Sound in 1937 as to whether the wide second growth zone is truly a regional difference that occurs annually, or whether it was only a characteristic of the 1935 year-class. However, scale measurements from samplings of bass of the same age—2 years old in the spring of 1937—as those from Currituck Sound but taken in different areas, southern New England and southern Chesapeake Bay, appear in figure 33. (The length-frequency curves of the scale measurements of the sample from Currituck Sound shown at the bottom of fig. 32 are also repeated for the sake of comparison at the bottom of fig. 33.) These provide proof that the members of the 1935 year-class that contributed to the population summering in northern waters as 2-year-olds in 1937 came, in the main, from the Chesapeake Bay area. Thus the middle set of curves in figure 33 are measurements of the growth zones of scales from fish that were just becoming 2-year-olds in Chesapeake Bay in 1937. They are, in other words, from bass that had not yet migrated to any great extent, and the curve for the second growth zone may therefore be considered typical for bass that had been born in1935 in Chesapeake Bay. The upper set of curves in figure 33 is from measurements of the growth zones of scales from 2-year-old fish taken from northern waters in the summer of 1937. They are from bass of unknown origin that had migrated north along the coast in the spring. It will be noted immediately that the curve for the second growth zone of the scales from northern fish in the summer of 1937 compares well with the similar curve for the bass of the same year-class known to be of Chesapeake Bay origin.

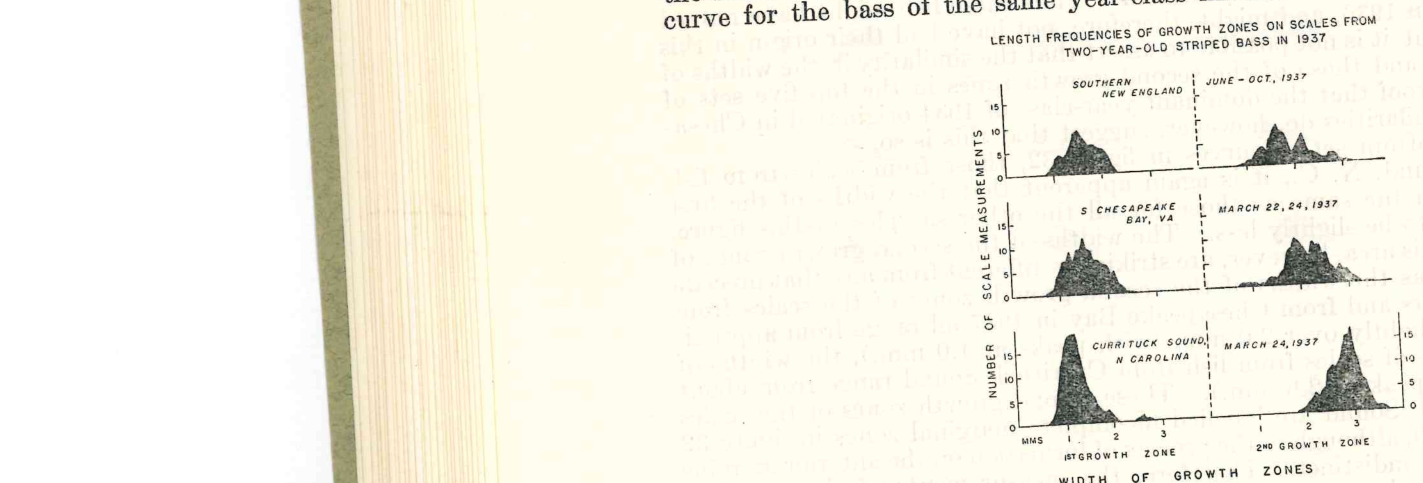

FIGURE 33.—The length-frequencies of the growth zones on scales from 2-year-old striped bass taken in southern New England southern Chesapeake Bay, and Currituck Sound (repeated from Figure 32 for comparative purposes), in 1937. The measurements making up each curve have been smoothed by a moving average of threes throughout.

However, it does not compare well with the similar curve for bass of the same year-class known to be of North Carolina origin. (See lower set of curves, figs. 32 and 33.) There is somewhat of an overlap between the curves of the widths of the second growth zones on scales from fish of the 1935 year-class of known origin from Chesapeake Bay and North Carolina, so that scales from fish of the same age-group but of unknown origin that show a second growth zone measuring from about 2.0–3.0 mm. might have been born in either of the above-mentioned areas. It is apparent that the majority of the widths of the second growth zones on the scales from fish taken in northern waters in the summer of 1937 fall below 2.0 mm. Judging from these measurements, it is possible to say that the North Carolina fish (assuming the Currituck Sound sampling to be representative of that area) contributed at an absolute maximum about 20 percent of the 2-year-olds summering in northern waters in 1937. The percentage that North Carolina contributed to the northern population at this time was probably much less. In fact, a comparison of the widths of the second growth zones of the scales from fish of the same year-class from Chesapeake Bay and from northern waters in 1937 (see fig. 33) shows that it is possible that North Carolina did not contribute anything directly to the population of 2-year-olds summering in the north in 1937, and that this population came entirely from the Chesapeake Bay area or north of it. The latter, however, is undoubtedly an extreme view.

It is thus apparent that in 1937 North Carolina contributed directly not more than a small fraction of the 2-year-old striped bass summering in northern waters, and that the 2-year-old bass in northern areas in that summer came mainly from the Chesapeake Bay latitudes and perhaps from the Delaware Bay region. There is, however, a possibility that the fish born in North Carolina contribute indirectly to the popu-

lation summering in northern waters—that is, that they move up into Chesapeake Bay in the spring as 2-year-olds (e. g., see under the last part of the section on migrations) and then migrate to northern waters a year or more later. This is added evidence that the dominant 1934 year-class, which first appeared as 2-year-olds in northern waters in 1936, came from the general area of Chesapeake and perhaps Delaware Bays, although evidence of the above type should be obtained for several successive years before it can be considered conclusive proof of the fact that the contribution to northern waters in the spring and summer comes essentially from the latitudes of Chesapeake and Delaware Bays each year.

Measurements of the growth zones of scales from striped bass born in 1936 in the Delaware Bay and Albemarle Sound regions are shown in figure 34. It will be noted that the widths of the second growth zones of the scales from the fish of Delaware Bay origin born in 1936 are slightly below those for the growth zones on the scales from the fish of Chesapeake Bay origin born in 1935. (Compare upper set of curves in fig. 34 with middle set of curves in fig. 33.) It is probable that this difference is at least in part due to the fact that the second growth zones on the scales from the Delaware Bay fish were not yet quite complete (the fish were taken on November 8, 1937) because the annuli on scales do not appear until spring, although the growth from November to March is almost negligible. Whether or not there is a constant difference in the widths of the second growth zones of scales from fish of Delaware

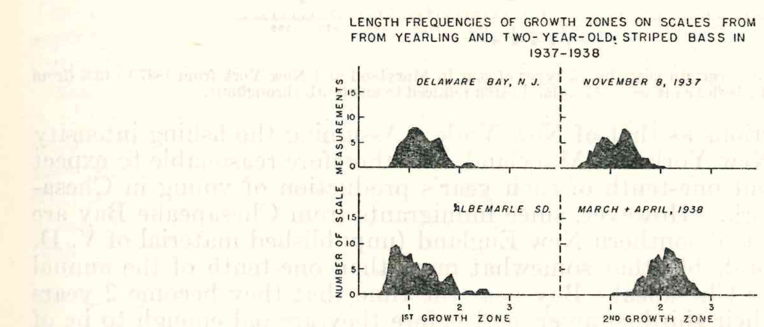

FIGURE 34.—The length-frequencies of the growth zones on scales from yearling and 2-year-old striped bass taken in Delaware Bay and Albemarle Sound in 1937 and 1938. The measurements making up these curves have been smoothed by threes throughout.

and Chesapeake Bay origin remains to be seen from sampling over a period of years. It is probable that this method will not provide a good means of distinguishing between bass born in these two regions, as the environmental differences are apparently insufficient to cause any constant difference in growth rate during the second year.

The widths of the second growth zones of scales from fish born in 1936 in Albemarle Sound (see lower set of curves in fig. 34) are interesting because although they are quite great, they are not so distinctively different from the others as those from North Carolina collected in 1937 (see bottom set of curves, figs. 32 and 33). They indicate, in other words, that although a wide second growth zone is apparently a characteristic of North Carolina fish from the general region of Albemarle Sound, this characteristic varies from year to year sufficiently so that it can only be used as a means of distinguishing fish of North Carolina origin from fish of Chesapeake Bay origin when the scales from fair samplings of bass that are just becoming 2 years old in the spring, before any coastal migrations have been undertaken, are available from both areas during any one year.

In conclusion it should be emphasized once more that the available evidence from general observation, scale analysis, and tagging experiments, gives every indication that the dominant 1934 year-class originated chiefly in the latitude of Chesapeake and Delaware Bays; that those fish produced in North Carolina contribute directly only a relatively small fraction to the population summering in northern waters; and that the main body of the northern summer population of striped bass comes from the area bounded on the south by Virginia and on the north by New Jersey. Further proof that Chesapeake Bay in general contributes a large proportion of the stock summering in northern waters is seen in figure 35, where the catches in New York and Maryland are compared in certain years from 1887 to 1935. (The material for this figure is taken from the U. S. Bureau of Fisheries canvass, and is not an annual comparison because the data are incomplete.) It will be noted that the trends of the catches in these two localities over this entire period show a remarkable correspondence—an agreement that could not reasonably be expected to occur unless the supply for both areas came mainly from the same source. In view of the evidence already presented, there can be little doubt that this source is the Chesapeake Bay area. In figure 35 the Maryland catch has been plotted at one-tenth its actual value throughout, a reduction which brings the annual catch in that State

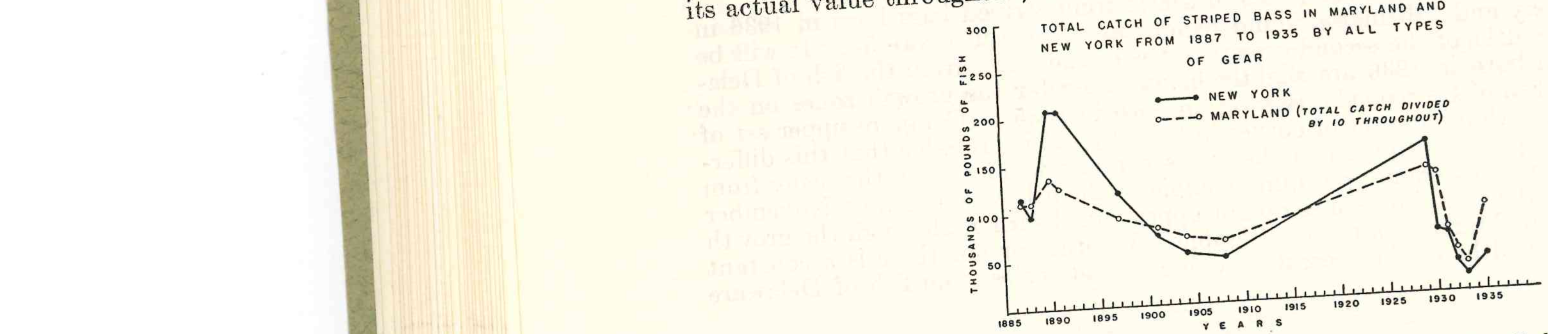

FIGURE 35.—Total catch of striped bass in certain years by all types of gear in Maryland and New York from 1887 to 1935 (from U. S. Bureau of Fisheries canvass). Maryland catch reduced to one-tenth throughout.

down to the same proportions as that of New York. Assuming the fishing intensity to be about the same in New York and Maryland, it is therefore reasonable to expect that this means that about one-tenth of each year's production of young in Chesapeake Bay reach New York. However, since immigrants from Chesapeake Bay are also taken in New Jersey and southern New England (unpublished material of V. D. Vladykov, p. 46), it is probable that somewhat more than one-tenth of the annual production of young leave Chesapeake Bay near the time that they become 2 years old, at the beginning of their third summer, and before they are old enough to be of any great value to the Chesapeake Bay fishery.

FOOD OF THE STRIPED BASS

The stomach contents of over 550 striped bass ranging in size from 6.5 to 115 cm. have been examined during the course of this investigation. These fish were all taken from April to November 1936 and 1937. Most of them were caught in Connecticut waters, although a few came from the Massachusetts coast and others from Long Island and New Jersey. Of the total number of fish examined, the majority were caught on rod and line; the others were taken by net. Over 75 percent of the stomachs studied came from bass that ranged in size from 30 to 50 cm.

The rugose lining of the stomach of the striped bass probably indicates a rapid rate of digestion. It is apparently not a steady feeder, but may gorge itself over comparatively short periods of time and then stop feeding until its stomach is completely empty again. Stomach-content analyses of individuals taken in the same seine hauls often showed the food to be in similar states of digestion, thus providing evidence that the members of a single school of striped bass feed simultaneously and then digest their food over essentially the same period of time. Often a high percentage of the bass in one haul would be filled with recently eaten fish such as menhaden (*Brevoortia tyrannus*) or silversides (*Menidia menidia notata*). Stomach-content analysis of the bass taken in another haul would reveal partially or well-digested food. At other times most of the fish taken together would be entirely empty. Approximately 52 percent of all the stomachs examined were completely empty. This high percentage may be explained, at least in part, by the fact that a large portion of the total number of stomachs examined were from rod-and-line caught

fish, which are commonly empty because bass are more likely to be taken by anglers at the start of a feeding period when they usually have nothing in their stomachs, and also because bass taken on hook and line are often seen to regurgitate recently swallowed food.

Studies of the food of juvenile and yearling striped bass ranging from 3–11 cm. in standard length, seined on gravelly shoals of the Hudson River at Dennings Point, near Beacon, N. Y., have been made by Townes (1937) in connection with the biological survey of the Lower Hudson Watershed carried out in 1936 by the State of New York Conservation Department. The majority of these fish ranged from 3.0–5.5 cm. in length. It was found that the fresh-water shrimp (*Gammarus fasciatus*) formed about 60 percent of the food, with chironomid larvae the next most important item. Small fish remains (not identified, save for one eel, *Anguilla rostrata*), leptocerid larvae, and planktonic Crustacea such as *Latona*, *Cyclops*, and *Eurytemora*, formed a small percentage of the food. Hildebrand and Schroeder (1928) examined the stomach contents of small striped bass from the salt and brackish waters of Chesapeake Bay, and found that ". . . the young had fed on *Mysis*, *Gammarus*, annelids, and insects." The stomach-content analysis of small bass has been confined in the present study to 3 juveniles ranging from 6.0–7.5 cm. in standard length taken in the Parker River, Mass., on August 4, 1937, and 30 juvenile and yearling individuals from 11–23 cm. long taken in the Delaware River, near Pennsville, N. J., on November 8, 1937. Those from the Parker River all had their stomachs filled with the shrimp, *Crago septemspinosus*.[14] Those from the Delaware River were large enough to have become more voracious in their feeding habits, as is evidenced by the fact that 19 of the 30 examined contained the remains of fish of different species; the others were empty. A clupeoid species (probably menhaden, *Brevoortia tyrannus*) formed the main diet, while white perch, *Morone americana*, and shiners, *Notropis hudsonius amarus*, were also commonly eaten. It is of some interest that one bass 16.5 cm. (6½ inches) long contained a 7.5 cm. (2.95 inches) *Morone americana*, and examination of the stomach of an 18.5 cm. (7.28 inches) bass revealed the presence of a 10 cm. (3.94 inches) *Notropis* sp.

The examination of stomach contents of larger striped bass (above 25 cm.) has confirmed the commonly held view that this species is voracious in its feeding habits, and fairly general in its choice of food. It has also made it clear that bass often feed off the bottom, and blind individuals that were frequently taken in the Thames River, Conn. (see under section on parasites and abnormalities of the striped bass), appeared to manage well by feeding only on bottom-dwelling forms such as those included in the list below.

The most common form of food in Connecticut waters is the shiner, or silversides (*Menidia menidia notata*). This is a species which spawns in the spring (Hildebrand, 1922), and the young of each year stay so close to shore and are of such small size that they do not become available to the striped bass as food until August. At this time they reach 2 cm. in length and often stray farther offshore. The growth rate of juvenile *Menidia* is shown in figure 36. The length-frequency curves making up this graph are from random samples of the population seined at biweekly intervals from July to September 1937 in the Niantic River, Conn. It is apparent from a glance at the modes of these curves that in 1937 a peak of 2.0 cm. was attained shortly after the middle of August. Stomach-content analysis of striped bass 30–50 cm. long in this area in 1936 and 1937 showed that adult *Menidia* and the common prawn (*Palaemonetes vulgaris*) formed the main food from April to August, but that in August and September the bass fed on juvenile *Menidia* to a large extent. Shortly after this change in diet in 1936 there was a decided increase in the growth rate of the 2-year-old striped bass (see p. 28), which, despite the drop in water temperature (see fig. 30), was greatest in October. The presence of what was apparently an unusually great number of juvenile menhaden (*Brevoortia tyrannus*) in 1936 may also have played a part in this increased growth rate, for from August on striped bass commonly fed

[14] Identified by Dr. Charles J. Fish, Director of the Marine Laboratory at Narragansett, Rhode Island State College, Kingston, R. I.

heavily on this species during this year. However, juvenile menhaden were not as abundant in 1937 in this area, yet the growth rate of striped bass in September and October continued much as it had throughout the summer in spite of the drop in temperature (see fig. 18). It therefore appears that the increased food supply of striped bass resulting from the availability of juvenile *Menidia* after the middle of August may be correlated with the maintenance or increase of the growth rate in the early fall when the water temperature falls rapidly, and when the normal expectation

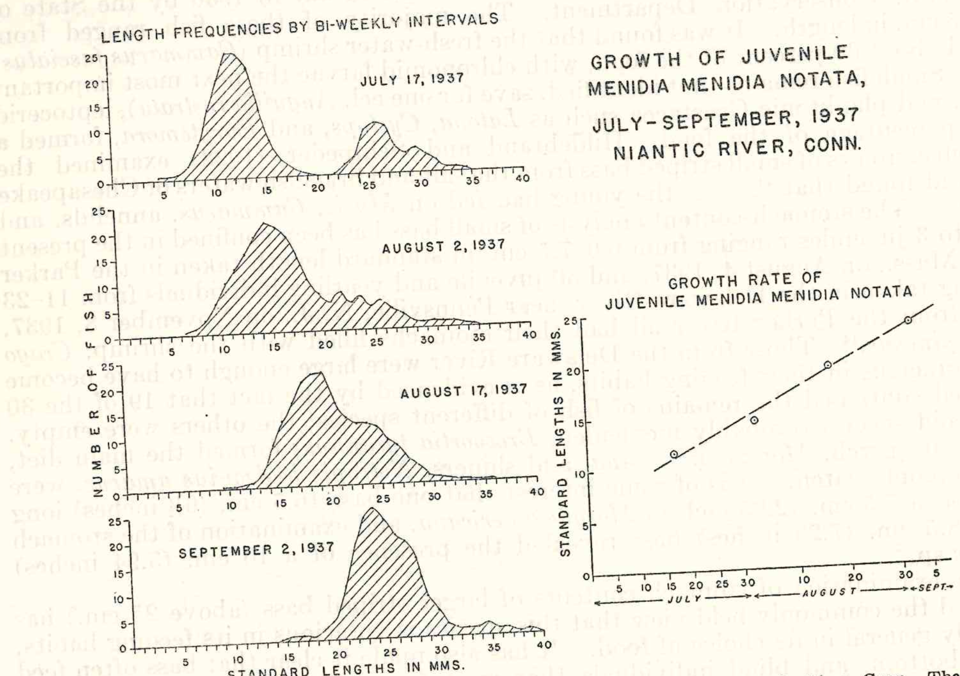

FIGURE 36.—The growth of *Menidia menidia notata*, from July to September 1937, in the Niantic River, Conn. The length-frequencies have been smoothed by a moving average of threes throughout (see Table 23 for original data).

would be that the growth rate would slow down. Other possible explanations of this apparently faster growth rate of striped bass in the late summer and early fall, such as faulty sampling and "compensatory growth," have been discussed in the section on the age and rate of growth of striped bass.

The following comprise all the forms of food found in the stomachs of the 550 striped bass examined in 1936 and 1937:

Common types:
- Shiners, or silversides (*Menidia menidia notata*).
- Menhaden (*Brevoortia tyrannus*).
- Shrimp, or prawns (*Palaemonetes vulgaris*).
- Mummichogs, or killifish (*Fundulus heteroclitus* and *majalis*).

Uncommon types:
- Sand Launces (*Ammodytes americanus*).
- Herring (*Clupea harengus*).
- Squid (*Loligo pealei*).
- Sandworms (*Nereis virens*).[15]
- Bloodworms (*Glycera dibranchiata*).[15]

Rare types:
- Flounders (*Pseudopleuronectes americanus*).
- Eels (*Anguilla rostrata*).
- Tomcod (*Microgadus tomcod*)—one 20 cm. specimen in a 40-cm. striped bass.
- Clams (*Mya arenaria*)—of small size.
- Crabs (*Callinectes sapidus* and *Ovalipes ocellatus*)—of small size.
- Snails (*Littorina*, sp. ?).
- Mussels (*Mytilus edulis*).
- White perch (*Morone americana*).
- Mullet (*Mugil cephalus*).
- Shiners (*Notropis hudsonius amarus*).
- Blennies (*Pholis gunellus*).
- Amphipods.
- Isopods.

[15] These 2 marine annelids are generally used for bait, thus pieces of them are often found in bass that were caught on rod and line. However, whole individuals also have been observed in the stomachs of striped bass.

It is apparent from a glance at this list that bass feed on a wide variety of animals, and it is likely that a study of stomach contents in other localities would yield as many more species as are common in the coastal waters inhabited by striped bass. In this connection, the examination of the stomach contents of 101 striped bass (yearling to 3-year-olds from the Albemarle Sound region and Manteo, N. C., in April 1938 yielded the following definitely identified forms, to say nothing of those that were too well digested to be identified: Teleosts.—Striped killifish (*Fundulus majalis*); sea trout, or spotted squeteague (*Cynoscion nebulosus*); silver perch (*Bairdiella chrysura*); croaker (*Micropogon undulatus*); gizzard shad (*Dorosoma cepedianum*); spotted ling, or hake, or codling (*Phycis regius*); anchovy (*Anchoviella mitchilli*); eel (*Anguilla rostrata*); white perch (*Morone americana*); glut herring (*Pomolobus aestivalis*); and minnow, or shiner (*Notropis*, sp.?). Crustacea[16].—Three species of shrimp (*Peneus brasiliensis*, *Palaemonetes carolinus*, *Crago septemspinosus*); young blue crab (*Callinectes sapidus*); and isopod (*Aegathoa oculata*).[17]

PARASITES AND ABNORMALITIES OF THE STRIPED BASS [18]

Parasites of the striped bass have been collected whenever they were observed from 1936 to 1938.

Two species of nematodes have been found that are endoparasitic on the striped bass. The first, *Goezia annulata* (syn.: *Lecanocephalus annulatus* Molin), was found in a single specimen in the stomach mucosa, and has been reported and described by Linton (1901) and MacCallum (1921). The second, *Dicheilonema rubrum* (syn.: *Filaria rubra* Linton), has been observed in innumerable striped bass. It was found in the peritoneal cavity, usually in the posterior end in close association with the gonads, but it never appeared to do any serious harm to its host. This species has been reported for the striped bass by Railliet (1918), and is described by Linton (1901).

Among the forms that are ectoparasitic on the striped bass are two species of copepods which have been found on various occasions. *Caligus rapax*, which occurs on many species of marine fish, and described by Wilson (1905 and 1932), is not uncommon. *Argulus alosae* Gould was taken on three striped bass in the Niantic River, Conn., in August and September, 1936, thus constituting a new host record for this species; it was described by Wilson (1903). It is also of interest that in the collection of juvenile bass taken from the western end of Albemarle Sound on May 11, 1938, a high percentage of the fish were parasitized by glochidia. It is supposed that these glochidia attached themselves to the fish in the fresh water at or near the mouth of the Roanoke River, and it is not known whether or not they can complete their normal encystment and development after being carried into the brackish waters of Albemarle Sound.

A review of the literature indicates that many other parasites have been reported for the striped bass. The monogenetic trematodes include *Lepidotes collinsi* (Mueller, 1936), *Aristocleidus hastatus* (Mueller, loc. cit.), *Epibdella melleni* (Nigrelli and Breder, 1934), *Microcotyle acanthophallus*, *M. eueides*, and *M. macroura*. Digenetic trematodes that have been reported on striped bass are *Distoma rufoviride* (syn.: *D. tenue*) (Linton, 1898), *D. tornatum* (Linton, 1901), and *D. galactosomum*. Two cestodes, *Rhynchobothrium bulbifer* and *R. speciosum*, have been reported by Linton (1901 and 1924), the former as plerocercoids in the intestine (adults in Selachians), the latter in cysts in the viscera. Besides the nematodes already mentioned, an *Ascaris* sp. has also been reported by Linton (1901). Two acanthocephalans, *Echinorhynchus gadi* (syn.: *E. acus*) (Linton, 1901) and *Pomphorhynchus laevis* (syn.: *E. proteus*), have been taken from striped bass. Two other copepods besides those found by the author are the Lernaeopodid, *Achtheres lacae* (Wilson, 1915), and the Ergasilid, *Ergasilus labracis* (Wilson, 1911 and 1932).

In regard to the general well-being of the striped bass, there is no evidence that any of the parasites that are associated with it are of any great importance. *Dicheilonema rubrum*, which is so commonly found in the peritoneal cavity, shows a tendency

[16] Identified by Dr. Charles J. Fish, Director of the Marine Laboratory at Narragansett, Rhode Island State College, Kingston, R. I.

[17] The isopod, *A. oculata*, is normally found parasitic on squid (*Loligo pealei*) and young mullet (*Mugil* sp.), but since neither of these forms was seen in the stomachs of these bass, it is probable that *A. oculata* was taken by the bass while it was free-swiming during the breeding season.

[18] The author wishes to express his gratitude to Dr. John S. Rankin, of the Department of Biology at Amherst College, for his assistance in the preparation of the material on the parasites of the striped bass, and for his identifications of the nematodes and copepods.

to become partially embedded in the mesenteries, but the infection never appears to be serious. *Goezia annulata*, although comparatively rare, is probably a much more serious pest. MacCallum (1921: 261) says:

> Its mode of living is calculated to interfere very materially with the function of the stomach, inasmuch as it burrows under the mucous membrane, in fact excavating in some cases quite a space where several worms cohabit. . . . There are often several of these nests in the stomach, each nest may be 30 mm. to 40 mm. across, and as they cause a good deal of swelling and irritation, they may and do in some cases so restrict the cavity of the host's stomach that its food cannot be taken in any quantity sufficient to keep it alive. Thus the worms are a very serious menace to the fish.

This species is not common in striped bass, however, and according to reports is quite cosmopolitan in its choice of host, having been recorded from many other species of fish. Trematode infections are probably sufficiently rare in striped bass in their natural habitat to be of small importance. Nigrelli and Breder (1934) have shown that many of the Serranid fishes have developed a resistance to *Epibdella melleni*, while Jahn and Kuhn (1932) noted that ". . . the possibility of the development of immunity seems to be more strongly suggested in this family" (*Serranidae*). Copepod parasites are also apparently of small consequence to the striped bass.

It is worth mention that a surprising number of striped bass were encountered in the Thames and Niantic Rivers, Conn., that had cataracts of the eye. These were found commonly only in the Thames River, where they sometimes reached above 10 percent of the catch by seine. This opacity of the lens was encountered in all degrees from a slightly cloudy to a dead-white condition. It was almost universally bilateral, was rare in 2-year-old bass, and more common in the larger sizes. It was equally common in all months from April to October. A number of dissections under low-power magnification failed to reveal any parasites, such as larval digenetic trematodes, which might reasonably be expected to cause such blindness. Hess (1937) has recently shown that bilateral cataracts are common in trout in New York State, both in hatchery and wild stock, and he has proved with rainbow trout (*Salmo irideus*) ". . . that cataract in these fish is due to an unbalanced diet." He has been able to demonstrate that contagious infection, light, and hereditary factors, are not in any way connected with the production of such cataracts, and that the feeding of trout exclusively on pig spleen caused a high incidence of cataract; while trout fed with beef liver and heart never showed any trace of cataract. It seems likely, therefore, that a dietary deficiency may perhaps account for the high percentage of blind striped bass in the Thames River. It is interesting in this connection that the extraction of carotene by acetone from the liver and fatty tissue of blind and normal bass has tended to show less carotene per gram of tissue in the blind than in the normal individuals, and it is thus possible that a lack of vitamin A is associated with the dietary deficiency causing cataracts.

It is also of interest that Schultz (1931) has recorded a case of what gave every appearance of being completely functional hermaphroditism in the striped bass. This fish was taken in Oregon in May, and the eggs in one half of the gonads measured about 1 mm. in diameter, close to the size at the time of spawning (see p. 19), while the male half of the gonads was apparently developing normally.

DISCUSSION

It has been pointed out that there has been a striking decline in the numbers of striped bass along the Atlantic coast over long-term periods. (See under section on fluctuations in abundance of the striped bass, p. 8, and figs. 3 and 4.) The records show that this decline has been fairly steady from at least as far back as the middle of the nineteenth century, and perhaps before. They also indicate that it has been interrupted only by the occasional appearance of dominant year-classes—groups of striped bass that were produced in such huge amounts in certain years that they caused a marked increase in the numbers caught for short periods (see p. 8, et seq.). It is apparent from the available catch records (see fig. 4), however, that these dominant year-classes did not bolster the stock for more than a few years, and that their effects invariably have been short lived. In other words, the surplus created by them was soon removed, no permanent increase in abundance—and a consequent permanent increase in catch—resulted, and the decline in numbers of striped bass, although temporarily interrupted, soon resumed its normal trend.

Of especial importance in this respect is the dominant year-class of 1934, probably the largest production of striped bass in a single year in the past half century, whose members appeared along the Atlantic coast as 2-year-olds in 1936 and were at once subjected to the highly intensive fishery that confronts this migratory species over the greater part of its range. Information gathered in the course of this investigation makes it possible to demonstrate that this dominant year-class was directly responsible for a greatly increased catch, and also to make a rough estimate of the approximate rate at which this surplus was removed. Such an estimate is based on the percentage of tag returns from 2- and 3-year-old striped bass of the dominant 1934 year-class. (See pp. 36–41 and tables 17–20.) It includes all the factors which show that the percentage of tag returns on this age-group was far lower than the actual percentage removed by the fishery from 1936 to 1938. (See pp. 15 and 36.) Using this method, the most reasonable approximations show that about 40 percent of the members of this year-class were removed as 2-year-olds, and that at least 25–30 percent of the remaining 3-year-olds were taken by the fishery in 1937 and 1938. If these estimates are correct it means that over 50 percent of the 2-year-olds entering the fishery in the spring of 1936 had been removed by the spring of 1938, neglecting the effect of natural mortality, which is taken up below (see p. 59, et seq.), and which is an important factor in the rate of removal of the members of any population. Even though these estimates are only rough approximations, it is plainly evident that the enormous surplus created by the production of the dominant 1934 year-class, resulting in the largest catch of many years in 1936 (see figs. 4 and 6), is rapidly being removed, and that the members of this age-group will soon have been depleted to such an extent that they will no longer bolster the annual catch.

Granting, then, that there has been a sharp decline in the numbers of striped bass along the Atlantic coast despite the occasional appearance of dominant year-classes that bolstered the stock temporarily, it is of interest to know what has caused this decline. Two factors appear to have been responsible—first, the destruction of spawning areas by pollution and dams, and second, overfishing. Let us now consider these two factors in some detail.

There can be little doubt that striped bass formerly entered and spawned in nearly every river that was suitable along the better part of the Atlantic coast. As civilization advanced, dams were built, many of the streams were polluted, and the number of spawning areas that were available became less and less. It has been pointed out under the section on spawning habits and early life history, and elsewhere in this paper, that the majority of the spawning areas for striped bass are now confined to the coastal rivers from New Jersey south. There remain, however, a few isolated localities to the north that are still suitable—probably but a fraction of the areas that were once available. Yet it is clear from the production of the dominant 1934 year-class that there are still a sufficient number of good spawning areas left along the whole Atlantic coast to produce a large supply under the proper conditions. It should not be necessary to emphasize the fact that these remaining localities should be carefully protected against anything that might damage them, and other areas should be restored if it is possible.

Further investigations on the striped bass should continue the study of spawning areas along the Atlantic coast and determine the necessary requirements for the normal production, fertilization, and development of the eggs and larvae. In the case of some of the isolated spawning areas in northern waters, where the stock appears to have been maintained by a more or less self-supporting and partially resident population, there is some evidence that intensive winter and spring fisheries on the supply in the spawning localities have practically exhausted the stock. Under normal conditions the populations north of Cape Cod are probably not increased to any great extent by migrants from outside—especially from the south. This only occurs under exceptional cases, although it may occur more commonly in the future now that the Cape Cod canal provides an easy means of access to the north (see p. 41). Thus an intensive fishery in the winter and early spring when the members of such an isolated self-supporting stock are dormant and inactive, and hence more easily available for capture, may come close to entirely depleting a population of this sort.

Turning to the other factor, overfishing, which in conjunction with the destruction of spawning areas by dams and pollution has been responsible for the decline in abundance of striped bass, the problem is to see how overfishing affects the stock. Theoretically this factor may act in two ways—first, by the removal of too high a proportion of undersized and immature fish so that there are too few spawning individuals, and second, by failing to take the members of the available population at the most efficient size.

In regard to the removal of too great a number of striped bass before they have been given a single chance to spawn, evidence has already been presented to show that the fishery for the smaller size-categories of bass, 2- and 3-year-olds, is highly intensive, and that a large percentage of each successive year-class is caught before its members attain maturity. Yet there is no reason to believe that an additional supply of spawning individuals would result in an increased production, with the one possible exception noted below. Thus it has been emphasized in the section on fluctuations in abundance of the striped bass that the dominant 1934 year-class was apparently produced by as small a parental stock as there has ever been. This means that in southern waters the production of dominant year-classes is not completely dependent—at least down to a certain limit—on the quantity of spawning individuals. In other words, there appears to be no need for concern over the size of the spawning population in the south as long as it is at least as large as it was in 1934. If such a hypothesis be granted, there can be little good in raising the legal-length limit solely for the purpose of increasing the number of spawning fish—especially since we know that under the conditions of the present fishery the number of striped bass along the Atlantic coast is sufficient to produce a year-class of enormous proportions, such as the one that originated in 1934.

There is, however, one way in which an increased number of spawning adults may possibly bolster the supply in northern waters, for this supply has apparently declined in some cases to such an extent that the population has been practically wiped out. It has been shown before that in certain years striped bass from the south migrate north of Cape Cod. Since it has been well established that some of these migratory fish remain in northern waters through the winter, it is a reasonable expectation, if they were mature fish, that they would repopulate some of those areas which formerly supported small populations in northern waters and are still suitable for spawning purposes. Thus the striped bass has been virtually an unknown quantity north of Cape Cod for the past 30 years or more; that is, until the members of the dominant 1934 year-class came north of Cape Cod in huge quantities in 1936 and 1937 and provided a renewed sporting and commercial fishery of considerable size in those waters. It is certainly not unreasonable to predict that if a sufficient number of mature fish repopulate the spawning areas that still remain north of Cape Cod, the stock in northern waters can be replenished and the supply increased and maintained if the fish are given the proper protection.

It may therefore be said that measures designed to increase the supply of striped bass along the Atlantic coast by providing a greater number of spawning fish might quite possibly prove ineffective in the more southern waters of the Middle Atlantic Bight, for it is known that there are now a sufficient number of mature individuals to produce huge quantities of fish if the environmental factors are right; witness the dominant 1934 year-class. On the other hand, such measures would probably renew, at least partially, the supply north of Cape Cod where the stocks have been practically exhausted in many instances.

The other aspect of overfishing to be considered is whether or not the present fishery along the Atlantic coast takes the available members of the population at the most efficient size, or, whether or not the fishery makes the best possible use of the supply each year. Thompson and Bell (1934), Graham (1935), Thompson (1937), and others, have all discussed the theory of the effect of fishing on various stocks of fish, and have studied the problem of the most efficient utilization of the stock in different species. These papers have laid the foundation for future studies along this line, and it is possible to apply many of the principles set forth in them to the striped bass fishery of the Atlantic coast. Those who are critically interested in this whole subject should refer to the work of these authors.

The first problem in connection with the striped bass is to get some measure of the yield from the stock under the existing conditions of the fishery at the present time. Having attained this, it is possible to compare it with the yield from the stock under

different conditions of the fishery and thus determine which is the most advantageous, not only from the point of view of profit to the fisherman, but also in the light of what is known about the life history of this species. In other words, it is desirable to discover at what age (or length) it is most advantageous to start the fishery for striped bass; i. e., whether the fishery gets the most profit out of taking the fish for the first time when they are 2-year-olds (averaging roughly three-quarters of a pound and 12 inches in length) as it does at present, or whether it would benefit by allowing the fish one or two more growing seasons before catching them.

In order to find the answers to these questions it is essential that the fishing mortality at different ages—the percentage of fish of each age taken by the fishery—and the natural mortality, be known. This can only be done accurately by careful studies and the collection of detailed statistics on the annual catches of striped bass over long-term periods, although the present work has given some information along these lines. Considering the dominant 1934 year-class, it has been assumed from the percentage of tag returns (see p. 57) that approximately 40 percent of its members were taken by the fishery as 2-year-olds in 1936 and 1937, and that about 25 percent of the 3-year-olds of 1937 and 1938 were also taken by the fishery. It is known from various catch records from Virginia to Rhode Island that only about one-quarter as many 3-year-old striped bass were caught in 1937 as the 2-year-olds that were taken in 1936. This is demonstrated in figure 4, where the catches of a pound-net fisherman at Fort Pond Bay, Long Island, N. Y., were approximately four times as great by number in 1936 as they were in 1937, and where the catch was over 90 percent 2-year-olds in 1936 and 3-year-olds in 1937. Given this information it is possible to estimate the natural mortality in 1936 by the following equation:

$$NM = S_1 - (FM_1 + S_2),$$

wherein NM is the natural mortality in 1936, S_1 the stock available in 1936, FM_1 the fishing mortality in 1936, and S_2 the stock available in 1937. S_1 can be given any arbitrary value, for example, 1,000. If FM_1 is assumed to be 40 percent of S_1 (see above), FM_1 is 400. S_2 is equal to approximately $4 \times FM_2$, where FM_2 is the fishing mortality in 1937, for tagging experiments indicate that roughly 25 percent of the 3-year-olds were taken in 1937. FM_2 is known to be ¼ FM_1, as only one-quarter as many 3-year-olds were taken in 1937 as there were 2-year-olds taken in 1936. Under these conditions FM_2 therefore becomes 100, and in the equation above, where S_1 was assumed to be 1,000, S_2 becomes 400. Substituting these values in the equation, the natural mortality in 1936 attains a value of 200. Thus of the original 1,000 fish in 1936, 400 were caught as 2-year-olds, and of the remaining 600 fish, 200 were lost through natural mortality. It is therefore apparent that if the estimates on which the figures making up this equation are based are correct, natural mortality accounted for about one-third of the 2-year-olds in 1936 which were not taken by the fishery. It should be pointed out, however, that slight variations in the percentages assigned to FM_1 and FM_2, which are only rough approximations, can materially change the value obtained for NM.

Taking the figures in the equation above, since they seem to be the best available, it is possible to get some estimate of the yield from the stock under the existing conditions of the fishery. Table 1 is a theoretical treatment of 1,000 striped bass of the 1934 year-class to show the rate of removal by the fishery and natural mortality, the numbers and poundage caught, and the market value, when the fish of this age group were caught over a 5-year period from 1936–40 (as 2-, 3-, 4-, 5-, and 6-year-olds). This treatment, in other words, considers the value when the fishery starts catching striped bass for the first time as 2-year-olds, which is exactly what occurred in 1936 along the Atlantic coast. The natural mortality is figured at one-third of the population, excluding those taken by the fishery. The fishing mortality was estimated to be 40 percent in 1936, 25 percent in 1937, 15 percent in 1938 (when the members of the 1934 year-class were 4-year-olds), 10 percent in 1939 (5-year-olds), and 5 percent in 1940 (6-year-olds)—a declining fishing mortality that undoubtedly represents as sharp a decrease in the percentage of fish of any year-class caught each year as could possibly exist, and probably over-estimates the decline in the percentage taken by the fishery as the members of a year-class become older. It will also be noted in table 1 that the price per pound varies with the different size categories under consideration. Thus the 2-year-olds averaging three-quarters of a pound each are listed as bringing 6.5 cents a pound, the 3-year-olds averaging 2 pounds each as 9.5 cents a pound, and the 4-, 5-, and 6-year-olds as bringing 10 cents a pound throughout. These prices were determined from information collected by the Bureau of Fisheries from an important dealer on the Atlantic coast. The average price per pound for the different size categories was determined by dividing the total dollar volume for each month by the total number of pounds of striped bass purchased each month from March through November 1937. The prices for each of these months were then averaged, giving the average price for the different size categories for the entire period. Since this dealer handled a total of approximately 200,000 pounds during this period, the prices for the different size categories should be accurate estimates.

TABLE 1.—*Theoretical treatment of 1,000 striped bass of the 1934 year-class to show the rate of removal by the fishery and natural mortality, the numbers and poundage caught, and the market value, when the fish were caught over a 5-year period from 1936–40. Note that in this treatment fish were caught for the first time when they were 2-year-olds*

	Age	Average length	Average weight	Total weight	Average price per lb.	Market value
	Years		*Pounds*	*Pounds*	*Cents*	
Assuming 1,000 bass were available in 1936, of which 400 would be caught in 1936 (fishing mortality, 40 percent); 200 would die in 1936 (natural mortality, 33 percent of those not caught), leaving	2	31 cm. (12.2 inches).	0.75	300.0	6.5	$19.5
400 bass available in 1937, of which 100 would be caught in 1937 (fishing mortality, 25 percent); 100 would die in 1937 (natural mortality, 33 percent of those not caught), leaving	3	41 cm. (16.1 inches).	2.0	200.0	9.5	19.00
200 bass available in 1938, of which 30 would be caught in 1938 (fishing mortality, 15 percent); 57 would die in 1938 (natural mortality, 33 percent of those not caught), leaving	4	50 cm. (19.7 inches.)	3.5	105.0	10.0	10.50
113 bass available in 1939, of which 11 would be caught in 1939 (fishing mortality, 10 percent); 34 would die in 1939 (natural mortality, 33 percent of those not caught), leaving	5	58 cm. (22.8 inches).	5.5	60.5	10.0	6.05
68 bass available in 1940, of which 3 would be caught in 1940 (fishing mortality, 5 percent).	6	66 cm. (26.0 inches).	8.0	24.0	10.0	2.40
Total number of striped bass caught during 1936–40, 544.	Total			689.5	----------	57.45

In table 1 it will be seen that the total market value derived from 1,000 bass of the 1934 year-class over the 5-year period 1936–40 was $57.45, the total number of individuals caught was 544, and the total weight taken was 689.5 pounds. These figures represent the yield to the fishery when striped bass are caught for the first time as 2-year-olds (12 inches in length).

Table 2 gives similar information for the same number of bass of the 1934 year-class when the fishery did not catch them as 2-year-olds in 1936 but took them for the first time as 3-year-olds in 1937, and caught them over the 4-year period 1937–40. It will be noted that the total market value under these conditions was $64.48, the total number of individuals caught was 242, and the total weight taken was 661.5 pounds. Thus, less than half as many individuals were taken when the fishery first caught bass as 3-year-olds, yet the gross profit was substantially more. It is, therefore, plainly evident that if the figures upon which these calculations are based are reasonably accurate, the fishery is not utilizing the available supply of striped bass in the most efficient manner when it first takes them as 2-year-olds.

Since it has been shown that it is apparently more efficient for the striped bass fishery of the Atlantic coast to start taking the fish as 3-year-olds rather than as 2-year-olds, it is of interest to consider what the yield would be if the fishery waited still another year and did not begin to remove the members of the bass population until they became 4-year-olds. Treating the same 1,000 fish of the 1934 year-class in the same manner as shown in tables 1 and 2, with the sole difference that the fishery only operates over a 3-year period from 1938–40, the total market value drops to $43.60, and there appears to be an inefficient utilization of the available stock from every point of view. This striking drop in the gross profit under these conditions is

due to the high value estimated for natural mortality each year, for the amount added in total growth by allowing the fish to live until they are 4 years old does not compensate for the numbers lost through natural mortality under these conditions.

TABLE 2.—*Theoretical treatment of 1,000 striped bass of the 1934 year-class to show the rate of removal by the fishery and natural mortality, the numbers and poundage caught, and the market value, when the fish were caught over a 4-year period from 1937–40. Note that in this treatment the fish were caught for the first time when they were 3-year-olds*

	Age	Average length	Average weight	Total weight	Average price per pound	Market value
	Years		*Pounds*	*Pounds*	*Cents*	
Assuming 1,000 bass were available in 1936, of which 333 would die in 1936 (natural mortality, 33 percent), leaving	2	----------	----------	----------	----------	----------
667 bass available in 1937, of which 167 would be caught in 1937 (fishing mortality, 25 percent); 167 would die in 1937 (natural mortality, 33 percent of those not caught), leaving	3	41 cm. (16.1 inches).	2.0	334.0	9.5	$31.73
333 bas available in 1938, of which 50 would be caught in 1938 (fishing mortality, 15 percent); 94 would die in 1938 (natural mortality, 33 percent of those not caught), leaving	4	50 cm. (19.7 inches).	3.5	175.0	10.0	17.50
189 bass available in 1939, of which 19 would be caught in 1939 (fishing mortality, 10 percent); 57 would die in 1939 (natural mortality, 33 percent of those not caught), leaving	5	58 cm. (22.8 inches).	5.5	104.5	10.0	10.45
113 bass available in 1940, of which 6 would be caught in 1940 (fishing mortality, 5 percent).	6	66 cm. (26.0 inches).	8.0	48.0	10.0	4.80
Total number of striped bass caught during 1937–40, 242.	Total			661.5	----------	64.48

In tables 1 and 2 it was shown that the total market value of striped bass taken from the available stock of 1,000 fish of the 1934 year-class from 1936–40 (bass caught for the first time as 2-year-olds) was $57.45, as compared with $64.48 when this same stock was utilized by taking its members for the first time when they were 3-year-olds over the period from 1937–40. It should be pointed out that the gain from allowing the fish to become 3 years old before being caught has been figured in these examples as the least that can result. In the first place, the fishing mortality on the members of the 1934 year-class was estimated from tagging experiments as 40 percent in 1936 and 25 percent in 1937. It has been arbitrarily placed at 15 percent in 1938, 10 percent in 1939, and 5 percent in 1940, because they are considered the lowest values possible. Whether or not this annual decline in the percentage taken is as steep as indicated above and in tables 1 and 2 is extremely questionable. It is obvious that if this decline is less sharp, the gain from allowing the fish to become 3 years old before being caught is relatively greater. Further than this, the natural mortality of the bass of the 1934 year-class is estimated to be 33 percent of the population (neglecting fishing mortality) in 1936, and it has been arbitrarily placed at 33 percent for the years from 1937 to 1940. Actually, it is extremely unlikely that it remains as high as 33 percent over this period, for it is reasonable to assume that as bass become older than 2 years of age they are less likely to be killed through natural causes. It is possible that when bass become much older the death rate increases, but in the examples in tables 1 and 2 that stage is probably not reached. Thus it is likely that the annual natural mortality of 33 percent from 1937 to 1940 is far too high. If this be so, the gain from allowing the fish to become 3 years old before being caught is again relatively greater than is shown by the total market value in the examples given above. It is evident therefore that the gain from catching striped bass for the first time as 3-year-olds is far more than is shown in tables 1 and 2. Nor should it be necessary to point out that the figures used in the examples in tables 1 and 2 represent only gross values, and that the net values would be far greater.

It is also of importance that if the fishery first starts to operate on the striped bass population when its members are 3 years old, a greater proportion of the stock is given a chance to spawn. It has already been shown (see p. 22) that female striped bass first mature at 4 years of age. If the stocks available at this age are compared in tables 1 and 2, it will be seen that of the 1,000 original fish of the 1934 year-class only 200 were left by 1938 when the fishery started taking the fish for the first time as 2 year-olds, while 333 were left by 1938 when the fishery started to operate on 3-year-olds. In other words, on the basis of these calculations about 1⅜ times as many female striped bass would be given a chance to spawn if the fishery were to allow the 2-year-olds to remain in the water and first started to catch them as 3-year-olds. It has previously been pointed out that although a conservation measure designed to increase the stock by adding to the number of spawners in the south has no evidence to prove that it is not a fallacious policy, an increase in the number of mature fish in northern waters should repopulate this area to a certain extent and revive the fishery in this region. There are, of course, many spawning areas in northern waters that have been ruined by pollution and dams so that they could not be repopulated, but it is widely believed that depletion in northern waters is in part due to insufficient numbers of spawners. Thus Bigelow and Welsh (1925) say:

> Since striped bass have dwindled as nearly to the vanishing point in the St. John (which still sees a bountiful yearly run of salmon) as in the estuaries of rivers that have been dammed and fouled by manufacturing wastes, the chief blame for its present scarcity can not be laid to obstruction of the rivers; and as this is a very vulnerable fish, easily caught, always close inshore, always in shallow water, and with no offshore reservoir to draw on when the local stock of any particular locality is depleted by such wholesale methods of destruction as the early settlers employed—overfishing must be held responsible.

Probably one of the reasons why the depletion in northern waters has been so great is that bass which remain north in the winter become dormant and inactive (see p. 42), and hence far more easily available for capture, so that it is not impossible to wipe out an entire population. Under these circumstances there is good reason to believe that an added number of mature fish in northern waters would assist materially in renewing the supply in these areas, and that this supply could be maintained by affording the population adequate protection.

It should be mentioned at this point that the abundance of striped bass in California, where the present fishery arose as a result of two small original plantings (see p. 5), has been successfully maintained by protecting this species up to the time they become 4 years old, at which time they are about 20 inches in length. Thus Craig (1930) and Clark (1932 and 1933) have studied the fluctuations in abundance of the striped bass in California, and both of these authors came to the conclusion that "the striped bass population could support a commercial fishery as well as a sport fishery"—a conclusion to which, however, the California State legislature apparently paid scant attention, since commercial netting was prohibited by law after August 14, 1931.

In consideration of all the foregoing evidence, even though it is based on assumptions that need further corroboration by continued investigation of this species, it seems highly advisable to try the experiment of allowing striped bass to become 3 years old before they are caught in large quantities along the Atlantic coast. Both sportsmen and commercial fishermen should benefit by this apparently more efficient utilization of the available stock, the former by having an increased number of large bass to fish for, and the latter by making a definitely higher profit than they do under the present conditions. An addition to the spawning stock in northern waters, where the supply has been depleted to such an extent that an added number of mature individuals is badly needed, should also result from protecting this species up to the time it becomes 3 years old.

RECOMMENDATIONS

The preceding section has dealt with a theoretical discussion of the striped bass population of the Atlantic coast. The causes for its decline in numbers over long-term periods, its fluctuations, and the effects of different fishing intensities and natural mortality on the stock under the existing conditions have been considered. Also, an attempt has been made, on the basis of the limited information at hand, to determine how the available supply of striped bass can be utilized most efficiently from every point of view. The data tend to show that the way in which the fishery for striped bass along the Atlantic coast can make the best possible use of the available supply is to start taking the fish as 3-year-olds, when they average 41 cm. (16 inches) to the fork of the tail and weigh roughly from 1¾ to 2 pounds each. There is apparently

more profit when the fishery first starts to take the bass as 3-year-olds than there is when the fishery starts to take the bass as 2-year-olds, because the greatest increment in growth in the entire life of the striped bass takes place during the third year of life—when the fish are 2 years old. This growth in the third year is sufficient to more than compensate for the losses due to natural mortality, and its advantages are missed when the fish are caught for the first time as 2-year-olds.

It is therefore recommended, on the basis of existing knowledge and as a practical experiment in conservation, that striped bass on the Atlantic coast less than 16 inches in length be protected.

The problem is, then, how striped bass should be protected up to the time they become 3 years old. Unfortunately the commercial fishery is not one which exists for the purpose of catching this species alone; rather, striped bass are taken in association with many other forms by different types of gear along the whole coast. It is impossible to make any limitation on the size of mesh to be used, since this would affect the capture of other species that do not need to be protected up to as large a size as do striped bass. Further than this, the striped bass is highly migratory and should be protected along the entire length of its range. It is only feasible, on this account, to suggest a universal length limit (or at least a commercial sale limit) for the entire Atlantic coast, and let the individual States determine by appropriate investigation whether additional restrictions on the gear employed in the striped bass fishery, and on the seasons when the fishery shall operate, would be profitable. It is no great hardship for commercial fisheries to return undersized bass to the water, and it is to their ultimate advantage to do so—not only from the point of view of the increased return it should bring them, but also in order to eliminate any legitimate objection by anglers to their fishing methods. That the mortality of these undersized bass from being caught in a net and handled before being released would be small under normal conditions is abundantly illustrated by the fact that some of the most successful tagging experiments that have been carried on during this investigation have been made on fish that were caught in seines and pound-nets.

It is apparent that there is nothing to be lost and much to be gained by allowing the striped bass of the Atlantic coast one more growing season than they have under existing conditions in the fishery—that is, by allowing them to become 3-year-olds before they are taken in large quantities. However, the gains from such an experimental measure will depend directly upon its universal acceptance along the entire Atlantic coast, and on the complete cooperation of those engaged in the fishery. The adoption of measures designed to protect striped bass of less than 16 inches in length should result in greater profit to the commercial fishermen, an increased supply of larger fish for the sportsmen, and a larger number that reach maturity—of which a certain number should spawn in northern waters and possibly replenish stocks which have been badly depleted.

It is also apparent that there is need for much more study on the striped bass of the Atlantic coast. This is especially true since the specific recommendations as to the size limit of the striped bass made in this paper are suggested on an experimental basis. It is therefore essential that more detailed and more accurate catch records be made available, and further biological studies be undertaken in order to trace the results of the recommendation if adopted, to make possible a suitable revision of the size limit if the results indicate that modification would be desirable, and to amplify the results of the present investigation.

SUMMARY AND CONCLUSIONS

(1) The foregoing report is concerned with the results of an investigation of the striped bass (*Roccus saxatilis*) of the Atlantic coast, from April 1, 1936, to June 30, 1938.

(2) The general morphology and systematic characters of the species are described in detail on the basis of the literature and material afforded by fin-ray, scale, and vertebral counts, and measurements on more than 350 individuals.

(3) The striped bass is strictly coastal in its distribution from the Gulf of St. Lawrence to the Gulf of Mexico. Those most commonly taken at present range from less than 1 pound to 10 pounds in weight; but larger individuals are by no means rare. The largest striped bass of which there is authentic record weighed 125 pounds.

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(4) Studies of the fluctuations in abundance of the species over long-term periods show that there has been a sharp decline in numbers. Dominant year-classes have at times temporarily raised the level of abundance, but the intensity of the fishery is such that their effects have been short-lived. The dominant year-class of 1934 was the largest to be produced in the past half century, although the parental stock at this time was probably as small as it ever has been. Evidence is presented to show that there is a good correlation between the production of dominant year-classes of striped bass and below-the-mean temperatures during the period before and immediately after the main spawning season.

(5) The striped bass is anadromous, spawning from April through June, the exact time depending on the latitude and temperature. The majority of spawning takes place from New Jersey south, although there are a few isolated spawning areas in northern waters. The development of the eggs and larvae is pictured, and the size of the juveniles at different times of the year is discussed.

(6) Sex determinations of striped bass in Long Island and New England waters show that the number of males in this northern range of the species seldom reaches much over 10 percent of the population; the percentage of males apparently decreases in the age-categories above the 2-year-olds. In waters farther south the sex ratios are not so disproportionate. Studies of the age at maturity show that approximately 25 percent of the female striped bass first spawn just as they are becoming 4 years of age, that about 75 percent are mature as they reach 5 years of age, and that 95 percent have attained maturity by the time they become 6 years old. A large percentage of the male striped bass are mature at the time they become 2 years old, and probably close to 100 percent are mature by the time they become 3 years old. This difference in the age at maturity of male and female striped bass may well account for the small percentage of males in northern waters, for the time of the spawning season in the south coincides with the time of the spring coastal migration to the north, which is made up mainly of immature females. (See under migrations, p. 44.)

(7) The age and rate of growth have been studied by scale analysis and by the average sizes of different age groups. The scale method and its applicability to the striped bass is discussed in full. Striped bass are roughly 12 cm. long when they become 1 year old, 24 cm. when they become 2 years old, 38 cm. when they become 3 years old, and 45 cm. when they become 4 years old. Thereafter the annual increment in length is about 7–8 cm. up to the tenth year. The growth rate of striped bass in the summer months in 1937 was much greater just north of Cape Cod than it was slightly south of Cape Cod. The growth rate of 2-year-old striped bass in Connecticut waters was approximately the same from June through October 1937, and increased in September and October 1936, despite the drop in water temperature. This maintenance of or increase in the growth rate in the fall was probably due to increased food supply at this time. The growth and availability of juvenile silversides (*Menidia menidia notata*) are shown to be of direct consequence in this relation. The members of the 1934 dominant year-class averaged 2 cm. smaller than the members of the 1933 and 1935 year-classes, neither of which were large, at similar ages. This difference in size developed before these fish became 2 years old.

(8) A total of 3,937 striped bass have been marked by either external disc tags or internal belly tags. Returns from these tagged fish, and the examination of commercial catch records, show that there is a mass migration to the north in the spring and to the south in the fall, and that the population in northern waters is stationary in the summer. These migrations have their greatest intensity along the southern New England and Long Island shores. They take place chiefly between Massachusetts and Virginia, although bass north and south of these areas play some part in the migrations. The Middle Atlantic Bight is undoubtedly the center of abundance for the striped bass over its entire range, and tagging experiments indicate that there is little encroachment by this stock on the populations to the north and south. Temperature undoubtedly plays some part in the migrations, for in Connecticut waters they have been observed to occur on each occasion when the water reached 7°–8° C. The migrations of the striped bass, however, are not universal, for this species is caught through the summer in southern waters and in northern waters in the winter. Those fish that stay north in the winter often become dormant and inactive. The evidence is strong that the maximum tolerance limit for the species is 25°–26° C., which is about as high a temperature as coastal waters ever reach in the North and Middle Atlantic. Coastal migrations are not undertaken by bass less than 2 years old. Tagging experiments conducted in North Carolina in the springs of 1937 and 1938 tend to show that bass from this region contribute directly only a small percentage to the population summering in northern waters.

(9) The available evidence from general observation and scale analysis points to the conclusion that the dominant 1934 year-class originated chiefly in the latitude of Chesapeake and Delaware Bays, and confirms the results of the tagging experiments in North Carolina in the springs of 1937 and 1938 mentioned above.

(10) Stomach-content analyses on over 550 striped bass from northern waters, and on over 100 individuals from the south, show that bass are general in their choice of food—a large variety of fishes and crustacea forming the most common diet.

(11) Various nematodes and copepods have been found parasitic on the striped bass, and a number of trematodes, cestodes, and acanthocephalans have also been listed by other authors. Glochidia were found on small juveniles from the western end of Albemarle Sound. Several of the parasites listed constitute new host records. None of these parasites are of any great consequence to the general well-being of the striped bass population. A high percentage of bass in the Thames River, Conn., were found to have bilateral cataract. It is suggested that this is the result of a dietary deficiency.

(12) The decline in abundance of the striped bass of the Atlantic coast over long-term periods and its causes are discussed, and it is pointed out that the present practice of taking such a large proportion of the 2-year-olds annually is apparently not an efficient utilization of the supply, and that both the fishery and the stock should benefit by protecting this species until it is 3 years old, at which time it is approximately 41 cm. (16 inches) long to the fork of the tail and weighs 1¾ to 2 pounds. The adoption of such experimental measures designed to protect striped bass up to the time they become 3 years old should result in a greater profit for the commercial fishermen, an increased supply of larger fish for the sportsmen, and an added number of individuals that reach maturity, some of which may possibly spawn in northern waters and thus replenish the stocks in these areas where in many instances the populations have been exhausted. The need for further studies on the striped bass is emphasized in order that the results of the recommendation, if adopted, may be traced, so that suitable revision of the size limit may be made if the results indicate that modifications would be desirable, and in order to amplify the results of the present investigation.

TABLE 3.—*Record of striped bass taken by members of Cuttyhunk Club, Cuttyhunk, Mass., 1865–1907*

Year	Number of fish	Average weight	Largest fish	Year	Number of fish	Average weight	Largest fish
1865	1,174	----------	28	1887	235	12	42
1866	659	6.75	24.50	1888	29	16.50	56
1867	906	6.25	55	1889	4	22.50	41
1868	942	6.75	57	1890	154	14	41.50
1869	887	6.50	48	1891	43	11.75	24.25
1870	615	7.25	47	1892	18	16.50	38.50
1871	804	8.50	42	1893	39	16.25	35.50
1872	581	8	39	1894	80	9	35.25
1873	592	6.75	37	1895	21	17.25	36.75
1874	500	8.25	55	1896	25	14.25	27
1875	724	9.25	50.25	1897	59	11.25	33.50
1876	835	7	51	1898	45	9	23.75
1877	321	10.25	51.50	1899	21	13	35
1878	648	8.25	51	1900	14	18	54
1879	499	9.75	49	1901	13	14	29
1880	403	9	50.25	1902	2	17	26
1881	184	9.25	44	1903	4	10.75	15.75
1882	200	10.25	64	1904	5	15	35
1883	154	8.25	31.75	1905	7	16	40
1884	124	9	43	1906	1	9.25	9.25
1885	46	9	29.50	1907	5	19	23.50
1886	3	22	27.25				

NOTE.—See fig. 3.

TABLE 4.—*Number of striped bass taken each year in pound-nets at Fort Pond Bay, Long Island, N. Y., 1884–1937*

Date	Number of striped bass	Number of pound-nets in operation	Date	Number of striped bass	Number of pound-nets in operation
1884	3,630	6	1911	221	9
1885	1,872	6	1912	702	9
1886	4,354	6	1913	378	9
1887	2,688	6	1914	1,579	10
1888	2,046	6	1915	236	10
1889	915	6	1916	804	9
1890	720	7	1917	197	8
1891	636	7	1918	1,310	7
1892	455	7	1919	157	7
1893	1,953	7	1920	463	7
1894	3,643	8	1921	240	7
1895	3,689	8	1922	1,976	7
1896	35	9	1923	401	7
1897	895	9	1924	878	7
1898	708	9	1925	389	7
1899	189	9	1926	321	7
1900	1,551	9	1927	121	7
1901	1,310	9	1928	184	6 ?
1902	348	9	1929	100	8–12
1903	1,107	9	1930	325	8–12
1904	219	9	1931	500	8–12
1905	64	9	1932	35	8–12
1906	3,374	9	1933	50	8–12
1907	926	9	1934	100	8–12
1908	425	9	1935	400	8–12
1909	300	9	1936	15,600	12
1910	496	9	1937	4,200	12

NOTE.—See figs. 4 and 24.

TABLE 5.—*Length-frequency distribution of striped bass making up the random samplings of the commercial catch in Cape Cod Bay, at Newport, R. I., and at Montauk, Long Island, N. Y., in 1937*

Length (cm.)	Number of individuals: Cape Cod Bay	Newport, R. I.	Montauk, Long Island, N. Y.	Length (cm.)	Number of individuals: Cape Cod Bay	Newport, R. I.	Montauk, Long Island, N. Y.
20	1			57	4		
22	1			58	2	3	
28	1			59	3	1	1
32			1	60	2		
34	1			61	4		
35	2		1	62	3	1	
36	6		2	63	2	1	
37	3		5	64	2		
38	16	2	9	65	3		
39	22	1	12	66	2		
40	17	4	24	67	3		
41	31	8	21	68	2		
42	21	22	40	70	2		
43	21	28	56	71	1		
44	19	29	61	73	2		
45	19	44	34	77	1		
46	17	39	39	78	1		
47	20	44	26	80	1		
48	12	25	31	81	1		
49	23	21	12	84	1		
50	16	17	18	90	2		
51	15	14	6	96	1		1
52	11	24	6	102			
53	9	21	4	108	2		
54	7	12	2	Total	366	378	413
55	5	7					
56	3	10	1				

NOTE.—See fig. 5 for length-frequency curves smoothed by threes made up from this material.

TABLE 6.—*Total catch of striped bass by seine at Point Judith, R. I., 1928–37*

Date	Number	Pounds	Number of days fishing (equalizing factor)	Average weight (pounds)	Date	Number	Pounds	Number of days fishing (equalizing factor)	Average weight (pounds)
1928	225	1,925	19 (×4.4)	8.5	1933	1,513	9,625	66 (×1.3)	6.2
1929	1,050	5,700	83 (×1.0)	5.4	1934	234	1,300	31 (×2.7)	5.5
1930	600	4,825	70 (×1.2)	8.0	1935	1,250	7,000	58 (×1.4)	5.6
1931	775	5,200	48 (×1.7)	6.6	1936	7,500	18,000	49 (×1.7)	2.4
1932	1,375	8,800	60 (×1.4)	6.4	1937	4,500	12,000	44 (×1.8)	2.7

NOTE.—See figs. 6 and 7.

TABLE 7.—*Length-frequency distribution of juvenile striped bass from the Hudson River, July 3–Sept. 1, 1936*

Length (mm.)	Number of individuals at each millimeter	Length (mm.)	Number of individuals at each millimeter	Length (mm.)	Number of individuals at each millimeter	Length (mm.)	Number of individuals at each millimeter
20	1	49	16	70	18	91	2
		50	14	71	12	92	1
30		51	16	72	11	93	3
31		52	23	73	10	94	
32		53	15	74	12	95	4
33	1	54	17	75	7	96	
34	1	55	19	76	5	97	1
35	2	56	22	77	13	98	
36	4	57	18	78	7	99	
37	2	58	17	79	11	100	
38		59	19	80	8	101	
39	2	60	28	81	5	102	1
40	2	61	17	82	8	103	
41	4	62	17	83	6	104	1
42	8	63	19	84	5	105	1
43	7	64	13	85	1	106	
44	8	65	10	86	3	107	1
45	10	66	17	87	6		
46	15	67	10	88	8	Total	628
47	10	68	18	89	4		
48	16	69	12	90	3		

NOTE.—See fig. 10 for length-frequency curve of this material smoothed by threes.

TABLE 8.—*Length-frequency distribution of juvenile and yearling striped bass taken in the Delaware River, near Pennsville, N. J., Nov. 8, 1937*

Length (cm.)	Number of individuals
10	1
11	4
12	4
13	3
14	5
15	6
16	6
17	13
18	19
19	4
20	11
21	11
22	10
23	4
24	2
25	1
Total	104

NOTE.—See fig. 11 for length-frequency curve of this material smoothed by threes.

TABLE 9.—*Length-frequency distribution of juvenile striped bass taken in Albemarle Sound, N. C., on May 11, 1938*

Length (mm.)	Number of individuals
20	1
21	1
22	3
23	7
24	10
25	9
26	12
27	21
28	12
29	9
Total	85

NOTE.—See fig. 14 for length-frequency curves of this material smoothed by threes.

TABLE 10.—*Age at maturity of 109 female striped bass of known length*

Centimeters	2-year-olds (number of fish)		3-year-olds (number of fish)		4-year-olds (number of fish)		5-year-olds (number of fish)		6-year-olds and over (number of fish)	
	Immature	Mature	Immature	Mature	Immature	Mature	Immature	Mature	Immature	Mature
28	1									
31	2									
32	1									
33	2									
34	2									
35	3									
36	1									
37	2									
38	3									
39	1		1							
40	2		2							
41	1		1							
42	1		2							
43			2	1						
44				1						
45			3							
46			2	1						
47				2	3					
48					2					
49						3				
50			1		1	6				
51					2	3				
52						5				
53					1	7		1		
55						1		1		
56								1		
57							1	5		
58								1		
59								1		
60								1		
61								2		
62								1		1
63										1
65										1
66										2
67										1
68										1
69										1
72										1
74										1
76										1
78										2
83										4
97										1
113										1
Total	22 100%		14	5 26.6%	9	25 73.5%	1	14 93.3%		19 100%

NOTE.—Those individuals were listed as mature if their ova had attained sufficient size to indicate that spawning would occur the following season. See text (p. 21).

TABLE 11.—*Length-frequency distribution of all striped bass measured in Connecticut waters from April through October, 1936 and 1937*

Length (cm.)	Number of individuals		Length (cm.)	Number of individuals		Length (cm.)	Number of individuals	
	1936	1937		1936	1937		1936	1937
23	3		49	11	16	75	3	
24	4		50	13	17	76	4	
25	8		51	12	9	77	3	3
26	16	1	52	5	6	78	1	
27	21	2	53	7	7	79	1	
28	43	6	54	11	7	80		
29	61	22	55	5	8	81	2	
30	83	50	56	7	6	82	3	
31	121	62	57	8	5	83	1	
32	138	85	58	6	2	84	2	
33	190	127	59	7	2	85	2	
34	174	111	60	9		86	1	
35	198	111	61	5	2	87		
36	162	118	62	2		88	2	
37	136	102	63	6	2	89		
38	81	100	64	4	2	90	1	
39	35	81	65	5	1	91	2	
40	53	72	66	10	2	92		2
41	35	70	67	6		93	1	
42	35	57	68	7		94		
43	28	43	69	6		95	1	
44	16	40	70	4		96		
45	27	30	71	4		97	1	
46	15	25	72	4	1	Total	1,933	1,460
47	25	24	73	4				
48	23	20	74	3	1			

NOTE.—See fig. 17 for length-frequency curves of this material smoothed by threes.

TABLE 12.—*Length-frequency distribution of 2- and 3-year-old striped bass seined in Connecticut waters during 1936 and 1937, grouped by months*

Length in centimeters	Number of Individuals																			
	2-year-olds, 1936					3-year-olds, 1936					2-year-olds, 1937					3-year-olds, 1937				
	June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
25		1																		
26	1	6									1									
27	9	8									2									
28	15	12	1	1							4	2								
29	11	17	6	7							16	2	2							
30	20	23	10	9	1						25	11	4							
31	12	25	27	25							22	14	11	1						
32	10	17	23	44	6						26	21	17	1		1				
33	10	15	34	68	7						23	22	32	2	6	1	3			
34	9	4	19	69	18						9	21	22	7	6	6	5			
35	8	3	26	80	17						11	21	24	8	5	11	5			
36	5	4	8	54	24	1					6	17	24	14	11	5	4	2	2	1
37	2	4	10	35	38	2	1				7	9	32	11	9	12	5	2	3	1
38	1	1	6	16	24	5					2	6	13	13	15	16	7	1	4	
39	2	1	4	7	26	4	2					3	11	7	14	14	5	3	4	
40	1	3	7	7	8	12	2	1			1	3	8	7	16	6	7	1	6	3
41			11	8	6	4	1					1	3	3	12	10	7	6	10	4
42		1	4	7	10	6	1	1			1	1	2		6	8	10	8	10	2
43			3	4	4		1	5	2			2	1		11	6	7	2	3	5
44			1	4		1	1	3					2	1	2	7	5	2	5	11
45			1	3	3	2	1	6							2	1	8	1	2	11
46				3		2		2							1	4	7	2	3	4
47							1	7	4	1					2		6	1	4	6
48							1	5	2	4							6		3	7
49								2	1								2	1	3	9
50								1		1							3	1	2	5
51																			1	3
52								1	1	1										2
53																			1	3
54										1										
55																				4
56																				3
57																				4
Total	116	145	201	451	192	39	12	34	10	8	156	156	208	75	118	108	102	33	66	88

NOTE.—See fig. 18 for length-frequency curves smoothed by threes to show growth from June to October each year.

TABLE 13.—*Length-frequency distribution of 2- and 3-year old striped bass taken north and south of Cape Cod, June to September 1937*

Length (cm.)	2-year-olds (number of individuals)		Length (cm.)	3-year-olds (number of individuals)	
	North of Cape Cod	South of Cape Cod		North of Cape Cod	South of Cape Cod
25			30		
26			31		
27			32		1
28			33		6
29	1		34		7
30		4	35		7
31	1	8	36	2	12
32	3	6	37		8
33	3	13	38	3	11
34	1	7	39	4	14
35	2	8	40	9	10
36	5	8	41	16	10
37		3	42	7	6
38	9	4	43	15	8
39	9	2	44	14	7
40	17	1	45	28	3
41	8		46	3	3
42	9	1	47	22	4
43	9	1	48	11	3
44	4		49	11	1
45	6		50	19	3
46			51	4	
47	1		52	4	
48			53	11	
49			54	8	
50			55	5	
Total	88	66	56	1	
			57	5	
			58	2	
			59	1	
			60		
			Total	205	124

NOTE.—See fig. 19 for length-frequency curves of this material smoothed by threes.

TABLE 14.—*Average lengths of striped bass at the time they become 1 year old, 2 years old, etc., to 9 years old*

Age	Average length		Age	Average length	
	Centimeters	Inches		Centimeters	Inches
1 year old	12.5	4.92	6 years old	61.0	24.02
2 years old	23.5	9.25	7 years old	68.5	26.97
3 years old	36.5	14.37	8 years old	75.0	29.53
4 years old	45.0	17.72	9 years old	82.0	32.28
5 years old	53.0	20.87			

NOTE.—See fig. 20.

TABLE 15.—*Original measurements of the radii of scales from 153 striped bass of measured length from 10.5–67 centimeters long*

Length (cm.)	Scale radius (mm.)	Length (cm.)	Scale radius (mm.)
10.5	1.22.	32.0	3.76.
11.0	1.37, 1.37.	32.5	4.16, 4.56.
11.5	1.52, 1.59.	33.0	4.12.
12.5	1.95, 1.59.	34.5	4.48, 4.30, 4.19, 4.09, 4.02.
13.5	1.81.	35.0	4.05, 4.26, 4.48, 4.26.
14.5	1.79, 1.70, 1.86.	35.5	4.38, 4.26, 5.03, 4.84, 4.48.
15.0	1.92, 1.85.	36.0	4.55, 4.84, 4.34.
15.5	2.02, 2.09.	36.5	4.52, 4.56, 4.30.
16.0	1.95.	37.0	5.10, 4.78, 4.38.
16.5	2.09, 2.24, 2.24.	37.5	4.67, 4.41, 4.56.
17.5	2.24, 2.09.	38.0	4.84, 4.84, 4.91, 4.39, 4.70, 5.06.
18.0	2.24, 2.39, 2.31, 2.09, 2.24, 2.37, 2.31.	39.5	4.88, 4.42, 5.27.
18.5	2.24, 2.53, 2.46.	40.0	5.24, 5.24.
19.5	2.35, 2.35.	40.5	5.20, 5.24, 4.91.
20.0	2.60, 2.39, 2.53.	41.0	5.35, 4.70, 4.91.
20.5	2.55, 2.67, 2.53.	42.0	5.13, 5.49, 5.28.
21.0	2.89, 2.74, 2.43, 2.67.	43.0	5.67.
21.5	2.67, 2.69, 2.77, 3.10.	43.5	5.56, 6.11.
22.0	3.03, 2.82.	45.0	5.75.
22.5	2.89.	45.5	6.43.
23.0	2.70, 2.86.	46.0	6.18.
24.0	3.14.	46.5	5.99.
24.5	3.40.	47.0	5.71.
25.0	3.03.	47.5	6.40, 6.00, 6.43.
26.0	3.62.	48.0	6.40, 6.28, 5.85.
26.5	3.36.	48.5	6.36.
27.0	3.32, 3.58.	50.0	6.57, 6.36, 6.71.
27.5	3.83.	51.0	6.07, 6.14.
28.0	3.99.	52.0	6.36.
29.0	3.90, 3.69.	53.5	7.00.
29.5	3.52, 4.12.	54.0	6.79.
30.0	3.62.	55.0	6.93.
30.5	4.12, 4.12.	62.0	7.87.
31.0	4.19, 3.83.	63.0	8.73.
31.5	4.19, 4.34, 4.56, 4.05.	67.0	9.17.

NOTE.—See fig. 21 for graph of relationship of scale growth to body growth in the striped bass, plotted from data in this table.

TABLE 16.—*Annual increment in the length of the striped bass*

Age	Increment	
	Centimeters	Inches
First year	12.5	4.92
Second year	11.0	4.33
Third year	13.0	5.12
Fourth year	8.5	3.35
Fifth year	8.0	3.15
Sixth year	8.0	3.15
Seventh year	7.5	2.95
Eighth year	6.5	2.56

NOTE.—See fig. 22.

TABLE 17.—*Returns from 1,397 striped bass tagged in Connecticut, Apr. 23 to Oct. 27, 1936*

Date of return	Total number tagged by the end of each month	Original point of release	Number of returns each month	Locality of recapture	Total number of returns each month
May 1936	121	Niantic River, Conn	2	Niantic River, Conn	
		do	2	Thames River, Conn	
		do	6	Point Judith, R. I	
		do	2	Newport, R. I	12
June 1936	331	do	17	Niantic River, Conn	
		do	3	Thames River, Conn	20
July 1936	483	do	10	Niantic River, Conn	
		do	1	Thames River, Conn	11
August 1936	792	do	3	Niantic River, Conn	
		Thames River, Conn	2	Thames River, Conn	5
September 1936	1,217	Niantic River, Conn	70	Niantic River, Conn	
		Thames River, Conn	3	Thames River, Conn	73
October 1936	1,397	Niantic River, Conn	30	Niantic River, Conn	
		Thames River, Conn	2	do	
		do	1	Thames River, Conn	
		Niantic and Thames Rivers, Conn.	34	Montauk. Long Island, N. Y	
			10	South shore of Long Island, N. Y	77
November 1936	1,397	Niantic River, Conn	4	Niantic River, Conn	
		Thames River, Conn	4	do	
		Niantic and Thames Rivers, Conn.	59	Montauk, Long Island, N. Y	
			7	South shore Long Island, N. Y	74
December 1936	1,397	do	1	Manasquan River, N. J	
			1	Bradley Beach, N. J	
			2	Rehoboth Beach, Del	
			2	Cape Charles, Va	
			1	Manns Harbor, N. C	7
January 1937	1,397	do	3	Toms River, N. J	
			1	Columbia, N. C	
			1	Manns Harbor, N. C	5
February 1937	1,397	do	2	Toms River, N. J	
			1	Rehoboth Beach, Del	3
March 1937	1,397	Niantic River, Conn	1	Wicomico River, Md	1
April 1937	1,397	do	2	Niantic River, Conn	
		do	1	Hudson River, N. Y	
		Thames River, Conn	1	Oyster Bay, Long Island, N. Y	4
May 1937	1,397	Niantic River, Conn	8	Niantic River, Conn	
		do	1	Thames River, Conn	
		do	1	Wye River, Md	
		do	1	Cape Charles, Va	
		Thames River, Conn	5	Niantic River, Conn	
		do	1	Thames River, Conn	
		do	1	Connecticut River, Conn	18
June 1937	1,397	Niantic River, Conn	12	Niantic River, Conn	
		Thames River, Conn	3	Thames River, Conn	
		do	1	Niantic River, Conn	16
July 1937	1,397	Niantic River, Conn	5	do	
		Thames River, Conn	1	Thames River, Conn	6
August 1937	1,397	Niantic River, Conn	1	Niantic River, Conn	
		do	1	Thames River, Conn	2
September 1937	1,397	do	1	do	
		Thames River, Conn	1	do	2
May 1938	1,397	Niantic River, Conn	1	Hudson River, N. Y	1
Total recaptures.					337
Total percentage recaptured.					24.1

TABLE 18.—*Returns from 103 striped bass tagged and released at Fort Pond Bay, Montauk, Long Island, N. Y., May 15–19, 1937*

Date of return	Number of returns each month	Locality of recapture	Total number of returns each month
May 1937	1	Montauk, Long Island, N. Y	
	1	Shelter Island, Long Island, N. Y	
	1	Point Judith, R. I	3
June 1937	1	Connecticut River, Conn	1
July 1937	2	Peconic Bay, Long Island, N. Y	
	1	Oyster Bay, Long Island, N. Y	3
August 1937	1	Montauk, Long Island, N. Y	
	1	Peconic Bay, Long Island, N. Y	
	1	Smithtown, Long Island, N. Y	
	1	Cohasset, Mass	
	1	Cape Cod Bay, Mass	5
October 1937	1	Narragansett Pier, R. I	1
May 1938	1	Connecticut River, Conn	1
Total recaptures			14
Total percentage recaptured.			13.6

TABLE 19.—*Returns from 303 striped bass tagged and released at Fort Pond Bay, Montauk, L. I., N. Y., Oct. 25, 26, and 27, 1937*

Date of return	Number of returns each month	Locality of recapture	Total number of returns each month
October 1937	2	Gardiners Bay, Long Island, N. Y	
	23	Montauk, Long Island, N. Y	25
November 1937	1	Gardiners Bay, Long Island, N. Y	
	5	Montauk, Long Island, N. Y	
	27	South shore of Long Island, N. Y	
	1	Monmouth Beach, N. J	
	1	Barnegat Bay, N. J	35
December 1937	4	South shore of Long Island, N. Y	
	1	Mullica River, N. J	
	1	Indian River, Del	
	1	Rappahannock River, Va	
	1	Great Choptank River, Md	
	1	Cape Charles, Va	
	1	Croatan Sound, N. C	
	1	Stumpy Point, N. C	
	1	Pamlico Sound, N. C	12
January 1938	1	Barnegat Bay, N. J	
	1	Mullica River, N. J	
	1	Egg Harbor, N. J	
	1	Synapuxent Bay, Md	4
February 1938	3	South shore of Long Island, N. Y	
	1	Barnegat Bay, N. J	
	1	Great Egg Harbor River, N. J	
	1	Rappahannock River, Va	6
March 1938	2	Hudson River, N. J	
	2	Barnegat Bay, N. J	
	1	Great Egg Harbor River, N. J	
	2	Rappahannock River, Va	
	1	New Point, Va	
	1	Kitty Hawk, N. C	9
April 1938	1	Great Bay, N. J	
	1	York River, Va	
	1	Potomac River, Va	
	1	Rappahannock River, Va	4
May 1938	1	Plymouth, Mass	
	1	Point Judith, R. I	
	1	Asbury Park, N. J	3
June 1938	1	Oak Bluffs, Mass	
	1	Chatham, Mass	2
Total recaptures			100
Total percentage recaptured.			33.0

TABLE 20.—*Returns from 770 striped bass tagged in Connecticut, Apr. 19–Oct. 30, 1937*

Date of return	Total number tagged by the end of each month	Original point of release	Number of returns each month	Locality of recapture	Total number of returns each month
June 1937	182	Niantic River, Conn	3	Niantic River, Conn	
		do	1	Thames River, Conn	4
July 1937	434	do	4	Niantic River, Conn	
		Thames River, Conn	11	Thames River, Conn	15
August 1937	614	Niantic River, Conn	9	Niantic River, Conn	
		Thames River, Conn	2	Thames River, Conn	
		do	2	Harkness Point, Conn	13
September 1937	628	Niantic River, Conn	2	Niantic River, Conn	
		do	1	Harkness Point, Conn	
		Thames River, Conn	1	New London Light, Conn	
		do	2	Harkness Point, Conn	
		do	1	Milford, Conn	7
October 1937	770	Niantic River, Conn	11	Niantic River, Conn	
		do	1	Harkness Point, Conn	
		do	1	Gardiners Bay, Long Island, N. Y	
		do	1	Montauk, Long Island, N. Y	
		do	1	South shore of Long Island, N. Y	
		Thames River, Conn	4	Niantic River, Conn	
		do	1	Harkness Point, Conn	
		do	1	Montauk, Long Island, N. Y	21
November 1937	770	Niantic River, Conn	1	Niantic River, Conn	
		do	1	South shore of Long Island, N. Y	
		Thames River, Conn	3	Gardiners Bay, Long Island, N. Y	
		do	4	South shore of Long Island, N. Y	9
December 1937	770	Niantic River, Conn	1	do	
		do	1	Hampton, Va	
		Thames River, Conn	1	Barnegat Bay, N. J	3
January 1938	770	Niantic River, Conn	1	South shore of Long Island, N. Y	
		do	1	Broadkill River, Del	2
March 1938	770	do	1	Delaware Bay, N. J	
		Thames River, Conn	1	Hudson River, N. Y	
		do	1	Toms River, N. J	3
April 1938	770	Niantic River, Conn	1	Delaware Bay, N. J	
		do	2	Niantic River, Conn	
		Thames River, Conn	2	do	5
May 1938	770	Niantic River, Conn	6	do	
		do	1	Connecticut River, Conn	
		Thames River, Conn	1	Niantic River, Conn	3
June 1938	770	Niantic River, Conn	3	do	8
Total recaptures					93
Total precentage recaptured					12.1

TABLE 21.—*Chemical analysis of the water at 2 stations in the Thames River, Conn., in the summer of 1937* [1]

Locality	Date	pH	Dissolved oxygen, parts per million	Chloride, parts per million	Sulfate, parts per million	Calcium, parts per million	Phosphates, parts per million
Off the submarine base, 1 mile above New London on the east side of the Thames River	June 2	7.70	7.76	13,350	1,834	316	0.30
	July 1	7.64	6.30	14,250	2,027	364	.52
	Sept. 15	7.59	5.11	15,350	2,176	254	.69
Off the State pier at New London, on the west side of the Thames River	June 2	7.82	8.80	15,100	2,133	314	.20
	July 1	7.74	7.10	15,500	2,279	346	.52
	Sept. 15	7.69	6.07	16,400	2,279	400	1.38

[1] These water analyses were supplied by the Connecticut State Water Commission. The samples were taken as catch samples, and therefore in no way represent a complete tidal cycle. The 2 localities listed above are both places where striped bass are commonly caught, and where a good number of bass were found dead in late August and early September 1937.

TABLE 22A.—*Returns from 52 striped bass tagged and released at extreme west end of Albemarle Sound, N. C., Mar. 26, Apr. 9, and 21, 1937*

Date of return	Number of returns each month	Locality of recapture	Total number of returns each month
March 1937	6	Mackeys, N. C	
	5	Edenton, N. C	
	1	Columbia, N. C	12
April 1937	1	Pasquotank River, N. C.	
	4	Mackeys, N. C	
	1	Edenton, N. C	
	1	Hertford, N. C	7
Total recaptures.			19
Total percentage recaptured.			36.5

TABLE 22B.—*Returns from 17 striped bass tagged and released off Coinjock, Currituck Sound, N. C., Mar. 27, 1937*

Date of return	Number of returns each month	Locality of recapture	Total number of returns each month
October 1937	1	Currituck Sound, N. C.	1
November 1937	1	Kitty Hawk, N. C	
	1	Currituck Sound, N. C.	2
December 1937	1	Currituck Sound, N. C.	1
Total recaptures.			4
Total percentage recaptured.			23.5

TABLE 22C.—*Returns from 8 striped bass tagged and released at Kitty Hawk, N. C. (outer coast), Apr. 29 and May 10, 1937*

Date of return	Number of returns each month	Locality of recapture	Total number of returns each month
January 1938	1	Pasquotank River, N. C	1
Total recaptures			1
Total percentage recaptured			12.5

TABLE 23.—*Original measurements of* Menidia menidia notata *to show growth of juveniles from July through September 1937 in the Niantic River, Conn.*

Standard length in millimeters	Number of individuals at each length				Standard length in millimeters	Number of individuals at each length			
	July 17	Aug. 2	Aug. 17	Sept. 2		July 17	Aug. 2	Aug. 17	Sept. 2
5	2				24	5	7	11	24
6					25	16	3	10	20
7	1	1			26	9	6	5	16
8	7	2			27	3	2	7	21
9	13	5			28	4		2	10
10	22	10	1		29	5	2	1	3
11	23	13			30	6	1	1	3
12	29	13	1		31		1	1	2
13	21	19	2		32	1	1		
14	14	22	6		33	2	1		3
15	5	22	17	1	34			1	2
16	3	16	16	2	35				2
17	2	16	16		36				
18	1	10	29	1	37				2
19		3	20	5	38				
20		8	17	8	39				1
21		5	11	18					
22	1	8	12	27	Total	200	200	200	197
23	5	3	13	26					

NOTE.—See fig. 36 for length-frequency curves of this material smoothed by threes.

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