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

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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]

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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.

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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.

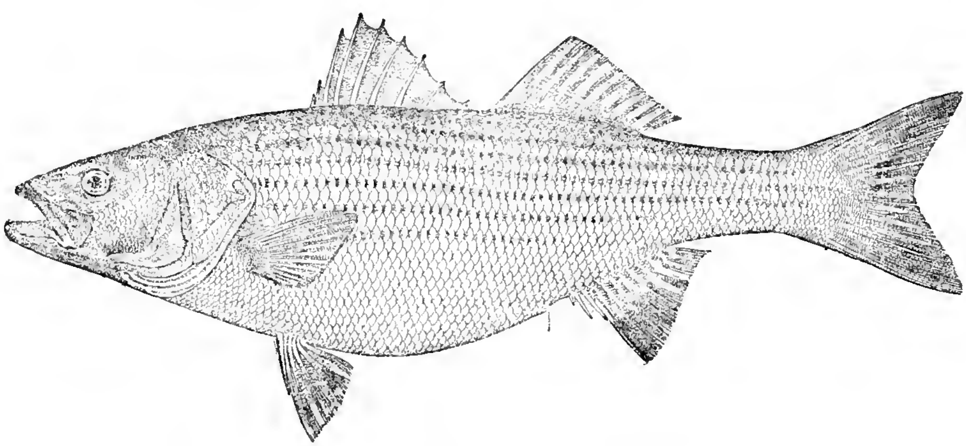

FIGURE 1.—The striped bass (*Roccus saxatilis*).

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

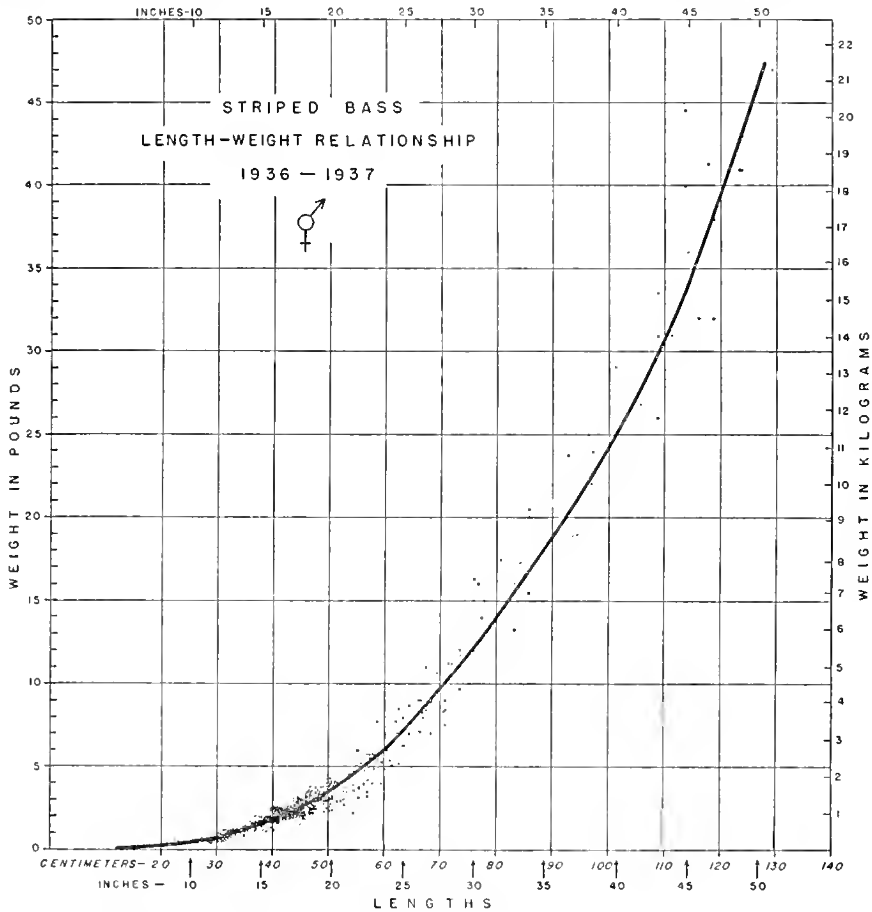

FIGURE 2.—Length-weight relationship of the striped bass, based on 526 fish. Measurements are to the fork of the tail.

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.

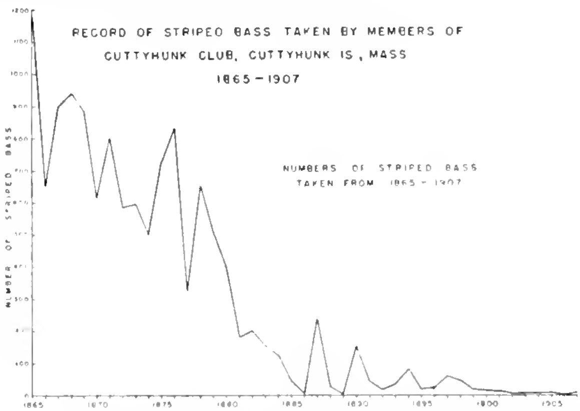

FIGURE 3.—Record of the numbers of striped bass taken by the members of the Cuttyhunk Club from 1865 to 1907 (see Table 3).

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.

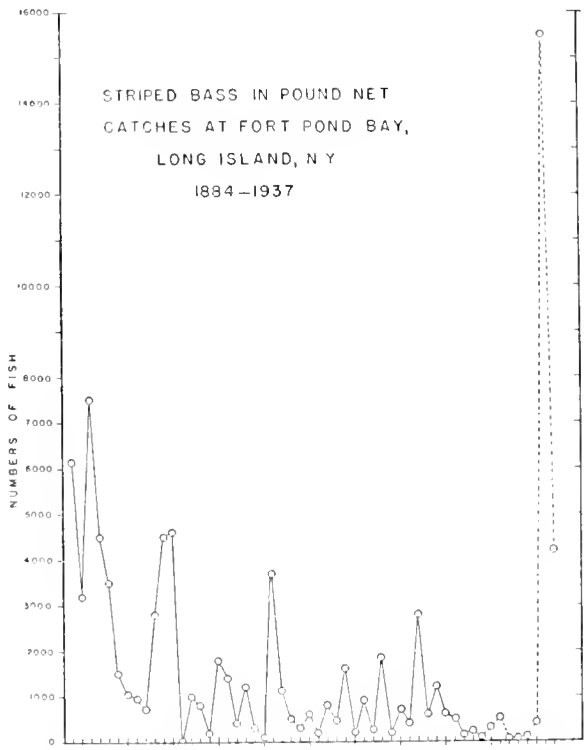

FIGURE 4.—Numbers of striped bass taken each year in the pound nets at Fort Pond Bay, L. I., N. Y., from 1884 to 1937. The fishing intensity has been equalized throughout (see Table 4).

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.

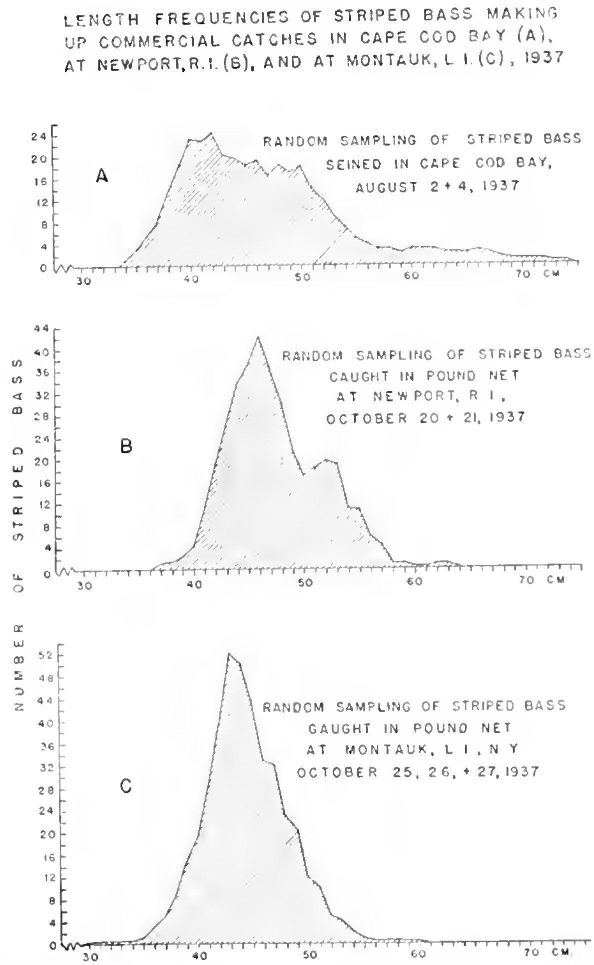

FIGURE 5.—Length-frequency curves made up from random samplings of the commercial catch in different localities in 1937. Data smoothed by threes in all cases (see Table 5 for original measurements).

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

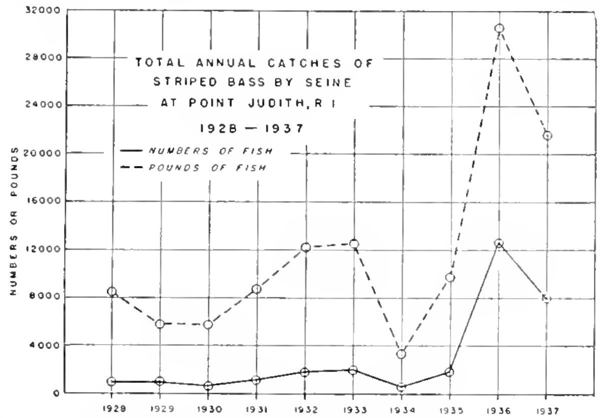

FIGURE 6.—Annual total catch of striped bass by seine at Point Judith, Rhode Island, 1928–37. Fishing intensity equalized throughout (see Table 6 for original data).

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

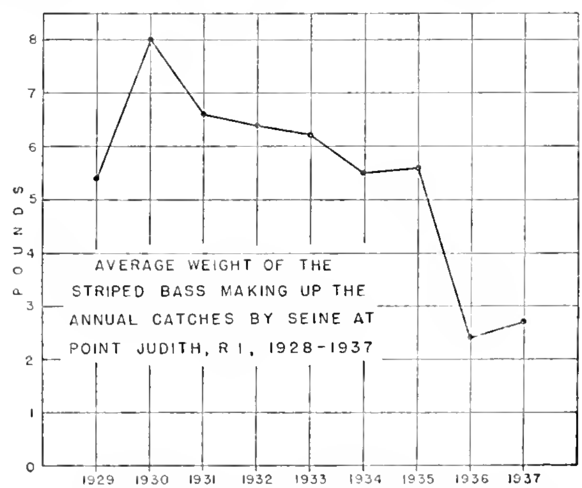

FIGURE 7.—Average weight of the striped bass making up the annual catches by seine at Point Judith, R. I., 1928–37 (see Table 6 for original data).

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.

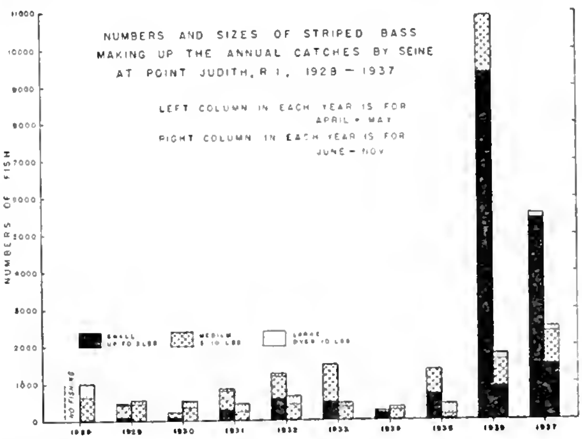

FIGURE 8.—Numbers and sizes of striped bass making up the annual catches by seine at Point Judith, R. I., 1928–37. The left column in each year is for April and May, and the right column for June to November. The fishing intensity has been equalized throughout.

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

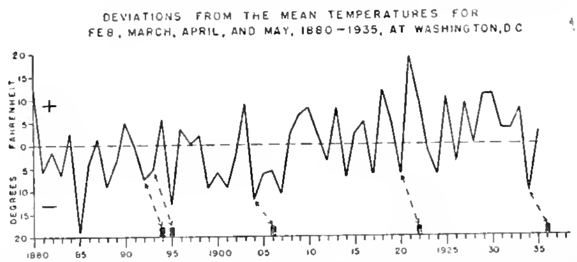

FIGURE 9.—The deviations from the mean temperature for February, March, April, and May, 1880–1935, at Washington, D. C. The black columns on the base line indicate the years when exceptionally good catches of striped bass were made, and the arrows connect them with the temperatures 2 years before, when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

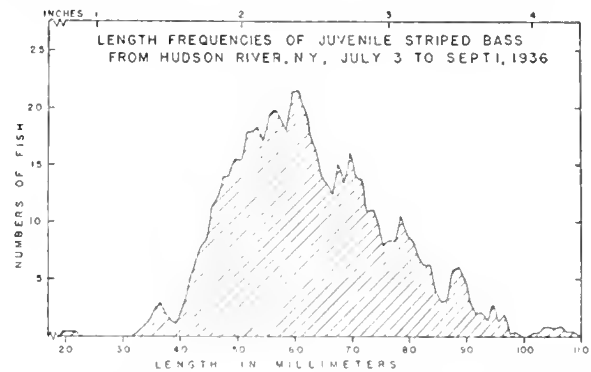

FIGURE 10.—Length-frequency curve of juvenile striped bass from the Hudson River, July 3 to Sept. 1, 1936. The number of fish making up this curve is 628. The data have been smoothed by threes. The great majority of these fish were taken in late August (see Table 7 for original measurements).

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.

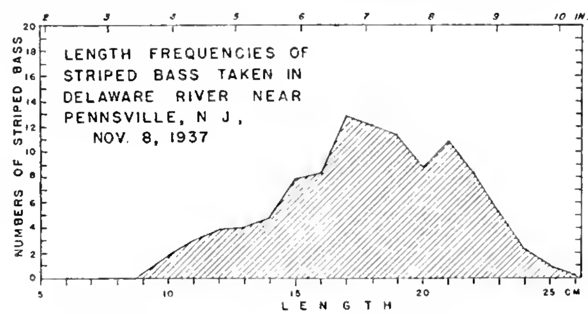

FIGURE 11.—Length-frequency curve of juvenile and yearling striped bass taken in the Delaware River, near Pennsville, N. J., on Nov. 8, 1937. The number of fish included in this graph is 104. The data have been smoothed by threes (see Table 9 for original measurements).

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.

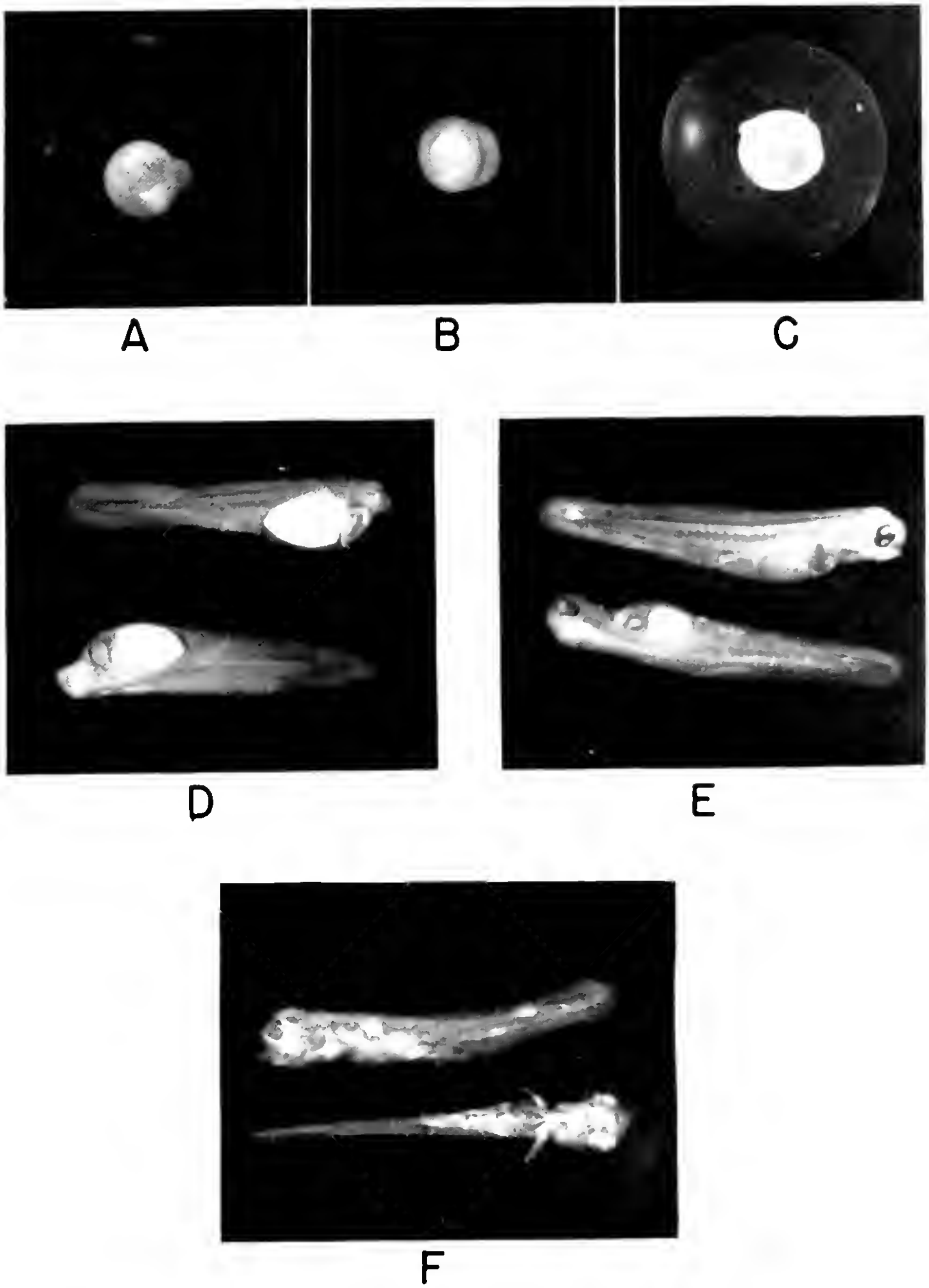

FIGURE 12.—Six developmental stages of striped bass eggs and larvae raised at the hatchery at Weldon, N. C., at a temperature of 70–72° F. Hatching occurred at 30 hours. Magnification equals × 8.2 throughout. A. 1 hour after fertilization. B. 17 hours after fertilization. C. 29 hours after fertilization.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

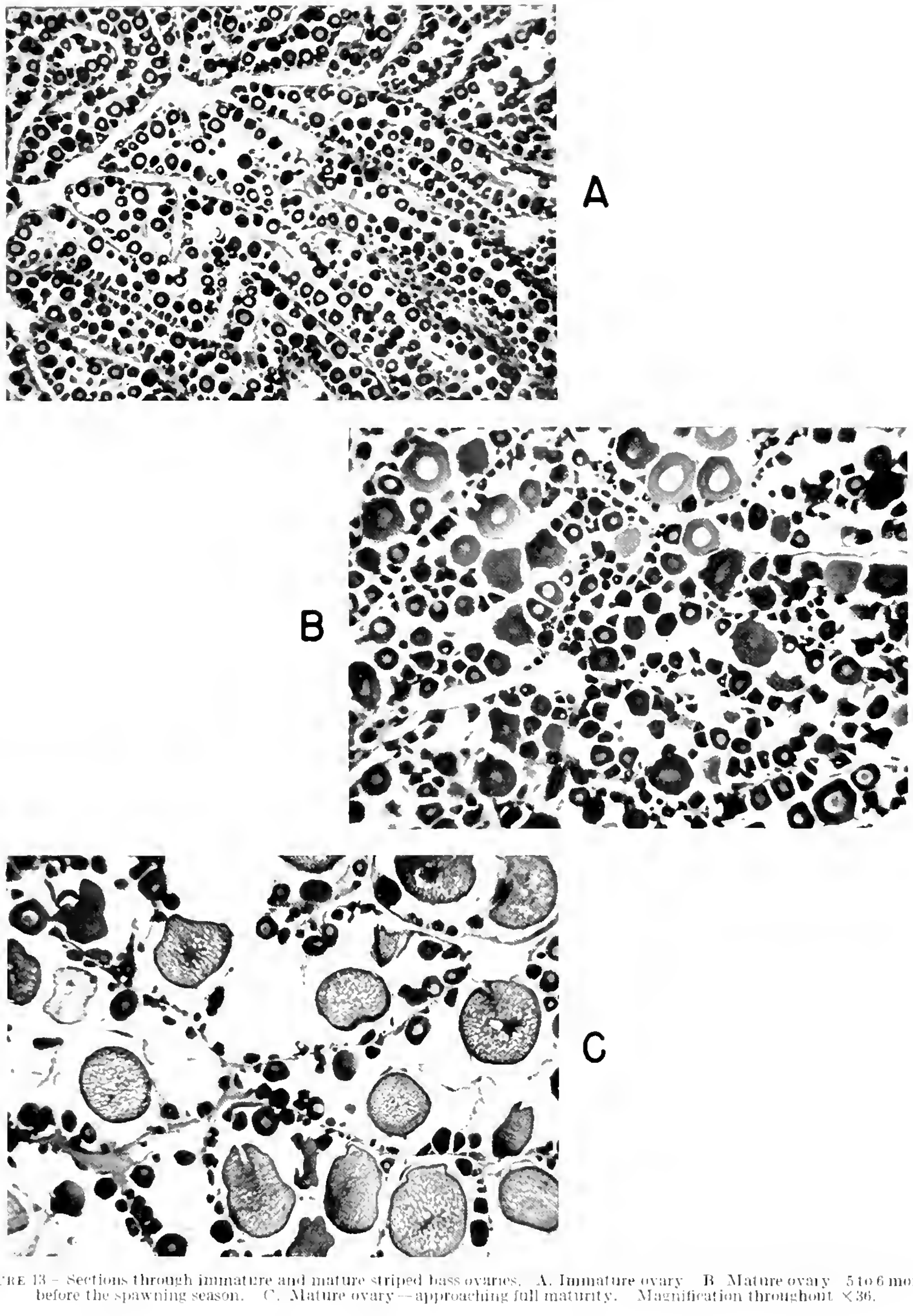

FIGURE 13 – Sections through immature and mature striped bass ovaries. A. Immature ovary. B. Mature ovary 5 to 6 months before the spawning season. C. Mature ovary—approaching full maturity. Magnification throughout ×36.

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

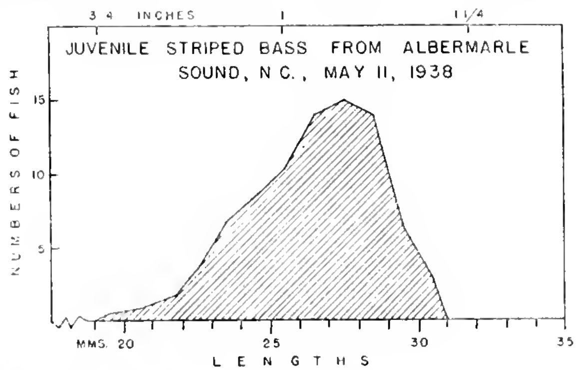

FIGURE 14.—A length-frequency curve of 85 juvenile striped bass taken in Albemarle Sound on May 11, 1938. Data smoothed by threes (see Table 9 for original measurements).

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.

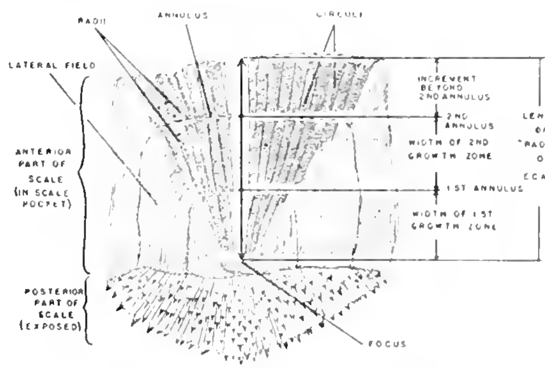

FIGURE 15.—Diagrammatic sketch of a striped bass scale to show parts and method of measurement.

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

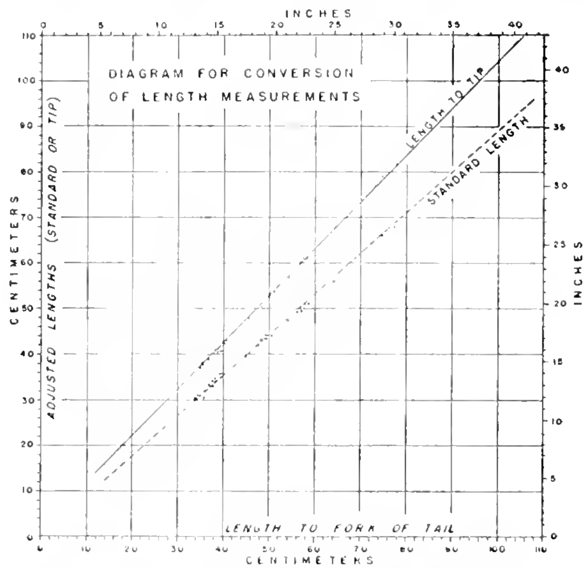

FIGURE 16.—Diagram for the conversion of different types of length measurements.

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-

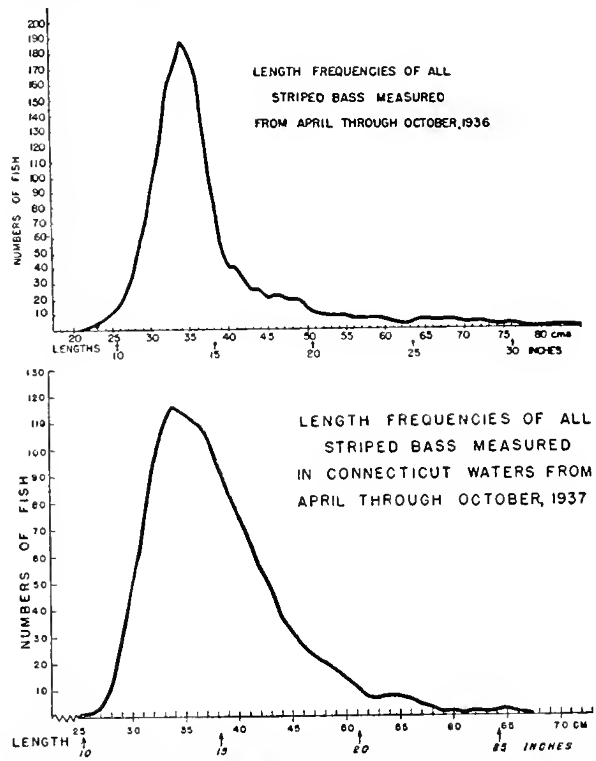

FIGURE 17.—Length-frequency curves of all the striped bass measured in Connecticut waters from April through October, 1936 and 1937. The data have been smoothed by threes throughout. See text for further discussion. See Table 11.

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

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.

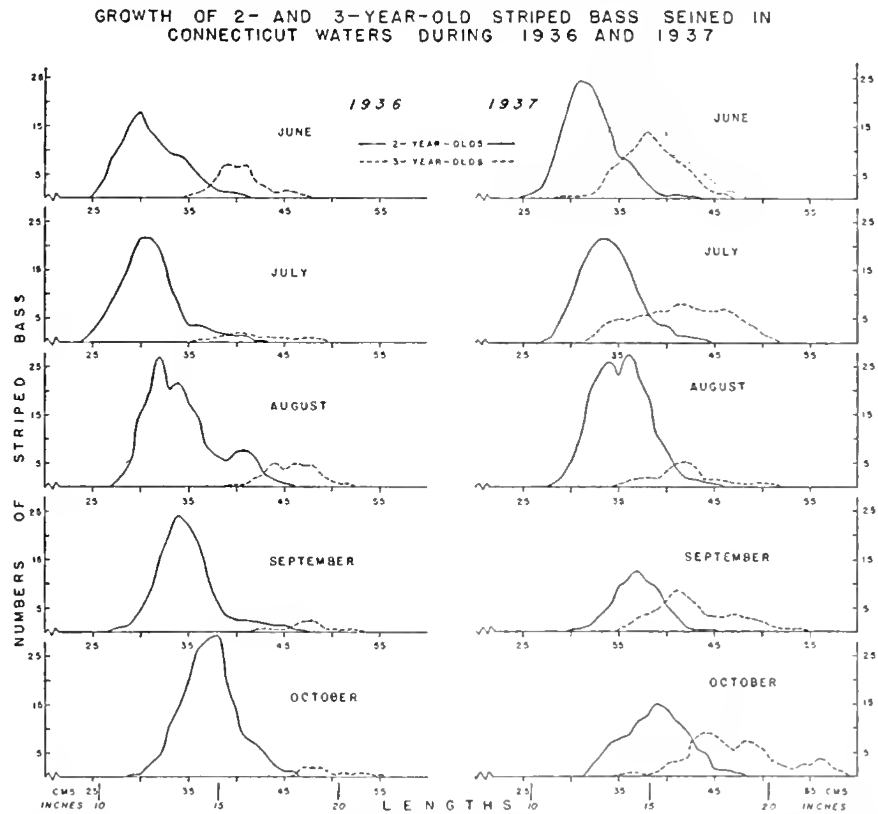

FIGURE 18.—The growth of the 2- and 3-year-old striped bass seined in Connecticut waters during 1936 and 1937. The curves are smoothed in every case by a moving average of threes. The numbers of fish making up each curve have not been equalized except in that for September 1936, where the total number 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 measurements 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

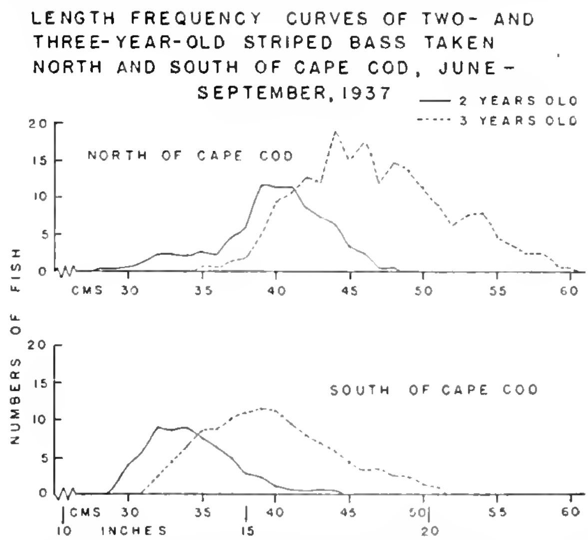

FIGURE 19.—Length-frequency curves of 2- and 3-year-old striped bass taken north and south of Cape Cod from June through September 1937. Data smoothed by a moving average of threes throughout (see Table 13 for original measurements).

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

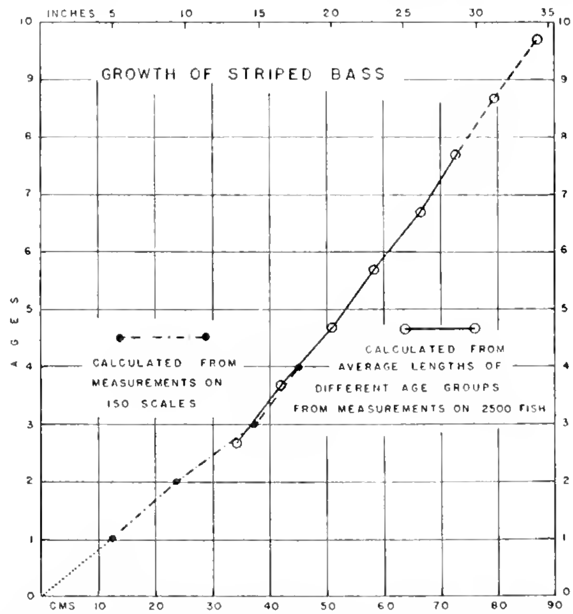

FIGURE 20.—The growth of the striped bass, as calculated from scales and the average lengths of differeut age groups. See Table 14 for average lengths of striped bass at the time they become 1 year old, 2 years old, etc., to 9 years old.

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

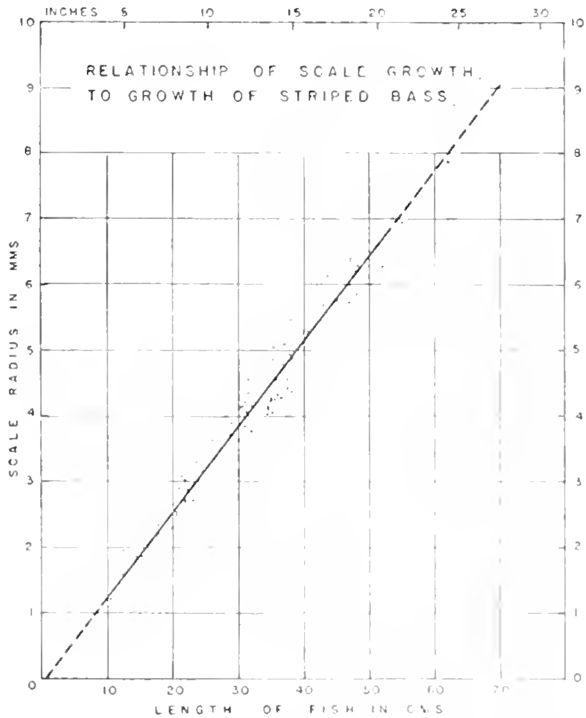

FIGURE 21.—The relationship of scale growth to body growth in the striped bass (see Table 15 for original data).

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

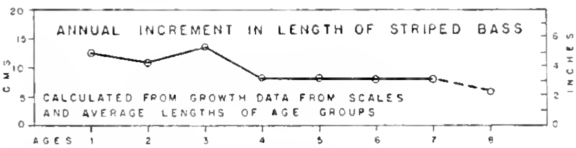

FIGURE 22.—The annual increment in the length of the striped bass. The annual increments through the fourth year are calculated from the scales from striped bass of the 1933 year-class caught in northern waters in the summer of 1937. The annual increments in the fifth to eighth years inclusive are calculated 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.

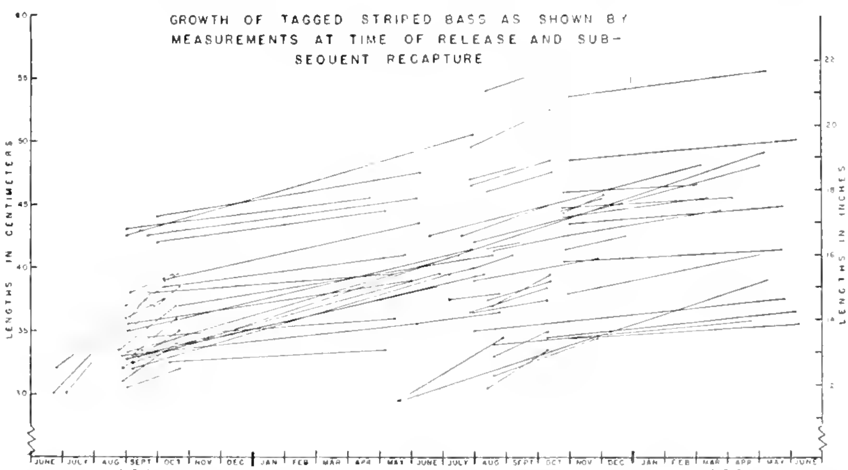

FIGURE 23.—The growth of tagged striped bass as shown by measurements at the time of release and subsequent recapture.

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 preceds 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 ⅓₂-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

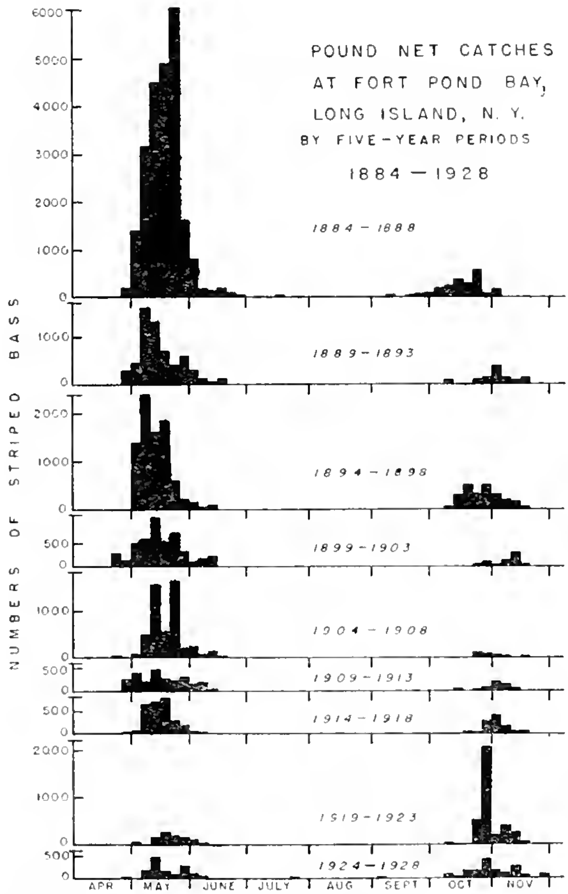

FIGURE 24.—Numbers of striped bass caught in the pound nets at Fort Pond Bay, L. I., N. Y., from 1884 to 1928, for each 5 days during the fishing season, by 5-year periods. The catches have been weighted to make them equivalent to a fishing intensity of 10 pound-nets throughout (see figure 4, table 4). 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

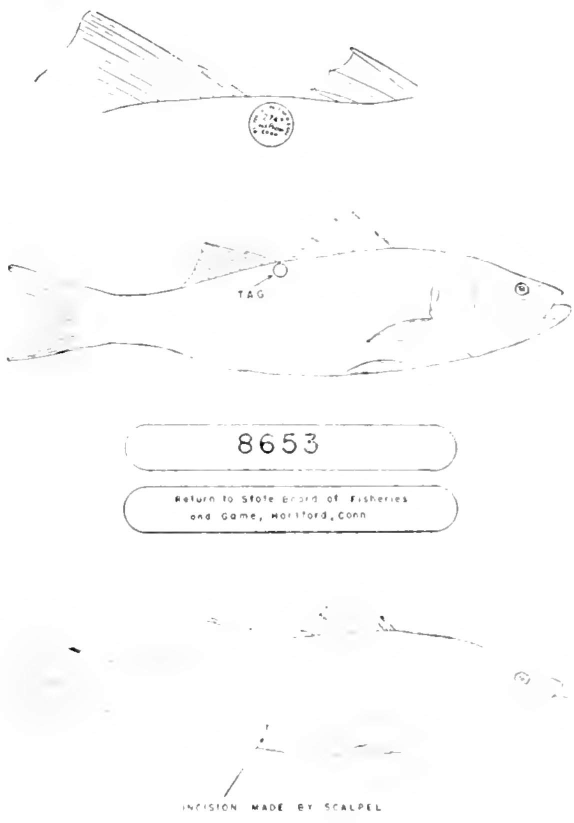

FIGURE 25.—Sketches to illustrate the external disc and internal belly tag methods of marking striped bass.

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, 1⁵⁄₁₆ 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 population through the summer and up to the latter part of October was shown by the consistent 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,

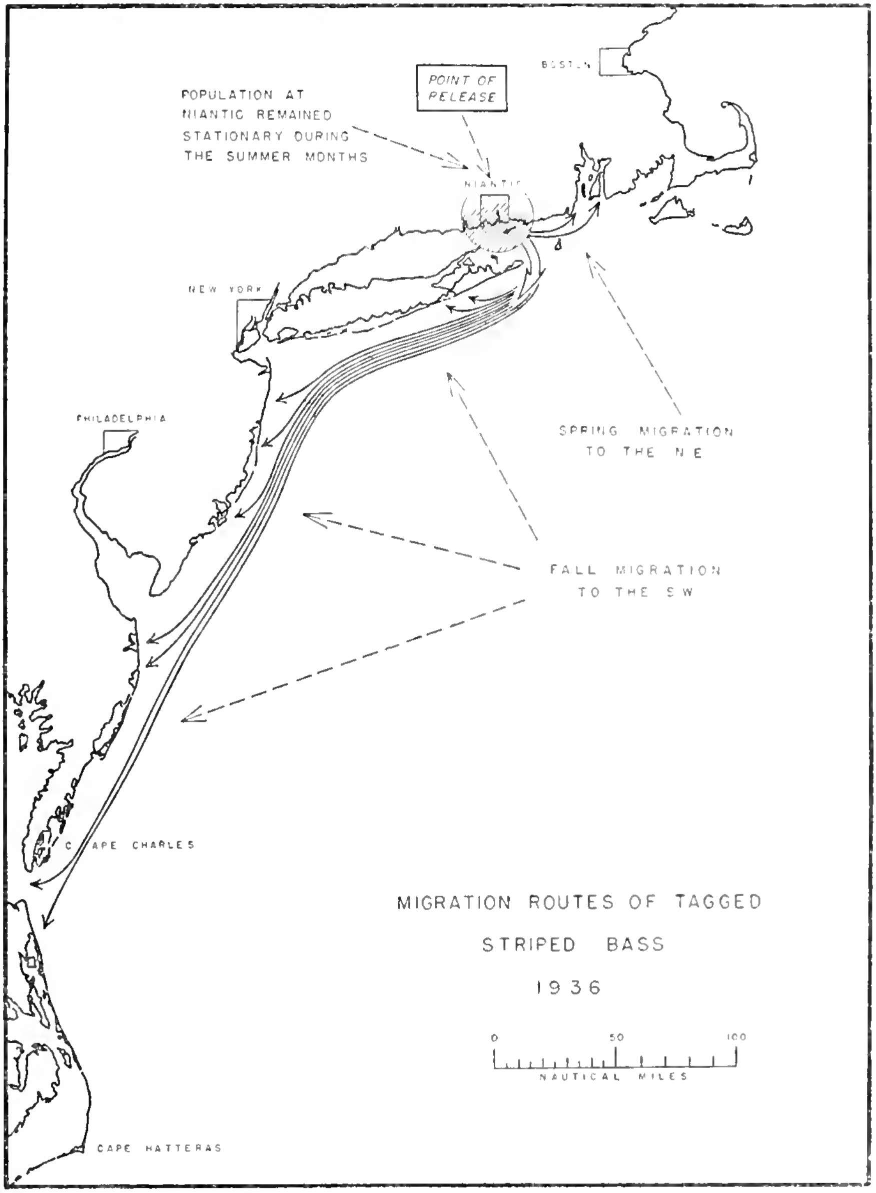

FIGURE 26.—Chart of the Atlantic coast showing the migrations of striped bass as determined by the returns from 1,397 individuals tagged from April through October 1936 (see table 17).

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

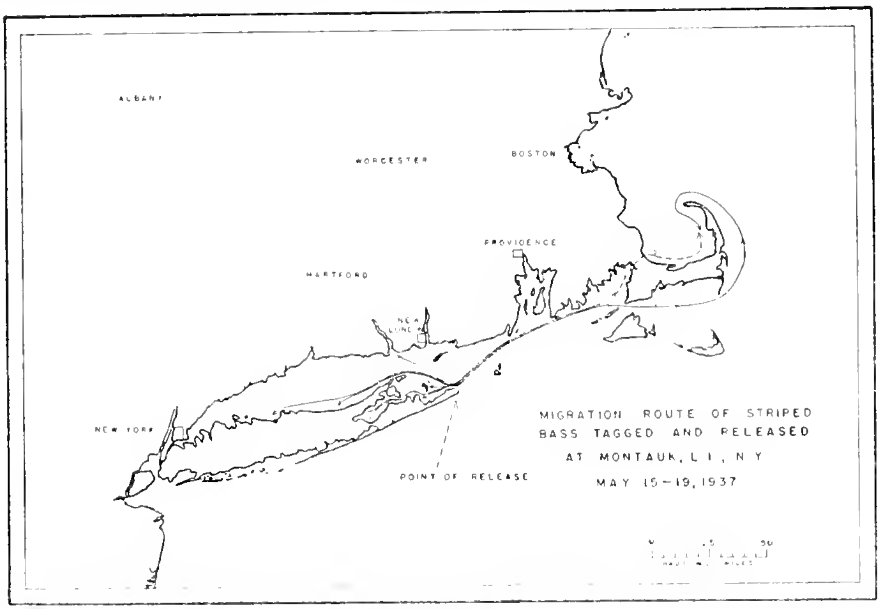

FIGURE 27.—Migration routes of striped bass tagged and released at Montauk, L. I., N. Y., May 15-19, 1937. The number of fish tagged was 103, the number of returns 14 (13.6 percent of the total). Note that there were no returns from the south, and contrast with the results of tagging from the same area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

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.

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

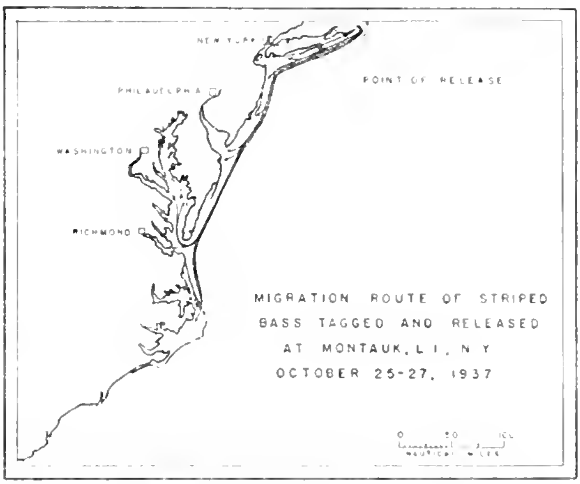

FIGURE 28.—Migration route of striped bass tagged and released at Montauk, L. I., N. Y., Oct. 25–27, 1937. The number of fish tagged was 303, the number of returns 100 (33 percent of the total). Note that there were no returns of any significance to the north of the point of release, and contrast with 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

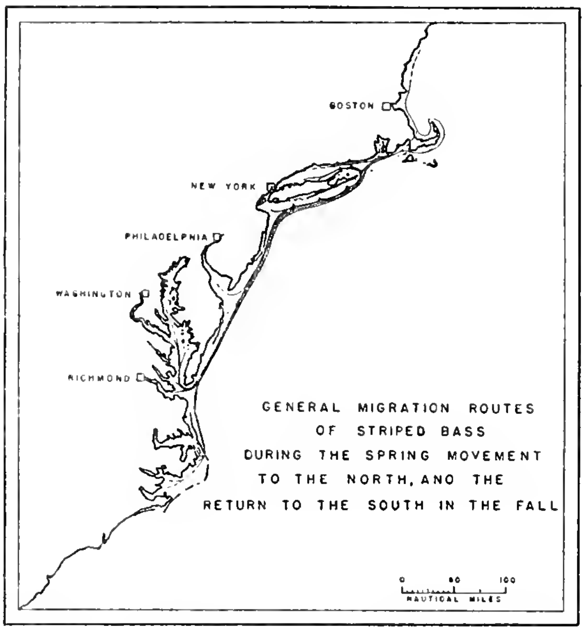

FIGURE 29.—The general migration routes of striped bass during the spring movement to the north, and the return to the south in the fall.

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

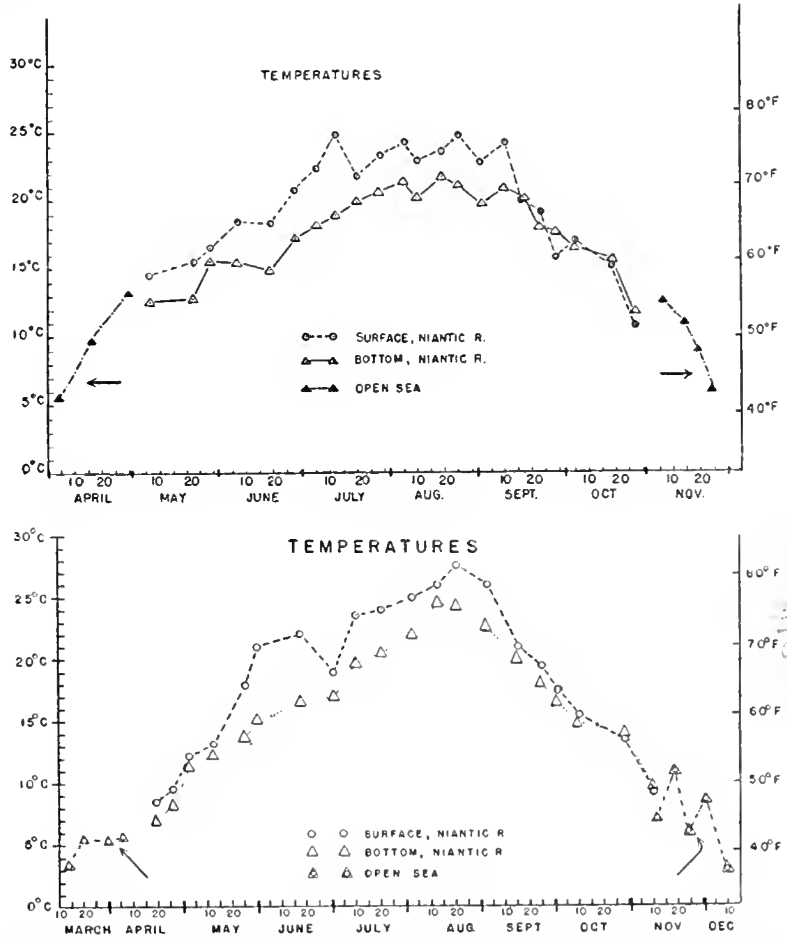

FIGURE 30.—Water temperatures in the Niantic River, Conn. The surface and bottom temperatures were taken in an area where striped bass were caught throughout the season. The open sea temperatures were taken at the mouth of the Niantic River, where the water passes through a narrow gut on the incoming 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

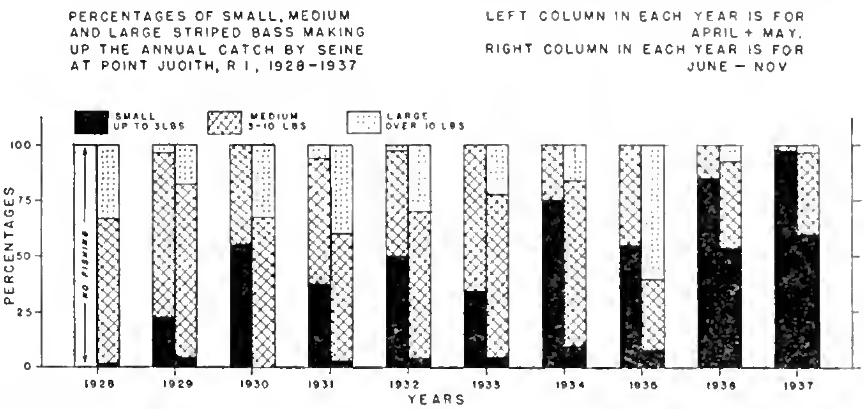

FIGURE 31.—The percentages of small, medium, and large striped bass making up the annual catch by seine before and after June at Point Judith, R. I., from 1928 to 1937. The left-hand column is for April and May, and the right-hand column for June to November in each year. See Figure 8 for the same material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

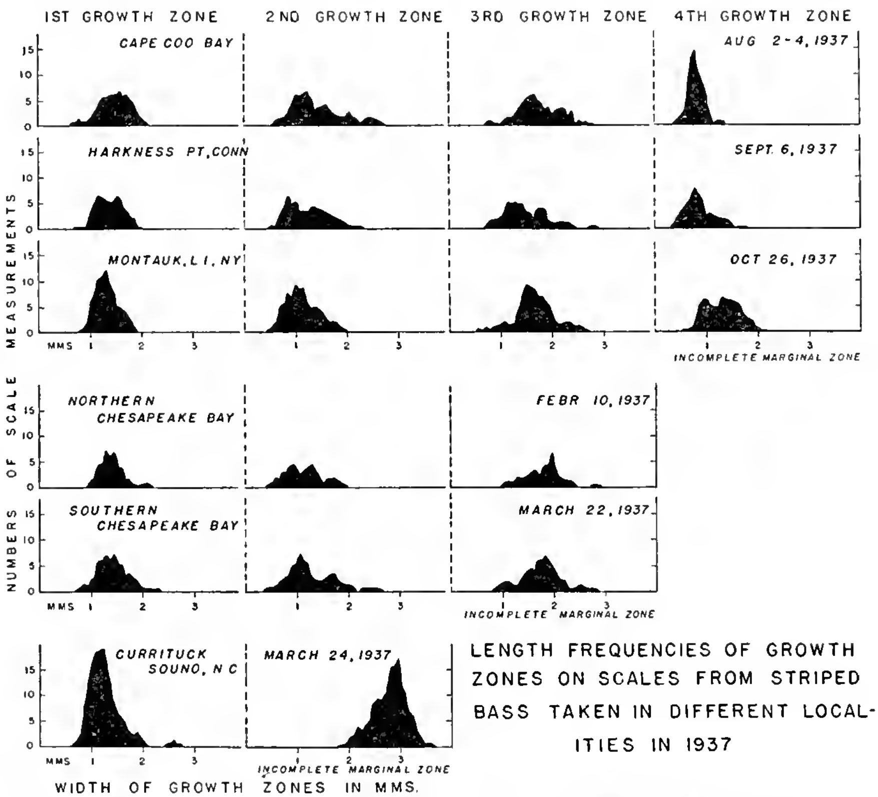

FIGURE 32.—The length-frequencies of the growth zones on scales from striped bass taken in different localities in 1937. The measurements making up each curve have been smoothed by a moving average of threes throughout.

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.

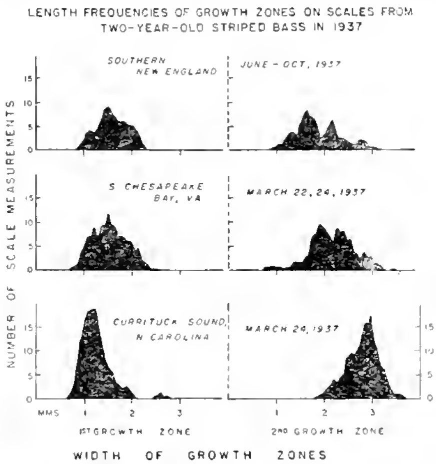

FIGURE 33.—The length-frequencies of the growth zones on scales from 2-year-old striped bass taken in southern New England southern Chesapeake Bay, and Currituck Sound (repeated from Figure 32 for comparative purposes), in 1937. The measurements making up each curve have been smoothed by a moving average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

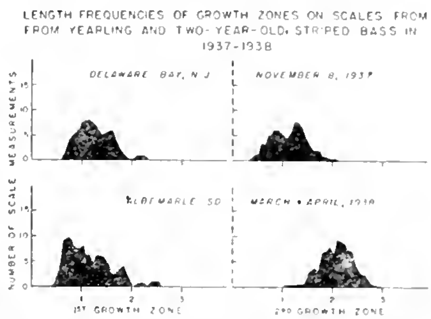

FIGURE 34.—The length-frequencies of the growth zones on scales from yearling and 2-year-old striped bass taken in Delaware Bay and Albemarle Sound in 1937 and 1938. The measurements making up these curves have been smoothed by threes throughout.

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

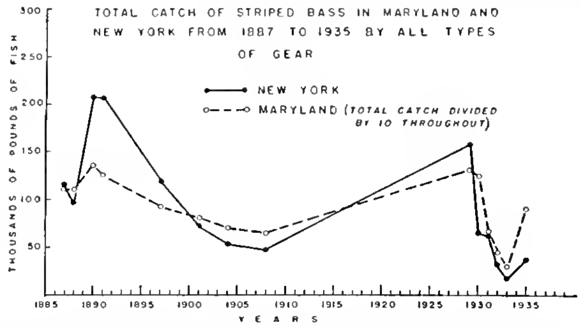

FIGURE 35.—Total catch of striped bass in certain years by all types of gear in Maryland and New York from 1887 to 1935 (from U. S. Bureau of Fisheries canvass). Maryland catch reduced to one-tenth throughout.

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

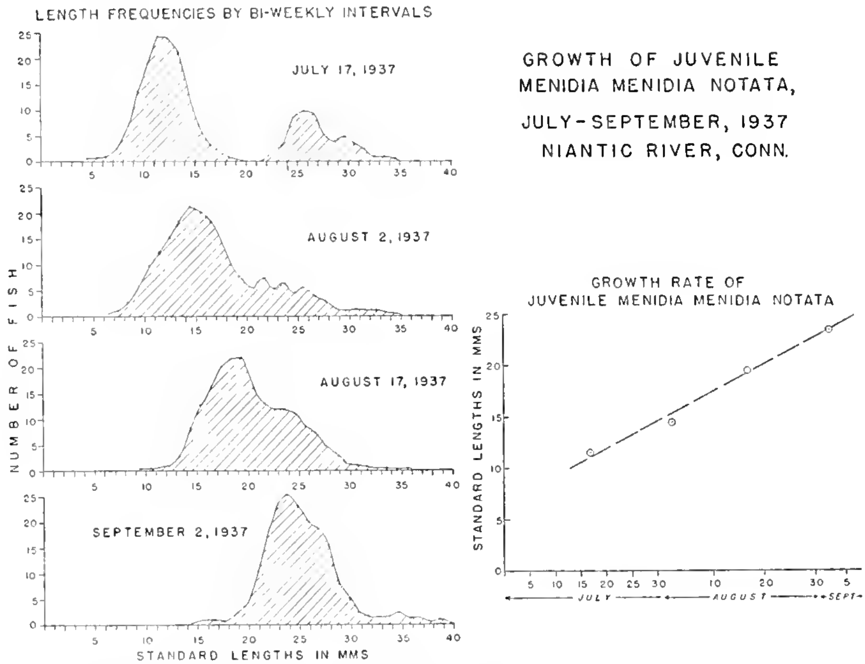

FIGURE 36.—The growth of *Menidia menidia notata*, from July to September 1937, in the Niantic River, Conn. The length-frequencies have been smoothed by a moving average of threes throughout (see Table 23 for original data).

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. eucides*, 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 1⅔ 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
1865	1,174	----------	28
1866	659	6.75	24.50
1867	906	6.25	55
1868	942	6.75	57
1869	887	6.50	48
1870	615	7.25	47
1871	804	8.50	42
1872	581	8	39
1873	592	6.75	37
1874	500	8.25	55
1875	724	9.25	50.25
1876	835	7	51
1877	321	10.25	51.50
1878	648	8.25	51
1879	499	9.75	49
1880	403	9	50.25
1881	184	9.25	44
1882	200	10.25	64
1883	154	8.25	31.75
1884	124	9	43
1885	46	9	29.50
1886	3	22	27.25
1887	235	12	42
1888	29	16.50	56
1889	4	22.50	41
1890	154	14	41.50
1891	43	11.75	24.25
1892	18	16.50	38.50
1893	39	16.25	35.50
1894	80	9	35.25
1895	21	17.25	36.75
1896	25	14.25	27
1897	59	11.25	33.50
1898	45	9	23.75
1899	21	13	35
1900	14	18	54
1901	13	14	29
1902	2	17	26
1903	4	10.75	15.75
1904	5	15	35
1905	7	10	40
1906	1	9.25	9.25
1907	5	19	23.50

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			Length (cm.)	Number of individuals		
	Cape Cod Bay	Newport, R. I.	Montauk, Long Island, N. Y.		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		
52	11	24	6	102			1
53	9	21	4	108	2		
54	7	12	2				
55	5	7		Total	366	378	413
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		14	5	9	25	1	14		19
	100%			26.6%		73.5%		93.3%		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			
47	25	24	73	4		Total	1,933	1,460
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	6	4	8	64	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	6	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	6	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	
			56	1	
Total	88	66	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.
		40.0	5.24, 5.24.
18.5	2.24, 2.53, 2.46.	40.5	5.20, 5.24, 4.91.
19.5	2.35, 2.35.	41.0	5.35, 4.70, 4.91.
20.0	2.60, 2.39, 2.53.	42.0	5.13, 5.49, 5.28.
20.5	2.55, 2.67, 2.53.	43.0	5.67.
21.0	2.89, 2.74, 2.43, 2.67.	43.5	5.56, 6.11.
21.5	2.67, 2.69, 2.77, 3.10.	45.0	5.75.
22.0	3.03, 2.82.	45.5	6.43.
22.5	2.89.	46.0	6.18.
23.0	2.70, 2.86.	46.5	5.99.
24.0	3.14.	47.0	5.71.
24.5	3.40.	47.5	6.40, 6.00, 6.43.
25.0	3.03.	48.0	6.40, 6.28, 5.85.
26.0	3.62.	48.5	6.36.
26.5	3.36.	50.0	6.57, 6.36, 6.71.
27.0	3.32, 3.58.	51.0	6.07, 6.14.
27.5	3.83.	52.0	6.36.
28.0	3.99.	53.5	7.00.
29.0	3.90, 3.69.	54.0	6.79.
29.5	3.52, 4.12.	55.0	6.93.
30.0	3.62.	62.0	7.87.
30.5	4.12, 4.12.	63.0	8.73.
31.0	4.19, 3.83.	67.0	9.17.
31.5	4.19, 4.34, 4.56, 4.05.		

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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Harold L. Ickes, Secretary

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THE YOUNG OF SOME MARINE FISHES TAKEN IN LOWER CHESAPEAKE BAY, VIRGINIA, WITH SPECIAL REFERENCE TO THE GRAY SEA TROUT *Cynoscion regalis* (BLOCH)

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ABSTRACT

Plankton collections made at the mouth of Chesapeake Bay, Va., yielded specimens of 45 species of marine fishes that were recognized. As a result of these weekly collections during the summer and biweekly collections during the winter, from May to October 1929, from April to December 1930, and during January and March 1931, sufficient data were acquired to provide distributional and descriptive data on 31 of the 45 species recognized.

Larval and postlarval stages of the gray sea trout, or weakfish, *Cynoscion regalis;* the bluefish, *Pomatomus saltatrix;* the butterfish, *Poronotus triacanthus;* the harvestfish, *Peprilus alepidotus;* and the stargazer, *Astroscopus guttatus,* are described and illustrated.

Collections of juvenile gray sea trout by seine and trawl indicate that this food fish attains an average total length of 16 to 20 cm. at the end of its first year of growth in lower Chesapeake Bay.

THE YOUNG OF SOME MARINE FISHES TAKEN IN LOWER CHESAPEAKE BAY, VIRGINIA, WITH SPECIAL REFERENCE TO THE GRAY SEA TROUT *Cynoscion regalis* (BLOCH)

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CONTENTS

INTRODUCTION

Our knowledge concerning seasonal and geographic distributions of the planktonic young of most inshore marine fishes of the Atlantic coast is meager. This is especially true of certain common food fishes such as the weakfish, or gray sea trout, *Cynoscion regalis,* which provides the most valuable inshore fishery along the Middle Atlantic seaboard. The importance of such information concerning our marine food fishes has been brought out by Bowman (1914), who asked

> Are the chief spawning places such that when the bulk of the larvae appear from the egg they find themselves in the immediate neighborhood of a locality suitable for development? To what extent do the prevailing physical conditions assist the passive eggs and helpless larvae in securing a suitable habitat for further development?

It is of considerable import to the annual success of the American fisheries that there should be an intimate connection between the spawning grounds of a species and the localities suitable for growth.

The present paper presents additional distributional and descriptive data on the young of a number of marine fishes regularly occurring in lower Chesapeake Bay. These data should help to increase our knowledge of the spawning season and spawning habitat of these fishes.[1]

METHODS

The area of Chesapeake Bay included in this study is bounded roughly by Cape Henry and Cape Charles on the east, Lynnhaven Roads on the south, Old Point Comfort on the west, and Back River Light on the north (fig. 1).

Plankton collections were made at weekly or biweekly intervals at definite points within this area with a meter ringnet towed by powerboat. All except two of the collecting stations were permanently marked with navigation buoys and nearly all plankton was taken at definite localities over the entire period of collection—extending from May to October 1929, from April to December 1930, and during January and March 1931. The period of each tow was standardized at 15 minutes, the tow usually being with the tide and at as constant a rate of speed as conditions permitted.[2] Collections were usually taken from 10:30 a. m. to 2:00 p. m. Both surface and subsurface tows were frequently made at each station. Subsurface tows were made from 10 to 20 feet below the surface of the water—the depth of water at no station exceeding 30 feet.

PLANKTONIC FISHES

Over 7,400 young fishes, representing 45 species, were taken in the plankton collections in lower Chesapeake Bay during 1929–30. Of the total number, 7,380 fishes were identified and separated into 31 recognizable species, while 50 fishes were separated into 14 unknown species. The planktonic young of the sea trout, *Cynoscion regalis,* constituted over 50 percent of the total number of fish identified; followed in abundance by the young of the common anchovy, *Anchoviella mitchilli;* the sea robin, *Prionotus* sp.; and the blenny, *Hypsoblennius hentz.*[3] The numerical seasonal relationship of the various species of larval and postlarval fishes in the plankton given by the month and year is presented in table 1.

The planktonic fishes, usually in larval or postlarval stages, were secured princi-

[1] Acknowledgment is due the War Department for extended use of laboratory space at Old Point Comfort, Va., and to the many fish dealers and fishermen about Hampton Roads for valued information and assistance. Special mention is due Miss Louella E. Cable for the original drawings (figs. 2 to 9, 12 to 21, 24, and 25) in this report.

[2] The length of the net was approximately 4 meters (13 feet), the upper 1½ meters of No. 0 silk bolting cloth (38 meshes to the inch), the lower 3 meters of No. 2 silk cloth (54 meshes to the inch), and a detachable cap of No. 12 silk cloth (150 meshes to the inch.

[3] Numerically the young of *A. mitchilli* were far more abundant in the plankton than the young of *C. regalis* but, owing to the labor involved, only a small proportion of young *mitchilli* was removed from the plankton, while all the young of *C. regalis* as well as all other species were removed and identified.

pally from April 1 to November 1.[4] The months from May to August yielded the most abundant catches, as well as the largest variety of species. While certain species, such as the blenny, *Hypsoblennius hentz*, and the common pipefish, *Syrictes fuscus*, were generally found widely distributed in the plankton from early spring until late fall, other species, such as the bluefish, *Pomatomus saltatrix*, occurred only once.

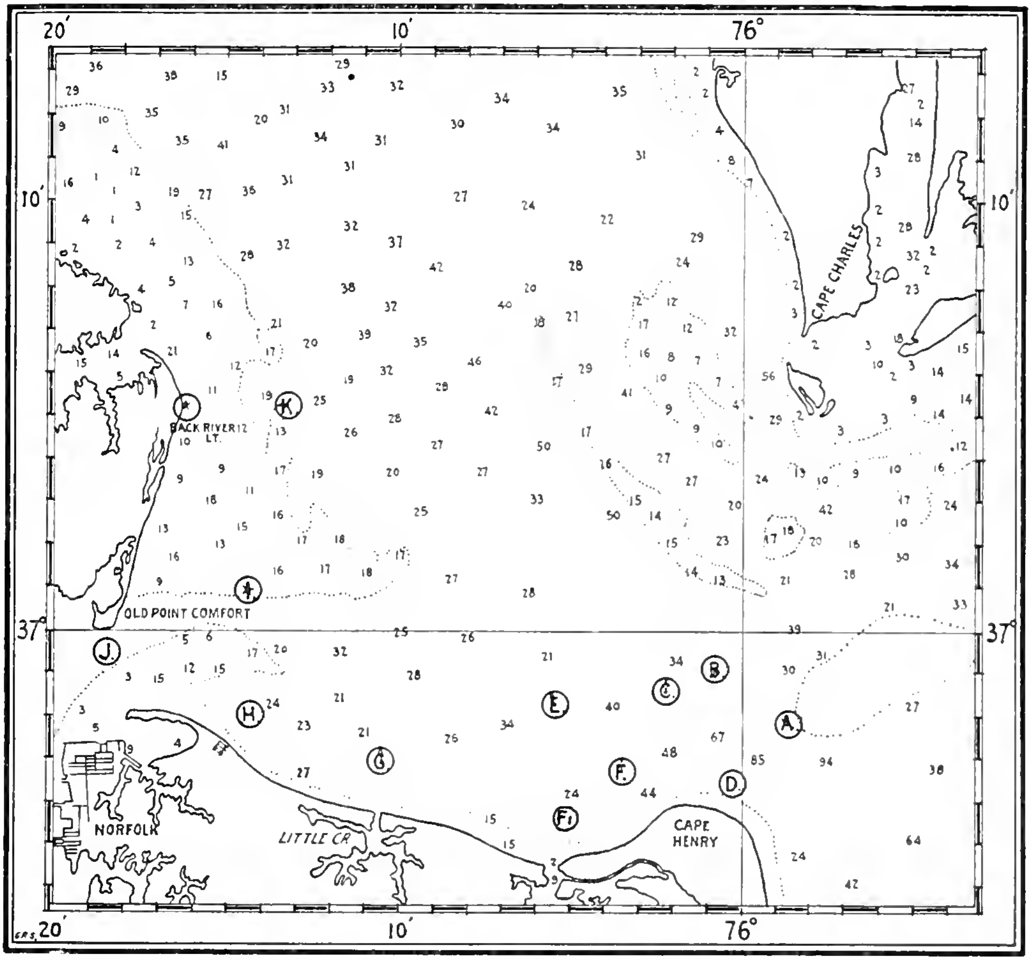

FIGURE 1.—Entrance to Chesapeake Bay, Va. Circled letters indicate plankton-collecting stations. Depth is given in feet.

Subsurface collections generally yielded a larger number of fishes than surface tows. Certain species, such as *Gobiesox strumosus*, however, were taken proportionately more often in surface than in subsurface hauls. Many investigators have found that the surface layers contain few larval fish during the day. Clark (1914), in a study of the larval and postlarval fishes in the vicinity of Plymouth, England, found that night

[4] The term "larval" as used in this paper refers to the growth stages of a fish from the time of hatching to the point where the fin rays appear differentiated and the young fish have considerable power of movement. The term "postlarval" refers to the growth stages following the development of the fin rays to a size where all traces of the larval fin fold have disappeared. The terms "larval" and "postlarval" fill a need for differentiating the more or less helpless young of many marine fishes from the juvenile young which have more or less complete control of their movements.

hauls yielded a much larger percentage of young forms from the surface layers than did day hauls. Possibly the same condition might have occurred if night collections had been made in Chesapeake Bay (table 2).

TABLE 1.—*Seasonal distribution of young fishes in the plankton, Chesapeake Bay, 1929–30. Nearly all fishes were taken in larval or early postlarval stages*

Species	April 1930	May		June 1929	July		August		September		October 1930	November 1930
		1929	1930		1929	1930	1929	1930	1929	1930		
Achirus fasciatus					34		34	45		1		
Anchoviella mitchilli			24	79	120	11	87	44	13	19		
Ancyclopsetta sp.					2							
Astroscopus guttatus					1	1						
Bairdiella chrysura				6	1							
Brevoortia tyrannus	2	1										
Centropristes striatus				1	55	2						
Conger conger	1											
Cynoscion regalis		9	8	2, 468	1, 540	268		5				
Etropus sp.				1	108	1						
Gobiesox strumosus		13	55	13	4		1	1				
Gobiosoma sp.				18	87	23	99	29	7	31	11	
Hippocampus hudsonius				6	3	2	2	2	1			
Hypsoblennius hentz		5	2	117	98	47	72	26	33	26	38	1
Lophius piscatorius			12									
Lophopsetta maculata	55	2	118									
Menidia menidia		7	12									
Menticirrhus americanus				30	34	73	23	4	10	1		
Microgobius thalassinus					11			1	1	12		
Micropogon undulatus						9		11	48	26	17	
Paralichthys sp.												1
Peprilus alepidotus					17	2	53	1				
Pomatomus saltatrix						4						
Poronotus triacanthus		5	4	82	75	32	26			8		
Prionotus sp.				138	223	63						
Rissola marginata					3	2	1		3	1	2	
Symphurus plagiusa					2							
Syngnathus floridae			2	3		1	1		1			
Syrictes fuscus		5	15	26	12	4	4	1	2	8	3	3
Tautoga onitis			10									
Sphoeroides maculatus			22	58	14	3	2			1		

TABLE 2.—*The surface and subsurface distribution of planktonic fishes in Chesapeake Bay, expressed as the percentage of hauls in which the various species occurred*

[108 surface and 140 subsurface hauls were made from May to October, 1929, and 111 surface and 168 subsurface hauls from April to December, 1930, omitting June. No fishes were obtained in 24 surface hauls and 47 subsurface hauls made in January and March, 1931]

Species	Percent of hauls, 1929		Percent of hauls, 1930		Species	Percent of hauls, 1929		Percent of hauls, 1930	
	Surface	Subsurface	Surface	Subsurface		Surface	Subsurface	Surface	Subsurface
Achirus fasciatus	3	14		3	*Lophopsetta maculata*	1	1	20	22
Anchoviella mitchilli	5	18	9	12	*Menidia menidia*	4		6	4
Ancyclopsetta sp.			1		*Menticirrhus americanus*	8	22	3	6
Astroscopus guttatus		1		1	*Microgobius thalassinus*	1	1		2
Bairdiella chrysura		4			*Micropogon undulatus*		3	5	12
Brevoortia tyrannus	2	1			*Paralichthys* sp.			1	
Centropristes striatus	1	5		2	*Peprilus alepidotus*	6	16	1	2
Conger conger				1	*Pomatomus saltatrix*				1
Cynoscion regalis	12	40	9	9	*Poronotus triacanthus*	12	25	2	10
Etropus sp.	3	9		1	*Prionotus* sp.	3	16	3	4
Gobiesox strumosus	10	8	11	6	*Rissola marginata*	1	5	1	2
Gobiosoma sp.	4	24	5	7	*Symphurus plagiusa*		1		
Hippocampus hudsonius	2	6	1	2	*Syngnathus floridae*	1	3	2	1
Hypsoblennius hentz	17	43	17	16	*Syrictes fuscus*	7	16	12	11
Lophius piscatorius			7	5	*Sphoeroides maculatus*	6	21	9	8
					Tautoga onitis	10	9		

BREVOORTIA TYRANNUS (Latrobe). Menhaden; Fatback

Distribution.—Young menhaden were taken four times during May 1929 and April 1930 near Old Point Comfort. The scarcity of young indicates that spawning probably occurs outside of the area of collection, although a limited number of menhaden eggs were taken during late summer. The occurrence of these young fish in early spring indicates that some spawning occurs during the winter months, as suggested by Hildebrand and Schroeder (1927).

Description.—The young menhaden were from 20 to 24 mm. in length. The young of the species have been described by Kuntz and Radcliffe (1918).

ANCHOVIELLA MITCHILLI (Cuvier and Valenciennes). Anchovy

Distribution.—Young anchovies were taken from July 6 to Sept. 13, 1929, and from May 16 to Sept. 13, 1930. The larval and postlarval young were the most numerous of all species of fishes in the plankton. The separation of *A. mitchilli* from its relative, *A. epsetus*, is difficult if not impossible for young under 5 mm. Consequently, numbers of young *A. epsetus* may be represented in the collections of *A. mitchilli.* According to the relative abundance of eggs and adults of the two species in lower Chesapeake Bay, however, *mitchilli* far outnumbers *epsetus*.

Description.—The size range of the young extended from 2.5 to 20.0 mm. The young of *A. mitchilli* have been described by Kuntz (1914) and the young of *A. epsetus* by Hildebrand and Cable (1930).

CONGER CONGER (Linnaeus). Conger eel

Distribution.—A leptocephalus, probably that of *C. conger*, was taken on Apr. 18, 1930, at Station J.

Description.—The larva measured 100 mm. in length and possessed 150+ myomeres.

LOPHOPSETTA MACULATA (Mitchell). Windowpane

Distribution.—The young of the windowpane flounder were taken during April and May 1930, at stations nearest the sea. The appearance of young only during April and May suggests an early spring spawning season in the region of Chesapeake Bay.

Description.—The young ranged from 2 to 10 mm. in length. They are quite distinctive in appearance. Several stages of the young have been described by Bigelow and Welsh (1925).

ETROPUS sp. Etrope

Distribution.—Planktonic young of this small flatfish were taken principally in July 1929.

Description.—This fish ranged in length from 2.5 to 13 mm. Although the correct generic identification of the young was possible through counts of fin rays of the larger specimens, doubt exists as to the specific identity owing to the probable presence of two species of the genus in the Chesapeake Bay area—namely, *E. crossotus* and *E. microstomus*.

PARALICHTHYS sp. Flounder

Distribution.—A fish, perhaps referable to the summer flounder, *P. dentatus,* was taken on Nov. 28, 1930, at Station B.

Description.—The fin rays of this fish, measuring 10 mm. in length, were differentiated, but the eye had not completed transition. Pigmentation consisted of three parallel rows of weak chromatophores lying along the dorsal, median, and ventral sides of the body. Each row contained eight distinct chromatophores. The specimen was too badly damaged to permit accurate fin-ray count, although the latter fell within the known range of *P. dentatus.*

ANCYLOPSETTA sp. Flounder

Distribution.—Two planktonic young taken on July 12, 1929, at Station B are probably referable to this genus of flatfishes.

Description.—The young measured 5 and 6 mm. in length. The most characteristic features of the two fish are the pronounced elongation of the first two dorsal rays, the latter reaching nearly a quarter the length of the body, and the elongation of one of the ventral fins into a filament extending to the vent. The other ventral fin is not evident and apparently is undifferentiated.

The pigmentation consists of a series of six chromatophores along the upper side of the body; a single chromatophore along the median line on the posterior part of the body; a thin, black, continuous line along the ventral edge of the body; and many branching chromatophores on the ventral surface of the abdominal cavity. The fishes are symmetrical in shape.

ACHIRUS FASCIATUS (Lacépède.) American sole; Hog choker

Distribution.—The planktonic young of this flatfish were taken during July 1929, August 1929–30, and September 1930. Most young were obtained during July 1929 and August 1929–30. This seasonal distribution indicates that the species spawns largely in midsummer. The greatest abundance of young was found about 1 mile off Little Creek, Virginia, near Station G. The latter estuary contains many adult and young fish during the summer months, and may constitute a spawning area.

Description.—The length range of planktonic young extended from 1.5 to 4 mm. At 4 mm. the fin rays are clearly differentiated and identification is easily determined. The close resemblance of larval fish at 1.5 mm. to larger sizes permits ready identification. A strikingly heavy black pigmentation is characteristic of all young *Achirus.* The latter at 4 mm. in length still retain a symmetrical shape with an eye on each side of the head.

The young have been described by Hildebrand and Cable (1938).

SYMPHURUS PLAGIUSA (Linnaeus). Tonguefish

Distribution.—Several larval tonguefish were secured at Station A on July 9, 1929.

Description.—The fish ranged from 5 to 6 mm. in length. The young of this species has been described by Hildebrand and Cable (1930) and is readily identified.

SYNGNATHUS FLORIDAE (Jordan and Gilbert). Pipefish

Distribution.—The young of this species were taken during June, August, and September 1929, and during May and July 1930, at many localities.

Description.—The young pipefish ranged in length from 14 to 48 mm. Identification was based on body and tail ring counts.

SYRICTES FUSCUS (Storer). Common pipefish

Distribution.—The young of this species were taken from May 11 to Sept. 16, 1929, and from May 6 to Nov. 22, 1930.

Description.—The length of the young ranged from 9 to 50 mm. Identification was based on body and tail ring counts.

HIPPOCAMPUS HUDSONIUS De Kay. Seahorse

Distribution.—The young of the seahorse, *Hippocampus hudsonius*, were taken in plankton from June 6 to Sept. 13, 1929, and from July 7 to Sept. 12, 1930. Although spawning may occur within the bay, the young seahorses were generally taken in masses of floating sea vegetation and probably had drifted in from open sea.

Description.—The young fish ranged from 6 to 33 mm., which included the distance from the tip of the snout (head flexed) to the end of the caudal fin. The young of the species has been described by Ryder (1881).

MENIDIA MENIDIA (Linnaeus). Silverside

Distribution.—The young of the silverside were taken in plankton during May 1929–30. Most young were secured at stations well within the bay. Hildebrand and Schroeder (1928) stated that the largest number of ripe adult *Menidia* occurred in April and May.

Description.—The length range of the young extended from 5 to 9 mm. The various developmental stages have been described by Kuntz and Radcliffe (1917) for the northern form, *M. menidia notata*, and by Hildebrand (1922) for the southern, or typical form, *M. menidia*.

PEPRILUS ALEPIDOTUS (Linnaeus). Harvestfish

Distribution.—The young of this important food fish were taken in the plankton during July and August, 1929–30, at all stations.

The appearance of the young fish accompanied the incursion of large numbers of the coelenterates, *Dactylometra* and *Cyanea*. The long tentacles of these stinging "jellyfish" appear to act as a shelter and possibly as a food provider for the young harvestfish, for young fish were frequently observed hovering under the coelenterates.

Description.—The lengths of the young fish ranged from 1.5 to 32 mm. The young harvestfish at 1.8 mm. in length has the larval yolksac absent and the larval fin fold entire. The larval gut is elongate, reaching about half the length of the body. A lateral pigmentation occurs as a scattering of black chromatophores on the body (fig. 2).

At 2.5 mm. the young fish possesses the lateral chromatophores in a more pronounced and characteristic pattern. One series of pigment cells follows the median line of the body from the pectoral fin to about half way the length of the body, while another, more regular series, lies along the lower side of the body dorsal to the gut. Scattering anastomosed chromatophores are found above the opercle and along the

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posterior sides of the abdominal cavity. The fin fold remains entire. A reduction in the length of the gut occurs at 2.5 mm. and what appears to be a secondary, or true vent is developed anterior to the gut. Several young at this length showed this peculiar structure, the exact nature of which has not been determined (fig. 3).

FIGURE 2.—*Peprilus alepidotus*. From a specimen 1.8 mm. long.

The harvestfish at 3.5 mm. is more compressed, the gut has become greatly reduced and only one vent is evident. The location of the chromatophores becomes

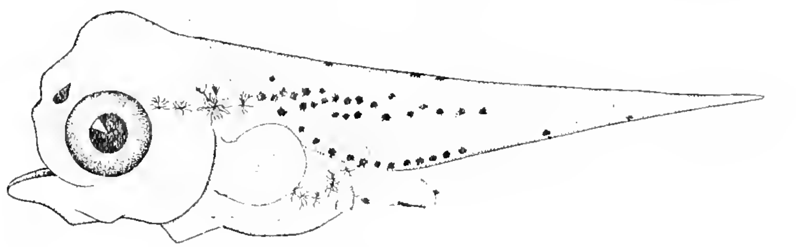

FIGURE 3.—*Peprilus alepidotus*. From a specimen 2.5 mm. long.

more elevated. The fin rays are slightly differentiated, although the fin fold remains entire (fig. 4).

The young fish can be easily recognized at 7 mm. for the fin rays are fully differentiated. A further deepening of the body takes place and the chromatophores

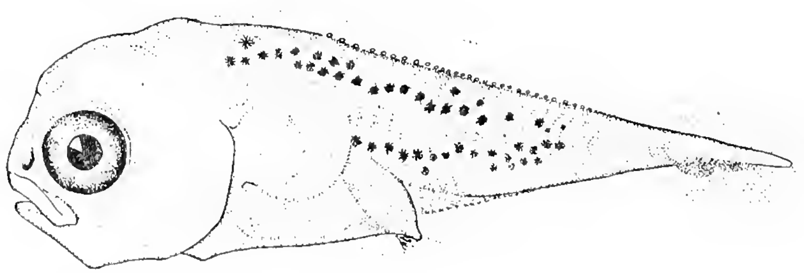

FIGURE 4.—*Peprilus alepidotus*. From a specimen 3.5 mm. long.

become more scattered, enlarged, and anastomosed. The pigmentation is confined to the forward part of the body (fig. 5).

The young fish becomes still further compressed at 9 mm. The pigmentation is darker and a considerable reduction in the size of each chromatophore occurs (fig. 6).

The fish has assumed a characteristic adult shape at a length of 62 mm. The body has become strongly compressed, deep, and oval. The caudal fin has become forked, while the dorsal and anal fins are similar in shape and notably elevated anteriorly. The body chromatophores have disappeared and their place is taken by a thick peppering of black dots over the sides. The tips of the elevated dorsal and anal fins are heavily pigmented with black (fig. 7).

PORONOTUS TRIACANTHUS (Peck). Butterfish

Distribution.—Young butterfish were taken abundantly in plankton from May 25 to Aug. 19, 1929, and from May 28 to Sept. 12, 1930. The young fish, similar to

FIGURE 5.—*Peprilus alepidotus.* From a specimen 7 mm. long.

Peprilus, were generally found in association with the coelenterates, *Dactylometra* and *Cyanea*. Butterfish 6 mm. long were secured from May 25 to July 23, indicating a late spring and early summer spawning season. The young were taken at all collecting points.

Description.—The young butterfish ranged from 1.8 to 57 mm. in length. On the basis of an extensive series of butterfish from Chesapeake Bay, the writer believes

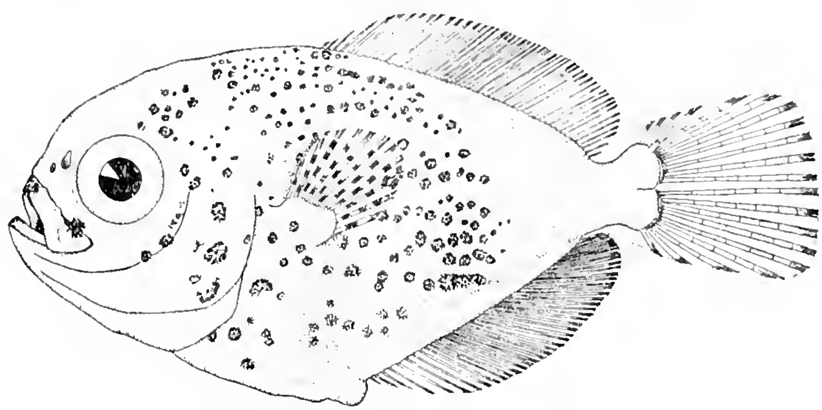

FIGURE 6.—*Peprilus alepidotus.* From a specimen 9 mm. long.

the fish represented in figures 62, 63, 64, and 65 (Kuntz and Radcliffe 1918) are not the young of the butterfish, *Poronotus triacanthus*, but most probably the young of a hake, *Urophycis*. Several fish obtained in Chesapeake Bay in 1929 are herein described as larval butterfish. Several figures of larger butterfish from Kuntz and Radcliffe (1918) are reproduced to show the gradual transformation to the adult shape.

The smallest butterfish taken in the plankton measured 1.8 mm. A fish at this length has lost the yolksac but has the larval fin fold entire. The pectorals are faintly outlined, and a few rays of the caudal are discernable. A series of anastomosed

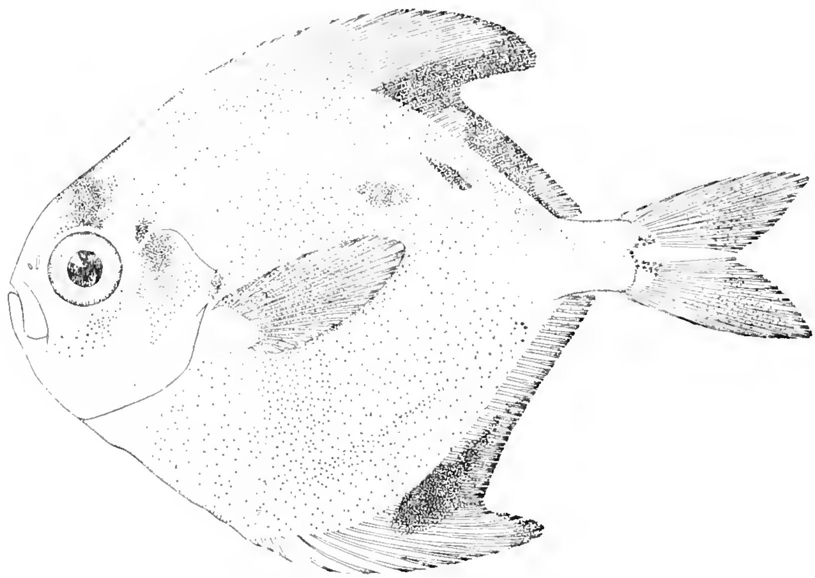

FIGURE 7.—*Peprilus alepidotus*. From a specimen 62 mm. long.

chromatophores lies along the dorsal region of the abdominal cavity. The ventral edge of the abdominal cavity and the body is sharply bordered with a solid narrow black line (fig. 8).

The young possesses a deeper body at 3.7 mm. The fin fold is still entire, although the rays of the caudal are becoming differentiated. The same arrangement

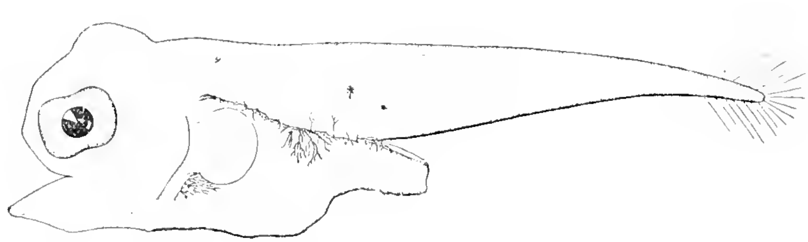

FIGURE 8.—*Poronotus triacanthus*. From a specimen 1.8 mm. long.

of chromatophores exists as in smaller fish, but an additional series of markings are now found along the ventral edge of the body from the gut to the caudal fin. Scattered chromatophores may appear at random along the sides, although never abundantly or in any definite arrangement as in young *Peprilus* (fig. 9).

Succeeding stages of development have been described by Kuntz and Radcliffe.[5] (figs. 10 and 11).

[5] Perlmutter (1939) has also recognized the erroneous descriptions by Kuntz and Radcliffe (1918) and has given figures of young butterfish 2.8 mm. and 3.5 mm. length.

POMATOMUS SALTATRIX (Linnaeus). Bluefish

Distribution.—One plankton tow on July 24, 1930 at Station B yielded four specimens of young bluefish.

Description.—The young ranged from 4 to 7 mm. in length. The bluefish at 4.3 mm. has the larval fin fold entire, although the dorsal, anal, and caudal fin rays

FIGURE 9.—*Poronotus triacanthus*. From a specimen 3.7 mm long.

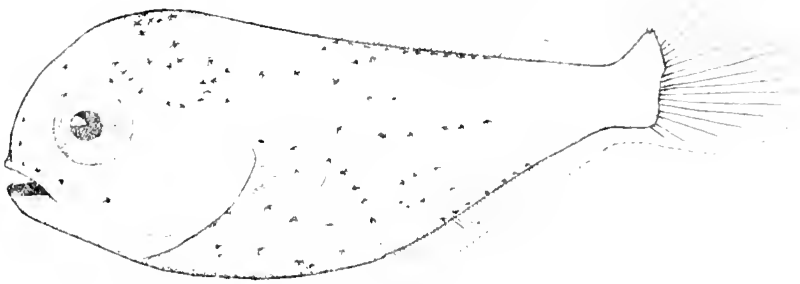

FIGURE 10.—*Poronotus triacanthus*. From a specimen 6 mm. long. From Kuntz and Radcliffe (1918).

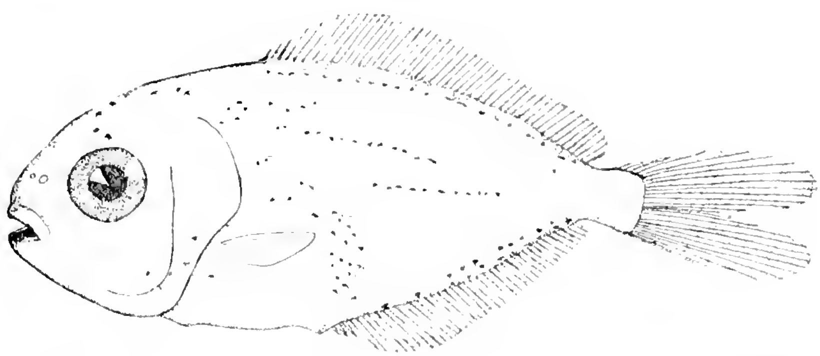

FIGURE 11.—*Poronotus triacanthus*. From a specimen 15 mm. long. From Kuntz and Radcliffe (1918).

are slightly differentiated. The yolksac is absent. Three distinctive series of black dashes occur laterally on the body; one along the dorsal ridge, another along the median line, and the other along the ventral edge. Other chromatophores occur above the abdominal cavity and on the top of the head. The teeth are well developed and appear quite diagnostic. The writer is unfamiliar with any other local fish in which the teeth are so strongly developed at such an early age (fig. 12).

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At 7.3 mm. the fish has lost its larval fin fold and the fin rays are clearly differentiated. The pigmentation remains essentially the same, but the lateral markings have become more pronounced and the dashes are now joined to form narrow black

FIGURE 12.—*Pomatomus saltatrix*. From a specimen 4.3 mm. long.

bands. The number of chromatophores on the head and on the abdominal cavity also increases (fig. 13).

A later stage at 26 mm. no longer possesses the lateral bands but the entire body

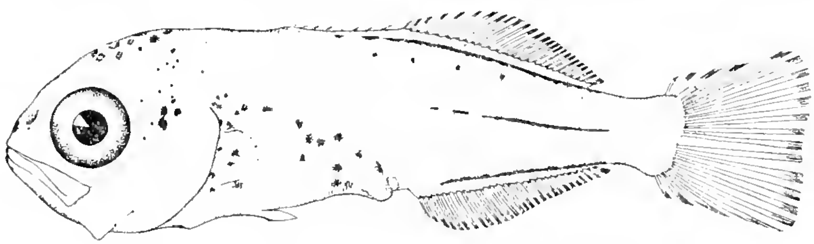

FIGURE 13.—*Pomatomus saltatrix*. From a specimen 7.3 mm. long.

is covered with fine black dots. The caudal fin has become forked and the fins, particularly the spinous dorsal, have become further developed (fig. 14).

At 72 mm. the young bluefish closely resemble the adult, except that the young fish has a silvery sheen in life and in preservation appears thickly peppered with fine

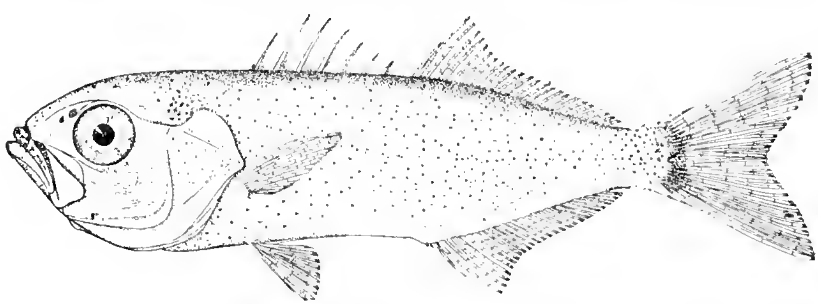

FIGURE 14.—*Pomatomus saltatrix*. From a specimen 26 mm. long.

dots (fig. 15). Both figures 14 and 15 were furnished to the writer by Samuel F. Hildebrand and Louella E. Cable. The bluefish represented in these illustrations were taken off the coast of North Carolina, near Beaufort.

***CENTROPRISTES STRIATUS* (Linnaeus).** Sea bass; Blackfish

Distribution.—Larval and early postlarval sea bass were secured during June 1929 and July 1929–30. Most young were taken in July 1929 at Station A.

Description.—The length range of the young extended from 2.5 to 9 mm. Young sea bass remain undescribed but comparison with a series of known sea bass from southern New England waters establishes the identity of the Chesapeake fish. Fin rays may be counted when the young reach 9 mm. in length. A distinctive type of pigmentation along the ventral edge of the body is characteristic of the larvae.

BAIRDIELLA CHRYSURA (Lacépède). Sand perch

Distribution.—The young of *Bairdiella chrysura* apparently are hatched largely outside of the area of collection, for only seven larval and postlarval fish were taken in the plankton. The young were secured from June 7 to July 1, 1929, principally at Stations A and B. Young fish ranging from 6 to 28 mm. were commonly taken by trawl on the muddy bottom in Little Creek in July 1930.

Description.—The planktonic fish were from 2.5 to 5 mm. in length. Larval and postlarval sand perch are recognized by two vertical bands, the first behind the head

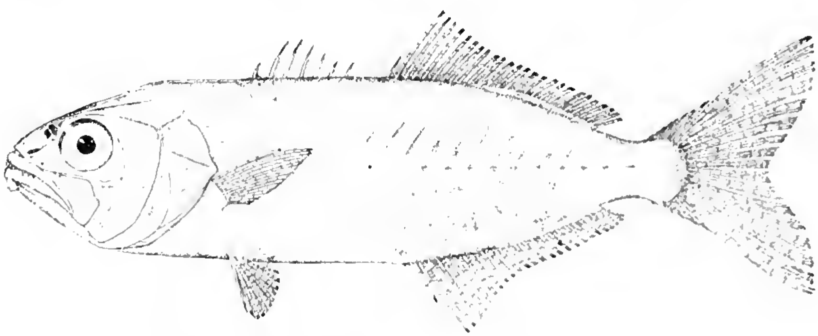

FIGURE 15.—*Pomatomus saltatrix*. From a specimen 72 mm. long.

and the second, less pronounced, about two-thirds the distance from the vent to the tip of the tail. The band nearest the tail is often weak and indistinct. Kuntz (1914) described the eggs and the young of the species.

MICROPOGON UNDULATUS (Linnaeus). Croaker

Distribution.—Notwithstanding a great abundance of juvenile croakers within lower Chesapeake Bay throughout the year, a relatively small number of larval and postlarval fish were taken in the plankton. Young fish were taken on Sept. 13, 1929, and from July 29 to Oct. 17, 1930. Practically all catches were made at stations nearest the sea.

An extended spawning period for croakers noted by Hildebrand and Cable (1930) in North Carolina evidently occurs also in the region of Chesapeake Bay.

Description.—The young croakers ranged from 1.5 to 15 mm. in length. Larval croakers and larval gray sea trout appeared together in the plankton on several occasions in late July 1930. The two species closely resemble each other when newly hatched. The young croaker at 2 mm. in length, however, possesses a much deeper body than the sea trout at the same size. The croaker usually has a dark, crescent-shaped area above the abdominal cavity, while this marking is usually not as distinct in young sea trout. The pronounced chromatophore at the base of the anal fin, found on all young sea trout, is not especially pronounced on young croakers, although the latter do have a series of ventral chromatophores that greatly resemble comparable markings on the sea trout. The ventral chromatophores on the croaker are more numerous, however, and more evenly spaced than on the young sea trout. A perceptible difference in the shape of the head and snout is also evident in the two species. Larval and young croakers have been described by Welsh and Breder (1923), Pearson (1929), and Hildebrand and Cable (1930).

MENTICIRRHUS AMERICANUS (Linnaeus). Kingfish; Whiting

Distribution.—The young of *Menticirrhus americanus* were secured abundantly from June 12 to Sept. 13, 1929, and from July 21 to Sept. 2, 1930. The largest collections were made at Stations A, B, and C.

Description.—The length-range of young extended from 1.5 to 7 mm. Young fish, 3 to 7 mm. long, are characterized by profuse jet-black chromatophores scattered over the entire body. Under 3 mm. pigmentation is restricted to an area along the median line of the body. The jaws at all sizes are tipped with black. Fin-ray counts are possible at 5 mm.

The young of *M. americanus* may be confused with the young of *M. saxatilus*, a closely related species. However, a comparison with a description of young *saxatilus* by Welsh and Breder (1923) and of *americanus* by Hildebrand and Cable (1934) indicates that the fish from Chesapeake Bay most probably represent the young of *americanus*.

CYNOSCION REGALIS (Bloch and Schneider). Gray sea trout; Weakfish; Squeteague

Distribution.—Over 4,000 young gray sea trout were taken in plankton hauls from May 25 to July 25, 1929. The majority of fish were secured at Stations A, B, C, and D during the latter half of June 1929. In 1930 planktonic sea trout were taken from May 21 to Aug. 1. The seasonal distribution of the young sea trout thus corresponds closely for 2 successive years (table 1 and fig. 23).

The young of the gray sea trout were taken in 55 subsurface tows, with an average of 67 fish to a tow, and occurred in 13 surface tows, with an average of 25 fish to a tow. While more subsurface than surface tows were made, a comparison of simultaneous surface and subsurface hauls at the same station indicates that in most instances the subsurface tow contained far more young fish than the surface tow.

The planktonic sea trout decreased in abundance at those stations farther within the bay, compared with localities nearer to the sea. However, protected coves and creeks in the vicinity of Lynnhaven Roads yielded large quantities of young fish (8 mm. and over) just leaving the planktonic existence for a semidemersal life. The young fish were found on the bottom, where they were readily obtainable by trawl and seine. Various creeks from Lynnhaven Roads to the York River also had their complement of young sea trout during early summer, all young probably originating on spawning grounds off the entrance to the bay.

Description.—The planktonic sea trout ranged from 1.5 to 7 mm. in length. At a length of 1.8 mm. they are characterized by a very elongated slender body and by a large eye covering most of the side of the head (fig. 16). The larval fin fold is entire but the pectorals are differentiated, although indistinct. The greatest depth of the body is contained 4.0 to 4.5 times in the length to the end of the notochord. A series of small black chromatophores is present along the ventral edge of the body extending from the vent to the tail. A chromatophore at midcaudal length, or at the primitive base of the anal, is consistently more pronounced than the rest. Several small chromatophores are found along the ventral edge of the abdomen. No other color markings are evident. The yolksac has been absorbed at 1.8 mm., although Welsh and Breder (1923) found a yolksac present on young of 2.2 mm. length taken in Delaware Bay.[6]

The young sea trout at 3 mm. has the body depth proportionately increased. The only color marking is the series of chromatophores along the ventral edge of the body. All chromatophores become more pronounced, particularly the one at midcaudal length. The fin fold remains entire. Minute teeth, usually evident at this length, help to distinguish the young sea trout from some related Sciaenidae such as the sand perch, *Bairdiella chrysura*, and the croaker, *Micropogon undulatus* (fig. 17).

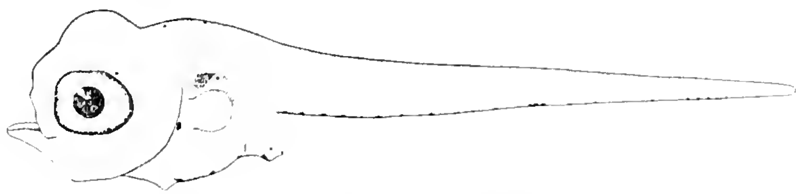

FIGURE 16.—*Cynoscion regalis*. From a specimen 1.8 mm. long.

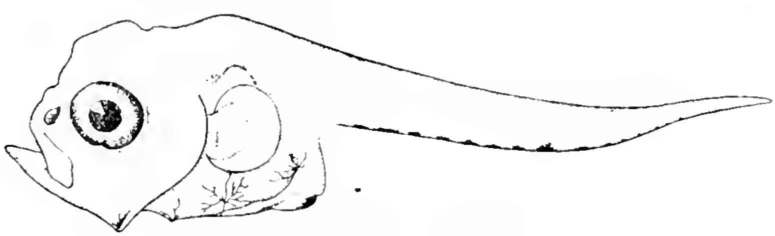

FIGURE 17.—*Cynoscion regalis*. From a specimen 3 mm. long.

The young sea trout at a length of 4.6 mm. has the caudal fin rays evident and shows a slight differentiation of the anal and dorsal fin rays. The fin fold remains entire. The greatest depth of the body is contained 2.7 to 3.0 times in the length to the end of the notochord. The series of ventral chromatophores has largely disappeared, with the exception of the spot at the base of the anal which appears enlarged and anastomosed. This anal spot is significant for it apparently distinguishes the young of *C. regalis* from both *C. nebulosus* and *C. nothus*. Markings on the abdominal cavity are also pronounced. The mouth is more oblique and the teeth further developed (fig. 18).

The young fish is quite readily identified at 8.2 mm. for the anal fin rays are usually distinct, while the soft dorsal rays are almost fully differentiated. The fin fold remains entire to the caudal fin. The greatest depth of the body is now contained about 2.8 times in the standard length. The snout is quite blunt, the lower jaw

[6] All length measurements in this paper are referable to preserved specimens and denote total length.

projecting but little. The chromatophore at the base of the anal is extremely pronounced, while the markings on the abdominal cavity are somewhat reduced in size and intensity (fig. 19).

At 10.5 mm. the young have usually passed out of a planktonic existence and have adopted a semibottom habitat in quiet, muddy coves and creeks. Lateral chroma-

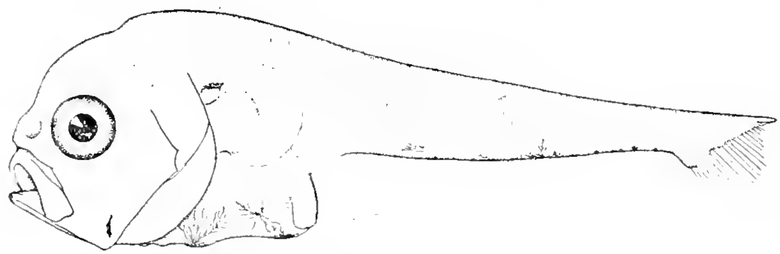

FIGURE 18.—*Cynoscion regalis.* From a specimen 4.6 mm. long.

tophores now profusely appear, although the spot at the base of the anal still persists. The fin fold has nearly disappeared, while the caudal fin has changed to a symmetrically pointed shape (fig. 20).

FIGURE 19.—*Cynoscion regalis.* From a specimen 8.2 mm. long.

At 17 mm. in length the young are characterized by the presence of heavy lateral chromatophores arranged in four indistinct vertical bands or saddles. The chromatophore at the base of the anal has now disappeared. The amount and intensity of

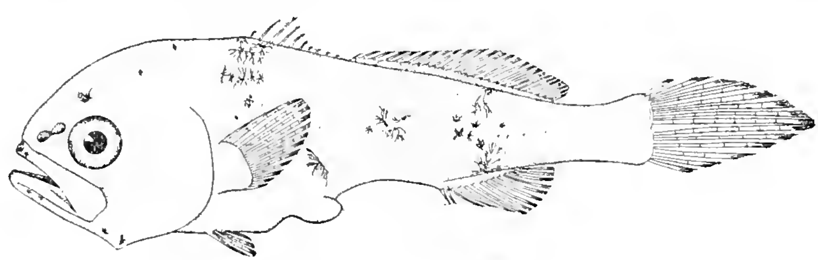

FIGURE 20.—*Cynoscion regalis.* From a specimen 10.5 mm. long.

pigmentation along the sides of the body seem to depend largely on the type of environment in which the fish is found. Young taken on sandy and light bottom do not have as much pigmentation as fish secured on a muddy, or dark bottom. Tracy (1908), for instance, found several young gray sea trout in sunken canvas bags off Rhode Island which at 6.5 and 12.5 mm. in length possessed more extensive pigmentation than fish of corresponding sizes taken in Chesapeake Bay. The greatest depth of the body is contained about 3.3 to 3.4 times in the standard length. In both larval and postlarval stages of the gray sea trout the body continues to increase in proportionate depth until at about 17 mm. it commences to decrease. In other words, the body becomes

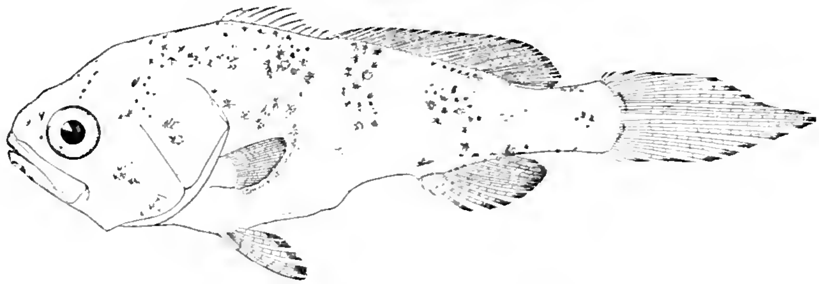

FIGURE 21.—*Cynoscion regalis*. From a specimen 17 mm. long.

progressively stouter and shorter in proportion to length from the slender, newly hatched fish up to about 17 mm. in length, while after 17 mm. is reached the body tends to become more slender and elongate (fig. 21).

Young sea trout over 17 mm. in length are characterized largely by four distinct saddles on the body. Both Eigenmann (1901) and Breder and Welch (1922) have described various stages of the young sea trout (fig. 22).

Growth.—Juvenile sea trout were found to grow rapidly during their first summer. Planktonic young ranging from 8 to 10 mm. soon settle to the bottom after entering

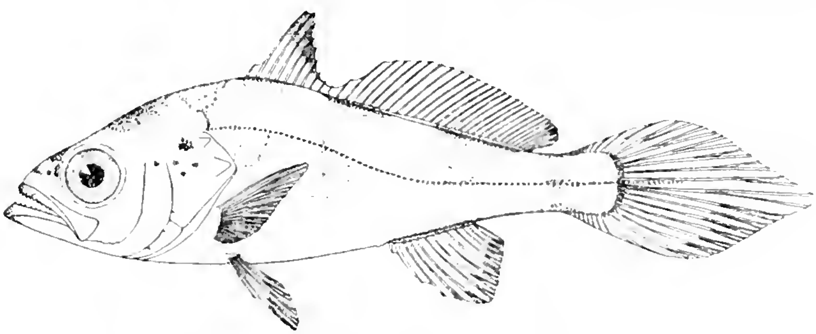

FIGURE 22.—*Cynoscion regalis*. From a specimen 32 mm. long. From Welsh and Breder (1923).

Chesapeake Bay. Brackish creeks and coves are favorite shelters for the young. Collections of fish at varying intervals during 1929–30 indicate that the young attain an average length of 16 to 20 cm. (6.3 to 7.8 in.) by the end of the first year. A growth diagram of young sea trout collected during their first summer and following spring is shown in figure 23.

The length-range of young fish taken during the summer of 1930 is considerably less than for fish secured in 1929. This difference appears largely due to size selection by the type of fishing gear employed. Seines were used exclusively during 1929 and allowed a greater escapement of the smaller fish than occurred in 1930, when fine-meshed trawls were employed. Similarly, year-old fish taken during the spring of 1930 by commercial pound nets were larger than fish of the same approximate age taken during June 1930 by experimental trawl. Unfortunately, larger series of young collected at regular intervals at various localities and with all types of gear could not be obtained in order to show the selectivity of the gear and the effect of environment on the size distribution of the young fish.

Notwithstanding limitations in the sampling of the juvenile sea trout population, it is believed that the average growth during the first year of life in lower Chesapeake Bay is reliably shown by figure 23. The young sea trout evidently have a length range of at least 10 cm. at the end of the first year of growth. Any clear-cut growth curve must involve large collections of young from diverse localities and by varied types of collecting gear.

Eigenmann (1901) stated that juvenile sea trout (squeteague) doubled their length during July and August. This observation appears substantiated for Chesa-

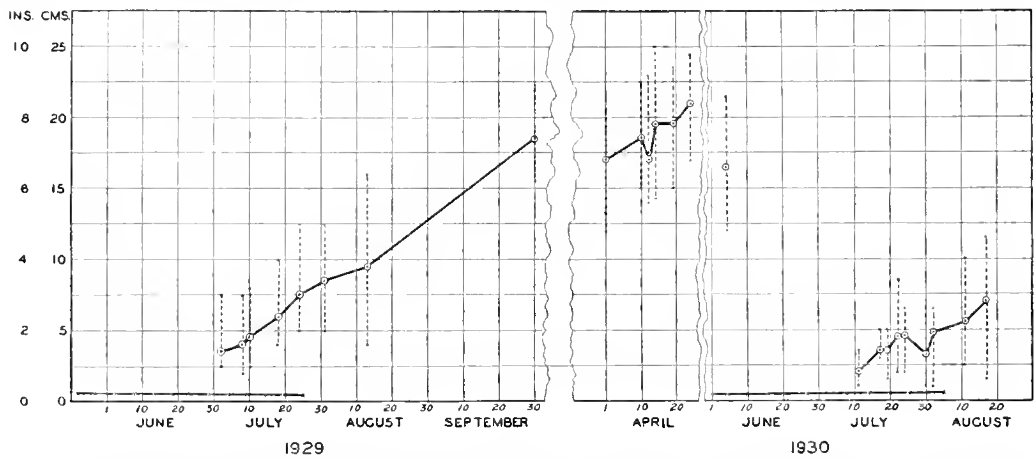

FIGURE 23.—Spawning period and juvenile growth of gray sea trout, *Cynoscion regalis*, in lower Chesapeake Bay. A circle is placed at the mean length of the frequency distribution represented by the vertical dotted line. The horizontal solid line at the half-centimeter unit shows the approximate spawning period as indicated by collections of larval fish under 6 mm. in length. Young fish taken in April 1930 were secured by commercial pound net. All other fish were captured with experimental gear.

peake Bay fish taken on July 2, 1929, having an average length of 3.5 cm. Apparently these fish reached an average length of 8 to 9 cm. by the end of the month. Young fish in all instances were secured at the same locality and by the same fishing gear.

Welsh and Breder (1923), on the basis of length-frequency distributions from Delaware Bay, reached the conclusion that sea trout, averaging 3 cm. on July 1, should be 17 cm. in length on October 1. Such growth also appears substantiated by the collections in lower Chesapeake Bay.

Young sea trout appear to gather in schools in autumn at various places along the coast for departure to their winter habitat. For a brief period before departure they frequently appear in considerable numbers in pound nets. In table 3 are listed the lengths of young sea trout secured by R. A. Nesbit from pound-net catches in various localities.

Many juvenile sea trout remain in lower Chesapeake Bay during the greater part of their first year of life. Juvenile fish were obtained by the writer in the bay from

March to October, while Hildebrand and Schroeder (1928) found young in November and December. Although some fish may remain in the deeper waters throughout the winter, most young seek the warmer offshore oceanic water. Trawlers operating off the Virginia and North Carolina coasts during the winter of 1930–31 secured many juvenile sea trout from 13 to 17 cm. in length (Pearson, 1931).

Hildebrand and Cable (1934) have presented extensive data on the growth of gray sea trout at Beaufort, N. C.

TABLE 3.—*Length-frequency distributions of gray sea trout,* Cynoscion regalis, *secured from pound nets at various localities along the Atlantic coast by R. A. Nesbit*

Length in centimeters	North Carolina		Chesapeake Bay			Exmore		Wildwood			Beach Haven		Northern New Jersey					Fire Island				Montauk				
	1933	1934	1931	1933	1934	1933	1934	1930	1932	1934	1930	1931	1928	1929	1930	1931	1934	1928	1929	1930	1931	1929	1930	1931	1932	1934
9.0	1																									
10.5	3																									
11.0	2																									
11.5	1																									
13.0						1																				
13.5	1																		1			1		1		
14.0	1																					2	1			
14.5	1																		4			5	1	1		
15.0	1					2													12			2	2	1		
15.5	9					2				1									14			11	2			
16.0	9				1	1				1									27			10	3	1		
16.5	13	2			3	5				6					1		3		31			11	7			2
17.0	15				3	14	1			8					2		6		48	1		8	11	2		10
17.5	8	2				17	2			9		1	1		8		3	2	100	1	1	13	10	1	2	19
18.0	12	1			3	25	4			18			5		4		8		156	2		7	16	6	9	30
18.5	11	5			9	44	9			26			11	1	7	1	12	1	136	3	2	17	20	2	11	44
19.0	15	6			7	57	26			28			16	1	9		20	3	172	4	1	22	21	4	23	49
19.5	4	8			9	71	24	2	3	25			9		9		30	1	175	3	1	26	16	8	25	54
20.0	3	6	1		15	56	21	1	4	30	1		39		9	1	32	3	208	3	3	12	27	7	20	30
20.5	3	5		2	11	65	11	5	9	24			32		13		42	6	158	8	4	9	15	7	12	29
21.0	2	4		1	2	51	9	5	13	29			21		13	2	49	2	89	3	1	11	28	9	5	9
21.5	1	9			3	46	3	4	5	31			22		17	2	41	4	91	14	4	3	6	12	6	4
22.0	2	6				16	2	6	4	24	2		18	1	17	4	26	4	98	8	4	6	12	14	5	4
22.5		4				17	1	4	2	7	1		6	1	18	6	22	1	46	11	10	2	7	9	4	2
23.0		1				7	1	5	3	5			6		5	3	14		33	12	4	2	11	18	2	1
23.5		1				2		6	3	2	1		3		5	6	8		35	9	9		3	16	2	
24.0						3		4	1	1			4		7	6	1		15	6	12		2	16	1	
24.5								4		3			4	1	1	2	1		5	3	4	1	2	12		
25.0										2	1		1		1	7			7	1	4		1	10	1	
25.5										1													1	4		
26.0																								2		
26.5																								1		
27.0																								3		
27.5																								1		
Total	118	60	1	3	66	502	114	46	47	281	6	1	198	5	146	40	318	27	1,661	92	64	181	225	168	128	287

PRIONOTUS sp. Sea robin

Distribution.—The young of the genus, *Prionotus*, were taken abundantly from June 19 to July 29, 1929, and from July 21 to July 29, 1930, principally at points adjacent to the sea.

Description.—The lengths of the young ranged from 1.5 to 11 mm. Positive specific identification of these young *Prionotus* could not be made. On the basis of descriptions of *P. carolinus* by Kuntz and Radcliffe (1917), the writer is inclined to believe that the Chesapeake Bay fish may belong to the closely related species, *P. evolans*. The larval stages of both species are perhaps quite similar and separation may prove impossible.

TAUTOGA ONITIS (Linnaeus). Tautog

Distribution.—A few larvae of the tautog were secured at several localities from May 6 to May 23, 1930.

Description.—The lengths of the larvae ranged from 2 to 3.5 mm. Various stages of the young tautog have been described by Kuntz and Radcliffe (1918). Careful examination of larval tautogs is essential in order not to confuse the species with the young of the oysterfish, *Gobiesox strumosus*, which it strongly resembles.

MICROGOBIUS THALASSINUS (Jordan and Gilbert). Scaled goby

Distribution.—The young of this goby occurred in the plankton during July and September 1929, and August and September, 1930. Postlarval and juvenile fish from 9 to 36 mm. in length were taken by trawl in Little Creek during the summer. All gobies were secured at stations well within the bay.

Description.—The young ranged from 4.5 to 9 mm. in length. They can be distinguished by a series of 14 to 16 solid black dots along the edge of the anal fin. These dots are also evident along the ventral edge of the body prior to the formation of the anal fin. The union of the ventral fins to form the ventral disk occurs at about 10 mm.

The young have been described by Hildebrand and Cable (1938) under the name of *Microgobius holmesi.*

GOBIOSOMA sp. Naked goby

Distribution.—The young of this genus of gobies occurred abundantly in the plankton from June 6 to Sept. 9, 1929, and from July 29 to Oct. 3, 1930, at all localities. The period of maximum abundance was in July and August. Hildebrand and Schroeder (1927), on the basis of adult fish collections, observed that spawning of *G. bosci* takes place from June to October, and that the height of the spawning period probably occurred in July.

Description.—The length-range of the young extended from 2 to 14 mm. Kuntz (1916) and Hildebrand and Cable (1938) have described the young of the genus. The transparency of young fish is quite characteristic.

ASTROSCOPUS GUTTATUS (Abbott). Stargazer

Distribution.—Several pelagic young of this fish were taken in July 1929 and 1930 at Station A. Larger young were taken by seine during summer along sandy beaches within the lower bay.

Dcscription.—The fish ranged from 2.5 to 5 mm. in length. The young stargazer at 4.9 mm. has the eyes laterally placed, as contrasted with the dorsally situated eyes of the adult. A heavy pigmentation covers the body from the origin of the pectorals to the vent. The soft dorsal, anal, and caudal fins are slightly differentiated at this size, although the larval fin fold remains entire (fig. 24).

A marked change in the general shape and pigmentation of the body occurs at a length of 23 mm. The eyes have slowly migrated dorsally; the mouth becomes more vertical; the lips fringed; and the pigmentation more scattered. The fin rays become fully differentiated and the pectorals much enlarged. Two bony processes, apparently originating from the frontal bones of the skull, project from the surface of the skull (fig. 25). The migration of the eyes to a dorsal position is completed soon after 25 millimeters is reached (fig. 26).

HYPSOBLENNIUS HENTZ (Le Sueur). Blenny

Distribution.—The planktonic young were found widely distributed from May 8 to Sept. 13, 1929, and from May 16 to Nov. 22, 1930. The greatest abundance was noted during June and July. This young blenny occurred in more plankton hauls than any other species, but the number taken in any one tow was never large.

Description.—The length-range of the young extended from 2 to 8 mm. The larvae may be distinguished by the elongated black pectoral fins and the series of

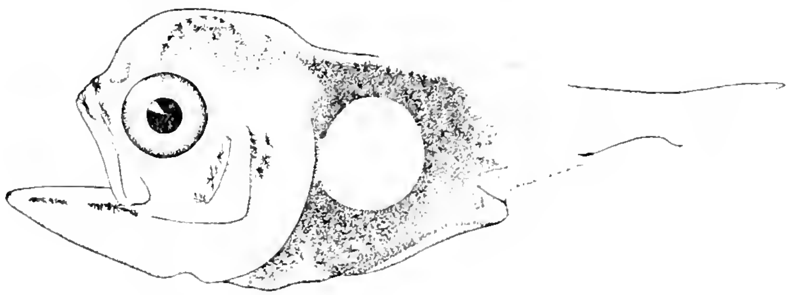

FIGURE 24.—*Astroscopus guttatus.* From a specimen 4.9 mm. long.

black dots along the ventral edge of the body posterior to the vent. Fin-ray counts are not definite until the fish reaches 8 mm. in length.

The young have been described by Hildebrand and Cable (1938).

RISSOLA MARGINATA (De Kay). Cusk eel

Distribution.—The young of the cusk eel were taken from July 1 to Sept. 13, 1929, and from July 21 to Oct. 3, 1930.

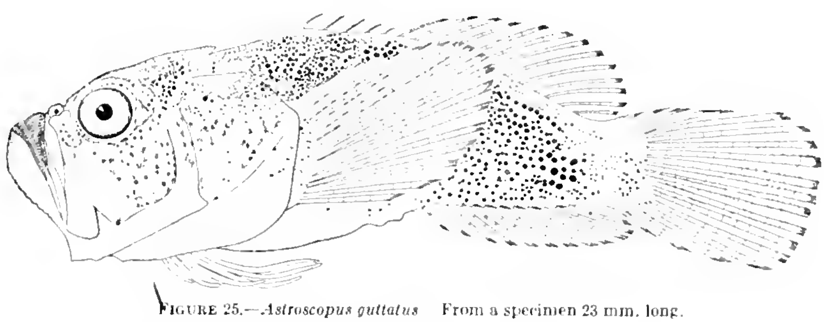

FIGURE 25.—*Astroscopus guttatus* From a specimen 23 mm. long.

Description.—The length range of young extended from 2 to 7.5 mm. The young are undescribed but can be distinguished by an extremely elongated body that possesses two narrow, parallel black lines along the ventral edge.

GOBIESOX STRUMOSUS Cope. Oysterfish; Clingfish

Distribution.—The spawning of the oysterfish occurs principally in the spring. Young fish were taken from May 2 to Aug. 1, 1929, and from May 6 to Aug. 29, 1930. The largest collections were obtained during May. Hildebrand and Schroeder (1928) recorded adult fish with well developed gonads during April and May in Chesapeake Bay.

Apparently the young oysterfish soon adopt the characteristic bottom habitat, for no fish over 45 mm. were obtained in the plankton. The young were taken largely over oyster reefs, where spawning probably occurs.

Description.—The young ranged from 2 to 4.5 mm. in length. They are rather broad, anteriorly depressed and posteriorly compressed, somewhat similar to the adult. The body pigmentation is heavy, consisting of diffuse chromatophores very similar in arrangement to those on the young tautog (*Tautoga onitis*). The posterior caudal region of both species remains free from pigment.

Larval *Gobiesox* resembles larval *Tautoga* closely. Care is essential in distinguishing the larval fish of these two species, which are at times found to occur simultaneously in the plankton. Young *Gobiesox* possesses a less distinctive chromatophore pattern and the pigmentation does not extend so far back on the body as in *Tautoga*. *Gobiesox* also has a shorter gut and lacks the black-tipped upper jaw most characteristic of young *Tautoga*.

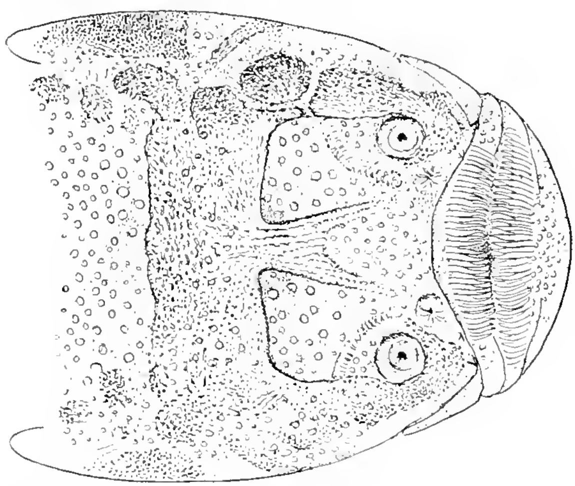

FIGURE 26.—*Astroscopus guttatus*. Dorsal surface of head; from a specimen 235 mm. long. From Hildebrand and Schroeder (1928).

SPHOEROIDES MACULATUS (Bloch and Schneider). Puffer

Distribution.—The young of the puffer were taken from June 5 to Aug. 15, 1929, and from May 9 to Sept. 2, 1930.

Description.—The lengths of the fish ranged from 1.5 to 4 mm. The early stages of the puffer have been described by Welsh and Breder (1922).

LOPHIUS PISCATORIUS Linnaeus. Goosefish

Distribution.—The young of this species were taken in small numbers during May 1930 at Stations A, B, and C. Since the adult fish are rarely taken within the bay, spawning probably occurs offshore. Hildebrand and Schroeder (1927) secured newly hatched young on June 10, 1916, in the lower bay.

Description.—The young ranged from 3 to 5.5 mm. in length. Bigelow and Welsh (1925) have described the larvae of the species.

SUMMARY

1. The area of study is located at the mouth of Chesapeake Bay and is bounded roughly by Cape Charles and Cape Henry on the east, Lynnhaven Roads on the south, Old Point Comfort on the west, and Back River Light on the north.

2. A series of collecting stations was visited, usually weekly in summer and biweekly in winter, to determine the seasonal and geographic distribution and variation of the marine plankton. The present paper deals only with the young fishes taken in this plankton.

3. Forty-five species of fishes were recognized in the plankton. Thirty-one species were identified and 14 remain unidentified. Larval and postlarval stages of the gray sea trout, or weakfish, *Cynoscion regalis;* the bluefish, *Pomatomus saltatrix;* the harvestfish, *Peprilus alepidotus;* the butterfish, *Poronotus triacanthus;* and the stargazer, *Astroscopus guttatus,* are described and figured.

4. Collections of juvenile gray sea trout by seine and trawl indicate that this food fish attains an average total length of 16 to 20 cm. (6.3 to 7.8 in.) at the end of its first year of growth in lower Chesapeake Bay.

5. Brief distributional and descriptive records for the planktonic young of 31 species of marine fishes are given.

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THE SALMON RUNS OF THE COLUMBIA RIVER IN 1938

By WILLIS H. RICH

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ABSTRACT

EXCEPTIONAL DATA are available for the study of the salmon runs of the Columbia River in 1938. Detailed figures on catch were supplied by Oregon and Washington in such form that they could readily be combined with the counts at Bonneville Dam to provide a basis for estimating the escapement. Tables show the catch of each species for each week in each of six zones, and the counts at Bonneville and Rock Island dams. The general course of the run of each species is shown. The numbers of fish bound for the spawning grounds above Rock Island Dam are estimated as follows: Chinook salmon entering Columbia River before May 1, 4 percent; during May, 6 percent; June and July, 15 percent; and August to December, 1 percent. Blueback salmon entering the river during the above periods, 40 percent. Steelhead trout entering the river during June to September, 1 percent; during the rest of the year, 10 percent. Fishing intensities are shown by escapement to catch ratios. Percentages of chinook salmon escapement are less than 15 during May; 17 during June and July; and 33 during the remainder of the year. The June and July runs are now greatly depleted, and an important part of these runs spawns above Rock Island Dam. The blueback salmon escapement is about 20 percent, and of steelhead trout about 33 percent. Weekly and seasonal closed periods are shown to be almost entirely ineffective for increasing the spawning escapement. Exploitation is further increased by the intensive troll fishery conducted from Monterey Bay to southeastern Alaska. Chinook salmon are also subjected to a sport fishery of considerable importance. Main runs of salmon to the Columbia River are practically unprotected and are fished with destructive intensity.

THE SALMON RUNS OF THE COLUMBIA RIVER IN 1938[1]

By Willis H. Rich, *Professor of Biology, Stanford University and Director of Research, Fish Commission of Oregon; in cooperation with the Division of Fishery Biology, Fish and Wildlife Service*

CONTENTS

INTRODUCTION

With the announcement of plans for the construction of the Grand Coulee Dam on the Columbia River in eastern Washington, questions were raised as to the effect that this development would have on the salmon runs and as to the possible means for preserving those salmon populations that had formerly reproduced in the area above the site of the dam. Funds were provided by the United States Bureau of Reclamation to the Washington State Department of Fisheries for the purpose of making a preliminary study of possible means for preserving the runs. A report (Washington State Department of Fisheries 1938 [2]) was presented in January 1938, in which the chief recommendation was for an extensive system of artificial propagation. Later the Bureau of Reclamation appointed a board of consultants to review the proposed plan and to make recommendations. In their report (Calkins, Durand, and Rich 1939 [3]) these consultants recommended, substantially, the plan proposed by the Washington Department of Fisheries.

In the preparation of this report the writer made an analysis of the available data on the salmon runs of 1938 for the particular purpose of determining the relative importance of those fractions of the runs that would be affected by the construction of the Grand Coulee Dam. Various other facts bearing upon the state of the Columbia River salmon resources and the problems of their conservation were developed during the course of this analysis and it has seemed desirable to amplify the part of the

[1] Contribution No. 7, Department of Research, Fish Commission of Oregon.

[2] Report of the preliminary investigations into the possible methods of preserving the Columbia River salmon and steelhead at the Grand Coulee Dam. 121 pp. U. S. Bureau of Reclamation, Washington. (Processed.)

[3] Report of the board of consultants on the fish problems of the upper Columbia River. 83 pp. U. S. Bureau of Reclamation, Denver, Colo. (Processed.)

report that treats of the 1938 run and to present it as a separate publication. For this purpose the data presented in the original report of the board of consultants have been supplemented by data that have become available since the original report was prepared. At that time no catch data were available later than the close of the "spring" fishing season on August 25. In this revision the catch data for the "fall" season also have been included. Various omissions and minor changes have been made, and some additional analysis is given.

Acknowledgment is due the Bureau of Reclamation and the writer's associates on the board of consultants for permission to use here the material of the original report. Acknowledgment also is due the Washington Department of Fisheries, the Fish Commission of Oregon, the United States Army Engineers, and the Bureau of Reclamation for many data used in the original report and in this revision.

THE COLUMBIA RIVER SALMON FISHERY

Five species of salmon are taken in the commercial fishery on the Columbia River. These are (1) chinook salmon (*Oncorhynchus tschawytscha*), (2) silver salmon (*O. kisutch*), (3) blueback salmon (*O. nerka*), (4) chum salmon (*O. keta*), and (5) steelhead trout (*Salmo gairdnerii*).

Fishing is permitted throughout the year except during March and April, and during the period from August 25 to September 10. The open season from May 1 to August 25 is spoken of as the spring season, and that from September 10 to March 1 as the fall season. Comparatively few fish are taken during December, January, and February, however, so that the fall season is practically limited to the period from September 10 to about the end of November. In addition to these seasonal closed periods there is a weekly closed period extending from 6 o'clock Saturday evening until 6 o'clock Sunday evening, effective during the spring open season.

Because the estimate of the intensity of the fishery is based on the ratio of the commercial catch to the fish passing Bonneville Dam, it is important to consider the relative extent of spawning which, for each species, takes place above and below this point. Obviously, if a large proportion of the fish of any one species, population, or group of populations spawns below Bonneville Dam, estimates of relative spawning escapement based upon the number of fish passing Bonneville will be in error.

Practically all the bluebacks spawn above Bonneville. As is well known, their habit is to spawn only in lakes or the tributaries of lakes in which the young remain for 1 or more years before making the seaward migration, and no lakes typical of those in which bluebacks spawn are to be found in the tributaries of the lower Columbia.

The chinooks spawn in nearly all the accessible tributaries of the river, both above and below Bonneville; a fact certain to lead to some error. With one exception, however, this error is probably negligible during the main part of the run because it is chiefly the late fall fish that spawn in the lower tributaries. The exception is the considerable run of chinooks that ascends the Willamette River in April and early May. There are, unfortunately, no reliable estimates of the extent of this run, but it forms the basis for an extensive sport fishery in the Willamette River, especially just below the falls at Oregon City. No commercial fishing is permitted in the Willamette River itself and the peak of the run is ordinarily past Oregon City by the opening of the season on May 1. Although some of these Willamette River chinooks are undoubtedly taken in the commercial fishery in the Columbia below the mouth of the Willamette, it does not seem likely that these constitute a large percentage of the total commercial catch. It is believed, therefore, that error in the estimates of fishing intensity of chinooks, due to spawning in the tributaries that enter the Columbia below Bonneville Dam, is relatively small, even during the first few weeks of the spring open season. After about the middle of May it seems reasonably certain that there is very little error due to this cause until at least the first of August, at which time some fish that will eventually spawn in the smaller tributaries below Bonneville Dam begin to enter the river.

In none of these lower tributaries is there a large run of spawning fish while the count of fish passing Bonneville is at its peak during August and September. These facts indicate clearly that, even during these months, the error in the estimate of fishing intensity based on a comparison of catch with the count at Bonneville will not be serious. As the season advances, however, progressively larger percentages of the fish entering the river are destined to spawn in the lower tributaries. Although the total number of fall fish spawning below Bonneville Dam is probably not large compared with the number spawning above the dam, the error will tend to increase, and great dependence cannot be placed on the results of the study of the late fall fish.

Steelhead trout spawn generally throughout the accessible tributaries, but apparently are more abundant in the upper than in the lower streams. In the case of silver and chum salmon, a very large proportion of the spawning occurs in the tributaries below Bonneville Dam, so that the ratio between the count at the dam and the catch gives no reliable indication of the intensity of the fishery.

This report deals primarily with the salmon runs of 1938 and it is to be hoped that similar studies, either by this writer or by others, will be made of future runs for which similar data will be available. As a part of the "frame of reference" into which are placed these studies of the runs of individual years, however, it is important to present something of the earlier history of these runs. This has been done in some detail elsewhere (Craig 1938 [4]; Oregon State Planning Board 1938 [5]; Craig and Hacker 1940; and Rich 1940b) and there is presented here only a graph showing the average annual catch of each species for each 5-year period. The data for this graph have been taken from Craig (1938), and recent numbers of the Pacific Fisherman Year Book. Previous to 1888 there was no segregation of the salmon catch by species, but there can be no doubt that chinooks formed the bulk of the catch. For the first 2 decades during which the pack was segregated the chinooks formed about 80 percent of the total, and it has been assumed that approximately the same percentage existed prior to 1888. No attempt has been made to estimate the catch of the other species previous to the period 1890–94. The catch in pounds has been estimated from the figures for the canned and mild-cured packs, which include a large part of the total. Further details may be found in the several references given.

Figure 1 shows the rapid growth of the industry during the first 2 decades after its inception, a period of 35 or 40 years in which the catch of chinook salmon fluctuated from about 20,000,000 to 30,000,000 pounds and a final period of some 20 years in which there has been a constant decline. In all probability this decline is an indication of true depletion; that is, a reduction in productivity below the point that can be maintained over a long period of time. The picture is complicated by the existence of an extensive oceanic fishery extending from Monterey Bay to southeastern Alaska, which draws heavily upon the supply of Columbia River chinooks (Rich 1941).

[4] Memorandum regarding fishing in the Columbia River above and below Bonneville Dam. 16 pp., U. S. Bureau of Fisheries, Washington. (Processed.)

[5] Commercial fishing operations on the Columbia River. 73 pp. Oregon State Planning Board, Portland, Oreg. (Processed.)

The catch within the river does not, therefore, represent the entire productivity of the runs of this species, but with available data it is not possible to determine with much accuracy what this total productivity actually is. The constant decline of the last 20 years, however, taken in connection with data presented in this report, certainly warrants the conclusion that the chinook runs are seriously depleted.[6] We shall show below that the present exploitation of these depleted runs is being conducted with an intensity so great that it can only lead to disaster in the not far distant future unless the present trends can be altered.

The blueback salmon catch for both of the first 2 periods shown in figure 1 is approximately twice that of the succeeding periods, and there is some reason to think that the abundance of blueback salmon previous to 1890 was at least the equal of that

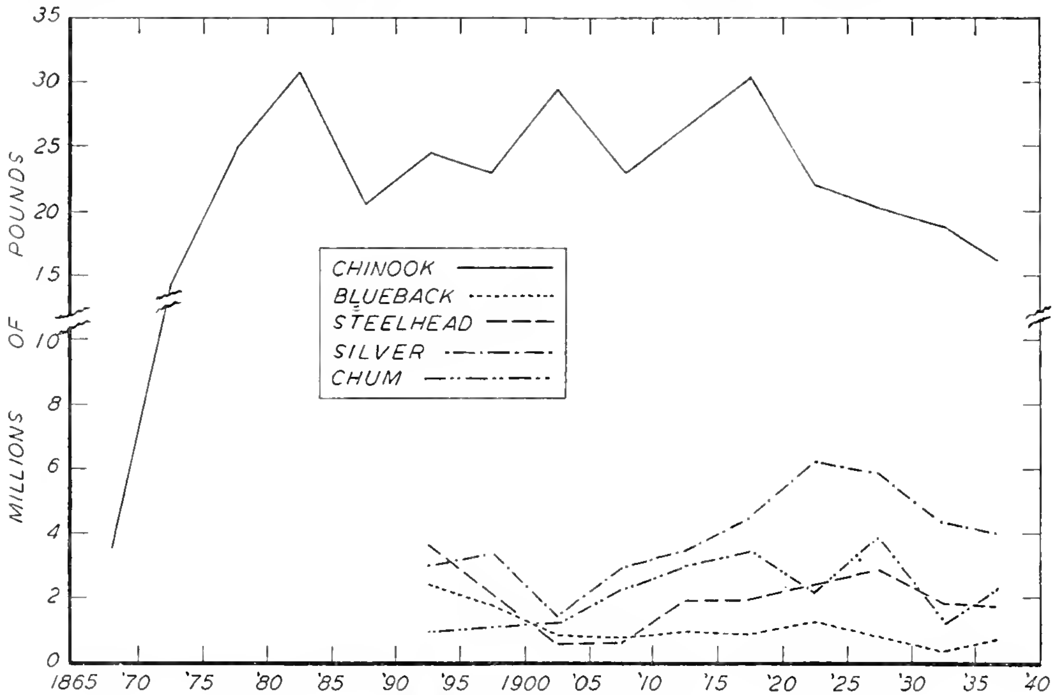

FIGURE 1.—Average annual catch by 5-year periods of chinook salmon, 1866–1938; and of blueback, silver, and chum salmon; and steelhead trout, 1891–1938.

which existed during the decade of the 90's. Since 1900, however, there has been little change—the trend is almost horizontal. These facts imply that this species originally was fairly abundant in the Columbia River, but that this early abundance was sharply reduced about 1900, and since that time there has been comparatively little change. This species almost universally spawns in or above lakes and it seems quite possible that the damming of lakes for use as reservoirs without providing adequate fishways, and the unrestricted use of unscreened irrigation ditches, were chiefly responsible for the depletion.

In figure 1 considerable fluctuation is shown in the estimated catch of steelhead trout, especially in the early years of the record, but there is little evidence of a marked

[6] Since this report was in page proof an additional study of these data has been made using the methods of the control chart as developed by Shewhart, Deming, and others, for the control of quality in manufactured products. The results show conclusively that the productivity of the chinook fishery since 1925 has been at a distinctly lower level than was maintained during the period 1876 to 1920. These will be published elsewhere.

trend. It suggests, however, that the slightly reduced averages for the past two 5-year periods may signify some real reduction in abundance.

The general trend for both silver and chum salmon is distinctly upward (fig. 1) despite rather wide fluctuations. This doubtless reflects an increased usage of these 2 less desirable species that has come with the reduced abundance of the other species, especially the chinook.

DATA FOR THE RUNS OF 1938

In this study of the 1938 salmon runs to the Columbia River, data have been available for the first time in the history of the fishery that have made it possible to evaluate the intensity of the fishery as a whole, the relative intensity at different times and in different parts of the river, and the proportion of the total that is formed by the run to the upper Columbia River (Clarks Fork). These data include the following series: (1) Daily commercial catch in pounds and by species in each of 6 districts corresponding to the 6 counties of the State of Washington that form the northern shore of the Columbia; (2) daily counts, by species, of the salmon passing Bonneville Dam beginning with May 7, and estimates for the period from February 15 to May 6; and (3) daily counts, by species, of the salmon passing Rock Island Dam across the upper Columbia near Wenatchee, Wash., about 100 miles below the site of the Grand Coulee Dam. The latter have been available since the season of 1933.

The importance of the data on the Bonneville count and the total daily catches to the proper development of a sound program for the conservation of the salmon of the Columbia River should be emphasized. Without them an intelligent consideration of the problems raised by the Grand Coulee Dam would have been impossible, and they will be of equal importance in the study of any other problems dealing with the maintenance of this valuable resource. For the previous three seasons the Washington Department of Fisheries had collected records of the daily deliveries of each species of salmon in each of the counties of the State bordering on the Columbia River. The Fish Commission of Oregon also had collected data on the daily deliveries of salmon, but not until 1938 were these presented in such form as to make it possible to combine them with the data from Washington so as to give a record of the total daily deliveries by species and by locality. For no other year are such data available, although figures for 1939 will be in suitable form for study when they are available. Now that a uniform system for presenting the catch data has been started by the two States, it probably will be continued so that in the future data will be available showing the total daily deliveries in each of the six districts.

Of equal importance has been the record of counts of fish passing the dams at Bonneville and Rock Island. Since 1933 there have been counts, more or less complete, at Rock Island, but the Bonneville Dam was not finally closed to the passage of fish previous to 1938, so that this year marks the beginning of the count at this point. The tremendous value in the conservation program of the count of salmon passing over the Bonneville Dam cannot well be overstated. This count should, by all means, be made a permanent feature and should be in the hands of competent men familiar with the fish and with the techniques of fishery research, and having a primary interest in the fishery problems upon which these data will bear.

In presenting these data it has been found expedient to sum them for the smallest practical time interval. The unit of 1 week was selected as the shortest period that would avoid insignificant fluctuations, particularly the disturbing effect of the Sunday closed period. For special purposes the data have also been arranged relative to longer time intervals, but these have been selected carefully on the basis of facts apparent from the tabulations made on a weekly interval. The use of relatively short time intervals has been important because of the considerable fluctuation in the commercial value of the salmon, particularly chinooks, during the season. The spring fish, entering the river during the period from April to the early part of August are much more valuable than those running later in the season. Furthermore, the magnitude of the run varies greatly from week to week and some portions of the run are far more seriously depleted than others. The intensity of fishing also varies, and the closed seasons tend to favor certain portions of the run and leave others practically unprotected from intensive exploitation. The commercial and biological importance of the various portions of the run of each species must, therefore, be determined independently, and to do this a relatively short time interval is essential. Because the fishing season begins May 1, the first week in May has been taken as the point of departure, and the weekly intervals, both before and after, are arranged to conform to this.

TABLE 1.—*Catch of chinook salmon in the Columbia River, 1938*

Week ending	Outside [1]	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Apr. 2	2, 393						
Apr. 9	38, 292						
Apr. 16	8, 193						
Apr. 23	11, 123						
Apr. 30	11, 309						
May 7		212, 139	390, 998	237, 612	38, 294	41, 327	14, 447
May 14	225	131, 269	116, 015	105, 441	29, 720	28, 531	38, 464
May 21		69, 042	71, 280	17, 411	5, 097	4, 662	19, 509
May 28		36, 655	43, 170	7, 619	1, 805	1, 476	7, 395
June 4	1, 388	35, 005	19, 783	539	20	129	4, 346
June 11	9, 062	53, 963	35, 554	736	51	30	6, 955
June 18	5, 872	81, 434	48, 300	3, 392	1, 683	947	4, 495
June 25	6, 398	110, 052	86, 608	11, 544	2, 931	1, 113	4, 248
July 2	12, 494	127, 078	66, 401	11, 230	4, 340	2, 306	1, 989
July 9	5, 984	189, 276	133, 845	26, 334	4, 572	4, 605	1, 217
July 16	5, 580	154, 680	108, 092	34, 388	5, 202	7, 358	1, 118
July 23	8, 577	187, 621	84, 095	30, 224	7, 414	5, 988	2, 872
July 30	21, 454	309, 210	123, 905	29, 035	11, 648	10, 111	2, 070
Aug. 6	40, 596	658, 106	127, 847	16, 158	7, 733	6, 899	6, 157
Aug. 13	12, 869	1, 000, 675	482, 395	55, 821	15, 180	9, 363	15, 373
Aug. 20	9, 911	1, 121, 367	617, 998	84, 876	7, 755	17, 030	40, 676
Aug. 27	26, 875	[2] 960, 365	288, 497	65, 964	19, 611	29, 544	37, 532
Sept. 3	18, 896						
Sept. 10	7, 573						
Sept. 17	12, 648	188, 933	142, 308	83, 724	[3] 94, 942	45, 331	[3] 772, 785
Sept. 24	2, 247	146, 414	164, 363	130, 829	39, 201	52, 156	398, 660
Oct. 1	2, 037	30, 414	30, 701	8, 264	14, 075		117, 743
Oct. 8	2, 794	8, 700	13, 987	4, 776	5, 385	34	69, 656
Oct. 15	502	14, 481	15, 990	6, 303	1, 371		23, 199
Oct. 22	1, 295	9, 356	9, 273	4, 446	1, 929	28	6, 022
Oct. 29		2, 635	6, 592	2, 852	671	63	5, 507
Nov. 5	6	1, 477	2, 952	1, 305	1, 035		1, 358
Nov. 12		547	812	701	151		
Nov. 19		83	167	177	142		
Nov. 26		65	141	30		26	11
Dec. 3			18				
Dec. 10			96				
Dec. 17			14				

[1] Outside may include some fish caught by troll inside the river and along the coast from Neah Bay to Coos Bay.
[2] The season on the river closed on August 25.
[3] The fall season opened at noon on September 10 and on that day 450 pounds were delivered in Zone 4 and 93,837 pounds in Zone 6. Since these catches represented a fishing period of only one-half day, they have been added to the catches of the following week.

TABLE 2.—*Catch of blueback salmon in the Columbia River, 1938*

Week ending	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Week ending	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
May 21	5						July 16	2,310	6,771	2,408	1,919	4,571	29,322
May 28							July 23	518	380	719	177	919	17,749
June 4	4						July 30	65	72	71	12	71	3,960
June 11	47	16				4	Aug. 6	7	8			6	1,125
June 18	2,282	8,138	905	468	834	203	Aug. 13						411
June 25	20,804	63,156	7,342	6,393	9,040	2,872	Aug. 20					48	57
July 2	18,326	59,368	13,534	7,325	10,579	15,312	Aug. 27 [1]						15
July 9	8,301	37,708	11,624	6,430	8,117	27,368							

[1] Season closed on August 25.

TABLE 3.—*Catch of steelhead trout in the Columbia River, 1938*

Week ending	Outside	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
May 7		1,833	5,347	1,174	169	449	1,298
May 14		1,166	4,366	851	75	184	3,253
May 21		722	2,465	213	41	56	2,212
May 28		447	1,703	144	56	74	1,203
June 4		566	627	28	5		737
June 11		898	890	39	7	10	503
June 18		3,448	5,070	171	113	57	255
June 25	667	17,724	20,566	1,247	371	327	416
July 2	358	20,149	38,342	2,929	1,008	503	451
July 9	38	59,666	94,512	10,610	2,112	1,701	829
July 16	22	50,226	76,705	23 060	3,224	3,821	1,029
July 23	46	36,914	56,598	24,920	4,686	3,409	6,204
July 30	72	37,928	58,537	11,797	2,225	2,210	3,524
Aug. 6	119	22,679	30,215	7,362	2,600	3,084	3,857
Aug. 13	50	45,215	94,016	11,274	2,908	2,204	15,784
Aug. 20	100	32,885	72,520	15,284	3,152	3,777	20,863
Aug. 27	66	[1] 21,852	40,807	11,017	3,524	3,293	11,566
Sept. 3	19						
Sept. 10	12						
Sept. 17		1,826	7,317	4,332	14,911	2,326	[2] 126,464
Sept. 24		11,583	30,153	10,036	5,600	3,008	99,731
Oct. 1		6,647	14,878	3,741	3,768		23,007
Oct. 8		2,258	5,025	2,021	1,007		10,723
Oct. 15		1,337	3,090	1,174	376		4,883
Oct. 22		1,730	2,585	982	104		1,456
Oct. 29		1,149	2,228	730	41	12	2 860
Nov. 5		1,130	2,503	993	50	14	1,250
Nov. 12		2,240	5,206	1,357		13	83
Nov. 19		2,810	5,497	1,520	91		
Nov. 26		2,127	8,459	2,694	177		
Dec. 3		930	7,180	2,133			
Dec. 10		2,757	18,101	1,852			
Dec. 17		1,094	8,800	1,203			
Dec. 24		774	6,955	1,996			
Dec. 31		427	9,660	1,741			

[1] Season closed on August 25

[2] Includes 14,531 delivered on September 10 (see footnote 3, table 1).

TABLE 4.—*Catch of silver salmon in the Columbia River, 1938* [1]

Week ending	Outside [2]	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Week ending	Outside [2]	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs*	*Lbs*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
June 4	1,456						Sept. 24	43,757	122,075	108,240	22,933	1,497	275
June 11	3,850						Oct. 1	68,257	83,878	60,661	10,330	1,326	
June 18	34,196						Oct. 8	94,171	41,359	64,417	18,546	9,811	20
June 25	43,611						Oct. 15	57,338	141,280	182,825	50,453	9,029	27
July 2	17,464						Oct. 22	104,462	154,600	164,545	45,604	7,593	266
July 9	61,362						Oct. 29	24	68,087	134,595	44,495	6,415	245
July 16	30,888						Nov. 5	799	74,463	158,286	37,209	3,698	373
July 23	51,354						Nov. 12	3,466	46,270	87,188	18,721	1,054	17
July 30	90,517						Nov. 19		12,127	49,966	14,793	1,165	
Aug. 6	114,834	8		7			Nov. 26		3,374	19,376	8,165	149	
Aug. 13	153,856	478	69	19			Dec. 3		1,312	14,610	8,410	234	
Aug. 20	257,407	7,848	6,692	100	27		Dec. 10		4,699	52,925	5,470		
Aug. 27	238,679	19,457	6,904	2,327	49		Dec. 17		754	9,040	2,039		
Sept. 3	327,076						Dec. 24		285	1,573	882		
Sept. 10	258,672						Dec. 31		97	1,430	487		
Sept. 17	154,168	[3] 23,730	21,906	7,674	1,198	152							

[1] No catch reported from Zone 6.

[2] May include some fish caught by troll inside the river and along the coast from Neah Bay to Coos Bay.

[3] Includes 43 pounds delivered September 10 (seef ootnote3 - table 1)

TABLE 5.—*Catch of chum salmon in the Columbia River, 1938*

Week ending	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Week ending	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Sept. 24	32					165	Nov. 19	29, 877	130, 691	43, 299	5, 589	1, 950	
Oct. 1	473	699				304	Nov. 26	7, 658	53, 078	24, 680	3, 476	2, 965	
Oct. 8	1, 732	1, 606	265	2, 577		247	Dec. 3	808	10, 021	11, 407	695		
Sept. 15	19, 686	28, 704	2, 962	241		693	Dec. 10	1, 784	21, 075	4, 395			
Oct. 22	54, 781	104, 820	13, 567	1, 815		69	Dec. 17	262	4, 264	568			
Oct. 29	60, 490	163, 206	22, 293	6, 945	73	3, 188	Dec. 24		439	232			
Nov. 5	106, 475	408, 107	43, 541	6, 419	3, 653	1, 380	Dec. 31		148	82			
Nov. 12	94, 797	321, 213	69, 073	2, 990	284								

TABLE 6 —*Miscellaneous catches in the Columbia River, 1938*

Month	Chinook	Steelhead	Blue-hack	Silver	Chum	Month	Chinook	Steelhead	Blue-back	Silver	Chum
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
April	59					October	9, 753	1, 186		4, 420	1, 060
May	18, 714	2, 725				November		571		3, 164	5, 551
June	1, 170	178	2, 219	166		December		423		21	29
July	1, 503	93	722	5	9						
August	8, 057	311	27	152		Total	86, 355	7, 561	2, 968	8, 146	6, 649
September	47, 099	2, 074		218							

Tables 1 to 5 give the aggregate Washington and Oregon catches for 1938, by species, weeks, and zones. These figures include only those catches that were reported by locality and date. There is a relatively small portion of the total catch that is reported without these important data and these have been excluded from this analysis, although for completeness they are given in table 6. The catch of chinook and silver salmon made in the ocean outside the mouth of the river by troll fishermen was not given in the original report by the board of consultants, but is included here. Occasionally deliveries are reported during the spring season as of Sunday. Since the period from 6 p. m. Saturday to 6 p. m. Sunday is closed to fishing each week during the spring season, such catches have been added to those of the preceding week. Catches made on Saturday are not infrequently held over and delivered on Sunday, and it rarely happens that catches are made after 6 p. m. on Sunday and delivered that same evening.

The zones correspond to the Washington counties bordering the river, beginning at the mouth. Zone 1 is that part of the river that is bounded on the north by Pacific County, Zone 2 by Wahkiakum County, Zone 3 by Cowlitz County, Zone 4 by Clark County, Zone 5 by Skamania County, and Zone 6 by Klickitat County. The catch in Zone 5 has, on the advice of both the Washington and Oregon officials, been referred wholly to the area below Bonneville Dam. This zone extends above Bonneville for some distance, but for a part of this distance the river is closed to all fishing and the catch in the remaining portion is so small as to be negligible, either when omitted from the record of the catch above or added to the record of that below Bonneville.

In this analysis we have necessarily omitted consideration of three elements in the catch which are recognized as important but which cannot, with the data at hand, be evaluated. These are: (1) The catch in the ocean by the troll fishery; (2) the hook-and-line catch by sport fishermen; and (3) the catch made by Indians for their own use, especially at Celilo Falls.

The troll fishery is very important, and from southeastern Alaska to the mouth of the Columbia it draws largely upon the supply of Columbia River chinooks—as demonstrated by tagging experiments (Pritchard 1934, Fisheries Service Bulletin, Jan. 3, 1928). Fairly good data are available as to the aggregate troll catch of chinooks and silvers in Alaska, Oregon, and Washington. The percentage of Columbia River fish in this catch, however, undoubtedly varies greatly during the season. There are no satisfactory data on this latter point. Even though we knew the proportions of Columbia River fish in the catch at different times and in different localities, it would be impossible to allocate these to the seasonal runs of the Columbia and thus, eventually, to determine the element in the troll catch derived from the runs to the Columbia River above Rock Island Dam. Likewise, we have no data on the catch of the sport fishery or on that part of the Indian catch that is not sold. All of these elements increase to some unknown extent the economic importance of the salmon runs with which we are here concerned.

TABLE 7.—*Estimates and counts of fish passing Bonneville, 1938*

[The figures up to and including May 7 are estimates based on partial counts only. Differences between the figures given here and those in the report by Calkins, Durand, and Rich are due to the fact that this table includes the final figures as given by the Army Engineers, in which minor corrections were made of the figures submitted weekly.]

Week ending	Chinook	Grilse [1]	Steelhead	Blueback	Silver	Chum
Feb. 19	----	----	55	----	----	----
Feb. 26	----	----	158	----	----	----
Mar. 5	4	----	204	----	----	----
Mar. 12	68	----	980	----	----	----
Mar. 19	84	----	1,267	----	----	----
Mar. 26	0	----	84	----	----	----
Apr. 2	14	----	981	----	----	----
Apr. 9	339	----	7,319	----	----	----
Apr. 16	402	----	1,927	----	----	----
Apr. 23	484	----	639	----	----	----
Apr. 30	1,545	----	320	----	----	----
May 7	3,359	----	138	----	----	----
May 14	12,936	1,357	3,217	131	----	----
May 21	5,097	842	1,622	572	----	----
May 28	3,827	871	1,644	318	----	----
June 4	205	53	164	24	----	----
June 11	1,981	710	632	153	----	----
June 18	2,932	515	652	1,358	----	----
June 25	2,230	334	520	5,719	----	----
July 2	1,240	164	641	15,441	----	----
July 9	884	102	800	16,491	----	----
July 16	1,855	204	4,061	21,673	----	----
July 23	1,534	337	7,161	7,835	----	----
July 30	1,753	430	6,667	2,770	----	----

Week ending	Chinook	Grilse [1]	Steelhead	Blueback	Silver	Chum
Aug. 6	1,327	329	4,886	1,125	----	----
Aug. 13	4,163	769	6,086	621	----	----
Aug. 20	5,104	1,010	6,457	279	0	----
Aug. 27	10,112	2,166	6,968	209	115	----
Sept. 3	53,753	9,452	17,689	156	6,961	----
Sept. 10	80,693	8,913	15,814	76	4,766	----
Sept. 17	63,224	5,756	13,744	71	1,933	----
Sept. 24	12,258	1,581	3,935	10	239	----
Oct. 1	2,057	406	1,204	1	56	0
Oct. 8	994	244	857	0	94	2
Oct. 15	489	99	604	3	389	68
Oct. 22	161	34	230	1	240	179
Oct. 29	231	17	253	1	212	945
Nov. 5	208	40	152	0	138	174
Nov. 12	47	10	90	2	18	236
Nov. 19	29	5	60	0	9	225
Nov. 26	9	1	58	0	4	202
Dec. 3	5	1	30	0	1	45
Dec. 10	21	5	43	0	7	46
Dec. 17	2	0	18	0	0	13
Dec. 24	0	0	1	0	0	1
Dec. 31	2	0	13	0	0	0
Total	277,665	36,757	120,985	75,040	15,185	2,136

[1] Grilse, locally designated as "jack" salmon, are precocious males. These are included in the preceding column headed "Chinooks," the figures in which are, therefore, the totals for this species.

In table 7 are given the counts and estimates of the number of salmon and steelhead passing Bonneville Dam during 1938. Actual counting did not begin until May 7, but estimates could be made from partial counts—the so-called "spot" counts—covering the period from the middle of February to and including May 6. These partial counts were made by observers stationed for portions of the day at the several fish ladders. The records consisted of (1) the length of time during which the observations were continued, and (2) the number of fish of each species observed. This is essentially a sampling method, and it is known that the fish do not run uniformly during the entire 24 hours, or even during the daylight hours. A fairly good estimate can be made from such records, however, if the hours during which the fish run are determined with care, and if the periods during which the counts are made are suitably distributed. The method adopted here for estimating the total number for the day from the partial counts is to multiply by 12 the average hourly count as determined from the records. This is the method recommended and used by Fred Morton, who was actively in charge of the count. This method assumes that the fish are passing over the ladders for 12 hours per day at the same average rate as observed during the period of the count and has been applied to each ladder separately and the sum is the estimated total for the day. For periods during which no count was made a linear interpolation between the preceding and the following days' estimated counts was used. Although not comparable in accuracy to the actual count, these estimates appear to give a reasonable basis for further calculations.

A chief source of error in these counts and estimates is undoubtedly the identification of species as the fish were passing up the ladders. After May 7, when the actual count began, the fish were forced to pass through a small opening in a weir placed across each fish ladder and over a submerged platform painted white. Identification of species under these conditions can be made with some accuracy by careful observers and, in general, reasonable confidence can be placed in the identifications so made. Those made under less favorable conditions must, necessarily, be accepted as the best available. Circumstances may arise in which a particular misidentification is especially likely to occur, in which case it may be recognized and steps taken either to improve the identification or to determine its influence and allow for it in the estimates of the number of fish of the species confused.

It is apparent that one such particular case of misidentification might easily arise during the time when the blueback run is at its peak. Grilse, which are approximately the same size as the bluebacks, are among the chinooks and run at the same time, and it has seemed likely that bluebacks might be mistaken for grilse or grilse for bluebacks. An analysis has been made in which the correlation was determined between the percentage of grilse in the total count of chinooks and the number of bluebacks for the 10 weeks of the blueback run—June 11 to August 13.

The Pearsonian coefficient of correlation is −0.72. Using the standard procedure the probability of chance occurrence of a coefficient of correlation as high as this is only 0.03, so that the observed negative correlation between the percentage of grilse and the number of bluebacks can be accepted as significant. Furthermore, it seems likely that the relationship between these two variables is curvilinear rather than rectilinear, as assumed by the Pearsonian coefficient, and that a true measure of the correlation would be even higher than that calculated. Our measure is, therefore, conservative. It seems quite likely that this negative correlation can be ascribed to a tendency on the part of the observers to mistake grilse for bluebacks when the bluebacks are numerous.

This raises the question as to what other errors there may be in the counts. It is certainly difficult to distinguish species under the conditions of counting unless there is a fairly well marked difference in size, shape, or markings, especially if light conditions are not favorable. Observers should not be blamed for making errors under these conditions, but, in view of the evidence of error in identification just given, it would seem proper to investigate carefully to see how extensive these errors may be. The importance of having properly trained and experienced observers is obvious.

TABLE 8.—*Counts of chinook salmon at Rock Island Dam, 1933 to 1938*

Week ending	1933	1934	1935	1936	1937	1938	Week ending	1933	1934	1935	1936	1937	1938
Apr. 16		2					Aug. 6	257	836	686	848	645	383
Apr. 23		11					Aug. 13	253	741	689	275	42	419
Apr. 30		9				14	Aug. 20	2,600	3,047	2,187	139	241	196
May 7		39	65	6		28	Aug. 27	409	386	3,342	65	172	82
May 14		87	117	13	2	70	Sept. 3	1,154	133	2,710	21	102	162
May 21		137	509	84	7	78	Sept. 10	656	57	1,104		61	171
May 28		93	532	399	30	650	Sept. 17	210	113	437		65	209
June 4		47	462	727	63	235	Sept. 24	70	67	1,077		371	515
June 11		26	282	254	25	195	Oct. 1		58	306		239	344
June 18		13	321	298	33	69	Oct. 8		111	629		65	344
June 25		11	86	201	19	94	Oct. 15		350	123		55	111
July 2		29	59	95	159	120	Oct. 22		30	41		9	8
July 9		104	116	91	180	39	Oct. 29		27	5			15
July 16		126	38	183	148	77	Nov. 5		3				
July 23	8	129	90	1,246	608	450							
July 30	51	258	288	1,530	1,791	725	Total	5,668	7,100	16,301	6,475	5,132	5,803

TABLE 9.—*Counts of blueback salmon at Rock Island Dam, 1933 to 1938*

Week ending	1933	1934	1935	1936	1937	1938	Week ending	1933	1934	1935	1936	1937	1938
May 21			18				Aug. 20	4,941	104	2,172	168	241	266
May 28			3				Aug. 27	827	35	561	20	74	93
June 4			2	1			Sept. 3	125	30	180	14	128	43
June 11			3	4			Sept. 10	56	15	23		45	35
June 18		2	5	6			Sept. 17	42	13	4		7	37
June 25			5			2	Sept. 24	26	4	3		12	96
July 2		22	5	9	4	80	Oct. 1		1	1		5	61
July 9		93	9	313	7	139	Oct. 8					5	
July 16		144	62	1,865	2,871	871	Oct. 15					8	
July 23	1,218	667	1,058	8,011	6,310	8,958	Oct. 22						
July 30	8,966	561	3,856	4,474	4,077	4,530	Oct. 29						1
Aug. 6	16,868	410	2,263	1,217	919	1,231							
Aug. 13	7,668	126	3,778	380	356	677	Total	40,737	2,227	14,011	16,482	15,069	17,123

TABLE 10.—*Counts of steelhead trout at Rock Island Dam, 1933 to 1938*

Week ending	1933	1934	1935	1936	1937	1938	Week ending	1933	1934	1935	1936	1937	1938
Apr. 9		14	8				Aug. 27	149	2	306	52	68	25
Apr. 16		7	8			49	Sept. 3	189	2	336	21	60	33
Apr. 23		71	29			222	Sept. 10	168	17	397		89	56
Apr. 30		62	191			143	Sept. 17	173	26	591		109	97
May 7		3	338	15		243	Sept. 24	30	25	411		312	200
May 14			146	35	9	67	Oct. 1		13	609		384	90
May 21		6	89	135	55	55	Oct. 8		36	677		265	126
May 28		1	132	304	211	395	Oct. 15		51	215		306	39
June 4		4	37	618	67	100	Oct. 22		31	306		42	34
June 11			9	70	15	53	Oct. 29		23	25			67
June 18		3	12	32	18	28	Nov. 5		16	5			
June 25		1	2	9	9	29	Nov. 12		20				
July 2		1		11	26	8	Nov. 19		8				
July 9		2	9	18	11	1	Nov. 26		4				
July 16		4	1	10	10	4	Dec. 3		3				
July 23		1	7	27		12	Dec. 10		11				
July 30	38	2	14	70		60	Dec. 17		5				
Aug. 6	131	3	46	77	12	62	Dec. 24		2				
Aug. 13	90	4	85	74	36	57							
Aug. 20	87		269	59	97	45	Total	1,055	481	[1] 5,411	1,637	2,214	2,400

[1] Includes 20 counted previous to the week ending April 9.

Tables 8, 9, and 10 give the counts made at Rock Island Dam during the years 1933 to 1938, inclusive. These were all actual counts which are presumably accurate, both as to number and identification. In addition to the records given in these tables, 78 silver salmon were counted at Rock Island Dam late in September and early in October 1938.

MODIFIED TABLES

The data on the run of 1938 (tables 1 to 10) are presented below in such form as to bring out certain facts bearing upon the biological and economic importance of different portions of the salmon runs and upon matters important to their conservation. This section deals with the methods used in forming these modified tables and the reasons for the various modifications that have been introduced. The chief purpose in the original report was to show the contribution that the Rock Island runs make to the commercial catch for different periods and also the intensity with which the run as a whole, and particularly the Rock Island component, is being exploited. In that report only the spring runs of chinook and blueback salmon and the steelhead trout were considered. In the present report all of the species of salmon found in commercial quantities in the Columbia River have been included and the data covering the fall season to the end of the year have been considered. Information not available at the time the original report was prepared has, we believe, made possible an improved analysis. Additional facts not pertinent to the original report but bearing on the more general problems of the depletion and conservation of these fishery resources have been introduced.

Primarily for the purpose of comparing commercial catch with escapement of fish to the spawning grounds, it has been necessary to convert the catch as given in pounds into numbers of fish. Entirely satisfactory conversion factors (average weights) are not available, so that the estimated numbers as given in the following tables cannot be considered as anything more than reasonable approximations. The terminal digits in the figures as given are not, therefore, to be taken as significant.

In the original report the following conversion factors were used in converting the catch, given as poundage landed, into numbers of fish: For chinook salmon 2 systems were used; (1) an average weight throughout the season of 22 pounds, and (2) an average of 15 pounds during May, 20 pounds during June, and 25 pounds during July and August. For bluebacks also 2 systems were used; (1) an average of 3 pounds throughout the season in all zones, and (2) an average of 3 pounds throughout the season below Bonneville (Zones 1 to 5) and 2½ pounds above Bonneville (Zone 6). For steelhead trout an average weight of 10 pounds throughout the season in all zones was assumed. In general these were in accord with accepted figures. In the present report we introduce no change in respect to the figures used for bluebacks and steelheads, but have considerably modified our treatment of the chinooks.

In another paper (Rich 1940a) the writer has described the seasonal changes in weight of chinook salmon in the commercial catch on the Columbia River during the season of 1939, and the estimated weekly average weights given in that paper have been used in this report to convert poundage to number of fish. The validity of applying the 1939 averages to the 1938 run is perhaps questionable, but appears to us to be by far the most acceptable procedure available.

It was shown in the paper just mentioned that a satisfactory empirical graduation of the observed weekly mean weights in 1939 is given by the use of two linear equations. Letting y=weekly mean weight, x=the week, with origin at the week of July 9, the data for the first part of the season, up to and including the week ending July 9, are fitted by the equation $y=30+1.78x$, and those for the last part of the season, including again the week of July 9, are fitted by the equation $y=30-0.55x$. Table 11, gives the estimated weights for each week of the spring season as determined from these equations. For this present report, estimated average weights for the weeks previous to the opening of the fishing season on May 1 and for the fall season have also been determined by the dubious method of extrapolation. We fully recognize the dangers of this procedure but, in the absence of any better objective basis for estimate, believe it to be justified here. This gives the following estimated weights: For the week ending April 30, 12.20 pounds; April 23, 10.42; September 3, 25.60; September 10, 25.05; September 17, 24.50; September 24, 23.95; October 1, 23.40; October 8, 22.85; October 15, 22.30; October 22, 21.75; October 29, 21.20; and for the week ending November 5, 20.65. After this date so few fish were taken in the fishery that an approximation on the basis of about 20 pounds is adequate for all purposes.

TABLE 11.—*Estimated weights of chinook salmon in the commercial catch in Zones 1 and 2 for the spring season of 1939. Figures for the first 3 weeks were extrapolated*

Week ending	Estimated mean weight	Week ending	Estimated mean weight	Week ending	Estimated mean weight	Week ending	Estimated mean weight
May 7	(13.98)	June 4	21.10	July 2	28.22	Aug. 6	27.80
May 14	(15.76)	June 11	22.88	July 9	30.00	Aug. 13	27.25
May 21	(17.54)	June 18	24.66	July 16	29.45	Aug. 20	26.70
May 28	19.32	June 25	26.44	July 23	28.90	Aug. 27	26.15
				July 30	28.35		

In converting poundage of silver and chum salmon to numbers of fish we here adopt an average weight of 10 pounds for both species—the same as that adopted for steelhead trout. This is not in accord with the figures commonly given, viz, 7–9 pounds for silvers and 8–10 pounds for chums. Some years ago, however, the writer measured and weighed several hundred silver and chum salmon taken on the lower Columbia River, and these gave averages for both species that were considerably over 10 pounds—240 chums averaged 10.3 pounds with a standard deviation of 2.0, and 133 silver salmon averaged 10.9 pounds with a standard deviation of 2.6. This average does not include 16 silver salmon grilse which were in the same collections. The samples came from fish caught in traps and the small grilse are seldom taken by gill nets although, as stated above, this form of gear is of primary importance in the Columbia River fishery. In view of these figures, and the purpose to which the estimates are to be put, it seems reasonable to use a conversion factor of 10 pounds for both of these species.[7]

Some time is required for the journey of the fish up the river, so that on a given day the fish in the upper river may be expected to represent an entirely different stock from that to be found simultaneously in the lower river, although it is the same stock as was to be found in the lower river during an earlier period. Therefore, in order to aid interpretation of some of the more important data, these have been presented so that as nearly as possible those referring to the same stocks of fish are placed on the same lines in the table. In other words, the several series of data have been so "lagged" that comparable portions are related to the same marginal date—which date is the end of the week in which the fish may reasonably be expected to have entered the river from the ocean. From a careful examination of tables 1 to 5 it appears that a given group of fish that entered the river and were to be found in Zones 1 and 2 in a given week (the week of the marginal date in the table) would be in Zones 3 to 5 the next week, at Bonneville and in Zone 6 during the second week, and at Rock Island the fourth week after their appearance in Zones 1 and 2.

In table 12 the dates given in the left-hand margin are those ending the weeks during which the fish were in Zones 1 and 2, the estimated catches made in Zones 3 to 5

[7] Since this report went to press a paper by Wilbert Chapman, of the Washington State Department of Fisheries, dealing with the weights of fish taken in the Columbia River fisheries has appeared. His figures are somewhat different from ours but it is not possible to give a critical discussion of them here.

were made 1 week later than that indicated by the marginal date, the Bonneville count and the estimated catch above Bonneville were made 2 weeks later than that indicated by the marginal date, and the Rock Island count 4 weeks later. For convenience we shall refer below to the assumed position of the fish during their upward migration as in Zones 1 and 2 the first week, in Zones 3 to 5 the second week, at Bonneville and in Zone 6 the third week, and at Rock Island the fifth week of their fresh-water migration. The same system was followed in preparing the similar tables for the other species.

Thus, reading across any one line, say the line for May 7 in table 12, the first column gives the estimated catch made in Zones 1 and 2 during the week ending May 7, the second column the estimated catch made in Zones 3 to 5 during the week ending May 14, the fourth column the count at Bonneville during the week ending May 21, the fifth column the estimated catch above Bonneville during the week ending May 21, and the seventh column the count at Rock Island during the week ending June 4. Columns 3 and 6 are derived by summing across the rows in the appropriate columns and therefore show totals for the run as a whole—all referred back to the week that the fish were presumably in the extreme lower part of the river and, therefore, approximately to the time that they entered the river.

Individual fish undoubtedly vary greatly in respect of their rate of travel upstream, but the obvious similarity in the trends of all the columns in this table is evidence that, on the average, these assumptions are well founded.

NATURE OF THE ANALYSIS OF RUNS

From the tables of this structure it is possible, for those species that largely spawn above the site of the Bonneville Dam, to estimate the number of fish of each species that escaped the intensive fishery below Celilo Falls (the upper limit of commercial fishing) in 1938 and were available for reproduction above Bonneville Dam. This is readily done for any desired portion of the season by subtracting the catch above Bonneville from the Bonneville count. Such an estimate of the escapement is subject to error from several causes, of which the following may be mentioned: (1) Error in the count of fish of the different species at Bonneville, (2) error in the catch figures due to the fact that a considerable catch that does not appear in the record is made by Indians, and to some extent by Whites for home use, and (3) error in converting pounds to number of fish. While these sources of error are present, it is believed that their total effect is relatively small and will not affect the general conclusions that may logically be drawn. Furthermore, in making these estimates no attempt has been made to correct for the spawning that takes place in the tributaries below Bonneville Dam. In the case of the silver and chum salmon such a large percentage of the spawning takes place below Bonneville that a similar analysis has not been made. Also, as mentioned above, there is a considerable part of the fall run of chinooks that spawns below Bonneville so that our study of the fall run is probably less reliable than that for the spring season. Since our estimate of the escapement is based primarily upon the count at Bonneville (from which is subtracted only the estimate of the number of fish in the recorded commercial catch above Bonneville) the spawning in the tributaries between Bonneville and the upper end of the commercial fishing district at Celilo Falls will not affect the results. If any considerable portion of the run that is actually derived from the tributaries below Bonneville be ascribed to the river above Bonneville, this will tend to magnify the importance of the spawning in the river above Bonneville, including that above Rock Island. Undoubtedly a part of the commercial catch of all species except the blueback is composed of fish derived from the tributaries below Bonneville, but it seems probable that this forms a relatively small part of the total catch of chinook salmon, at least until after the peak of the fall run. There is a very large count of chinooks at Bonneville immediately after the beginning of the closed period in August—certain evidence that a large proportion of the fish that are in the river at that time are derived from populations spawning in the higher tributaries. On the whole we feel fairly confident that only a relatively small part of the commercial catch of this important species that is made before the first of October comes from the runs into tributaries below Bonneville.

An understanding of the analysis of these runs, particularly in relation to the fish destined to spawn in the upper Columbia River above Rock Island Dam, may be aided by the following discussion (see also fig. 2).[8] While this particular treatment is related specifically to the run to Rock Island, a similar treatment could be applied to any other tributary runs for which similar data were available.

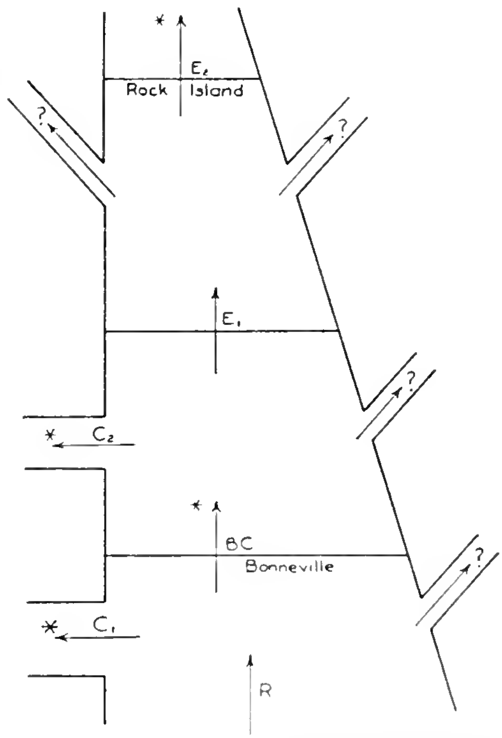

FIGURE 2.—Diagram of the ultimate subdivisions of the main run of chinook salmon entering the Columbia River, illustrating the various ratios. R denotes total run; C_1 denotes total catch below Bonneville Dam; BC denotes Bonneville count; C_2 denotes catch above Bonneville Dam; E_1 denotes escapement at upper limit of commercial fishing; E_2 denotes escapement at Rock Island Dam; ? denotes diversions of unknown amounts at various points in the river.

Let us assume:

A. That the estimated escapement at Celilo is the total escapement for the total run of the period; and

B. That the ratio between the escapement at Rock Island Dam and the catch made from the same stocks of fish that furnished this escapement is the same as that between the escapement at Celilo and the total catch. This assumes that there is no appreciable loss between Celilo and Rock Island, and that, for each species, the proportion of Rock Island fish caught is the same as the average for all salmon of the species that are passing through the fishery at the same time.

From this it would follow also that the relation between the escapement at Rock Island Dam and the run referable to this escapement will be the same as that between the escapement at Celilo and the total run.

Having then determined, for a selected time interval, the total catch, denoted by C, the escapement at Celilo, denoted by E_1, and the count at Rock Island, denoted by E_2, we are able to determine the following:

[8] This clarifying symbolic treatment was contributed to the original report of the Board of Consultants by Dr. Durand, who has kindly permitted slightly altered repetition here.

1. The fraction of the total run (R) derived from that portion normally spawning above Rock Island. This will be $\frac{E_2}{E_1}$.

2. The fraction of the total catch (C) referable to the Rock Island escapement (Rock Island count). This also will be $\frac{E_2}{E_1}$.

3. The catch derived from the Rock Island contingent. This will be $\frac{E_2}{E_1}C$. This catch in numbers of fish can then be converted into pounds weight on the basis of the assumed average weight per fish.

4. The total run referable to Rock Island. This will be $\left[\frac{E_2}{E_1}C+E_2.\right]$ Likewise, the ratio of the catch referable to Rock Island to the total run referable to Rock Island. This will be $\frac{E_2}{E_1}C\div\left[\frac{E_2}{E_1}C+E_2\right]$ which reduces directly to $C\div(C+E_1)$ or to total catch divided by total run, as might be expected. This may also be written, rather neatly, as $\frac{1}{1+\frac{E_1}{C}}$. That is, the ratio of the catch referable to Rock Island to the run referable to Rock Island is the same as the ratio of the total catch to the total run. This again follows from the assumptions A and B.

In carrying out the analysis along the lines indicated above, the catch in number of fish and in pounds that may properly be ascribed to fish of the runs to the river above Rock Island has been taken as a measure of what may be termed the absolute importance of the Rock Island factor in the commercial fishery. The percentage of the entire run that, for any period, may be ascribed to these Rock Island fish, may similarly be taken as a measure of the relative importance of the Rock Island factor. These two series serve somewhat different purposes. These values may be determined for any selected portion of the season, and this is important because the Rock Island complement in the total run varies widely from time to time and the ratio of catch to escapement also varies during the fishing season. But for any one period it is possible to determine the ratio of catch to escapement—a ratio that may be applied to the entire run for the period or to fish bound for other tributaries above Bonneville Dam as well as to those destined to tributaries above Rock Island Dam. Given the ratio for any period, the catch ascribable to the upper Columbia may be determined by multiplying the Rock Island count, E_2, for the corresponding period, by this ratio, $\frac{C}{E_1}$, giving $\left(\frac{C}{E_1}\right)E_2$. Or, on the other hand, we may use the fraction of the entire run that may be attributed to the river above Rock Island, $\frac{E_2}{E_1}$, and multiply the total catch, C, by this fraction to get the number of fish derived from those spawning above Rock Island giving $\left(\frac{E_2}{E_1}\right)C$. Mathematically these two procedures are obviously identical and, where either may be applied, they will give identical results; but the latter procedure, making use of fractions of Rock Island fish in the run, may be applied when necessary to determine the part that the Rock Island fish play in producing the catch in any portion of the river, while the former can only be applied to the catch as a whole.

We will now consider, specifically, certain runs and portions of runs in respect of their importance to the general problems of the preservation of the salmon of the Columbia River, and in particular of those that have derived from the river above Grand Coulee Dam. Although the data have been studied and presented on the basis of time units of 1 week, it is convenient and even more illuminating to consider them also for longer intervals of time which have been selected for various reasons as being of special importance.

CHINOOK SALMON

HISTORY OF THE RUN OF 1938

On account of the dominating importance of this species in the fishing industry, particular attention has been paid to it. The data are presented in tables 12 to 14 and are shown graphically in fig. 3.

The earliest part of the run to the Columbia River above Bonneville does not enter into the commercial fishery—it is past the commercial fishing area before the opening of the season on May 1. The first of the run to contribute to the commercial catch is that which enters the mouth of the river during the week ending April 23. These fish, in general, may be expected to pass Bonneville and to be in Zone 6 during the first week in May—the first week of the spring open season. We have therefore considered as a separate period the weeks up to and including the week ending on April 16. The next period includes the part of the run that provides the peaks in catch and Bonneville count that occur in May. We consider that this period terminates with the week ending May 28. The next period includes the succeeding 9 weeks ending on July 30, during which the catch and the Bonneville count were both relatively low, while at corresponding weeks the Rock Island count attained the maximum for the year.

In the original report the last period treated covered only the 4 weeks ending August 27—the last 4 weeks of the spring fishing season. It was impossible to carry the study beyond this because at the time the report was prepared data were not available for the fall season. But, with the data now on hand, it is obvious that the portion of the run beginning with the week ending August 6 and extending to the end of the year should be considered as forming a single unit rather than two or more units. In table 12 it is apparent that the run from the week of August 6 to the end of the year contains the main mode which, for purposes of study, should certainly not be broken up without good reason. Furthermore, table 12 and fig. 3 show that there is a mode in the Rock Island count for this period. In the present report, therefore, we shall take for the final period to be studied the entire remainder of the year after the week ending July 30.

The data for these selected periods are given in table 13, which, for comparison, also includes the figures for the last period considered in the original report—July 31–August 27. Table 14 gives some of the more significant comparative figures that may be derived from table 13.

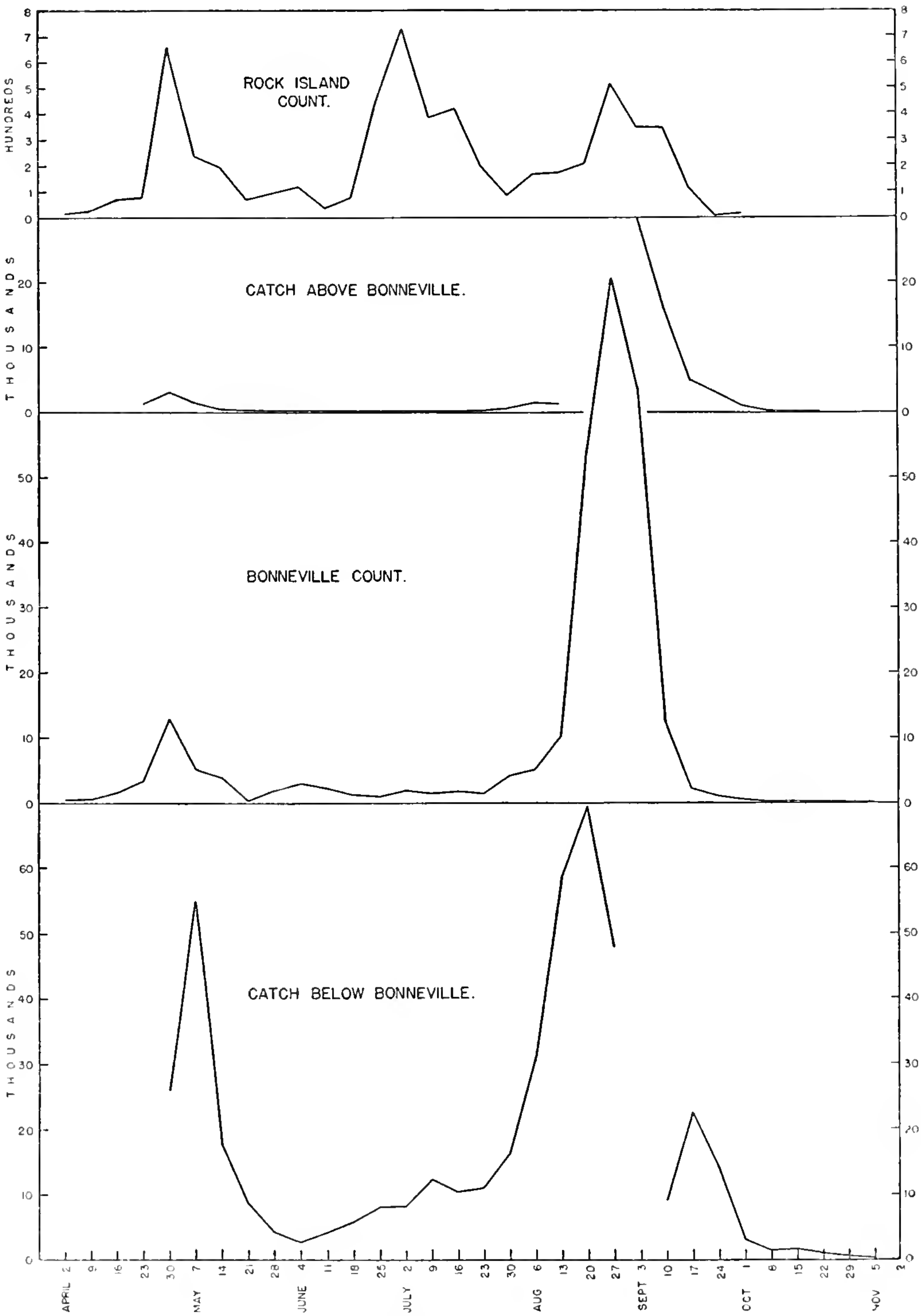

FIGURE 3.—Dominant elements in the 1938 chinook salmon run, by weeks.

TABLE 12.—*Chinook salmon run in the Columbia River, 1938*

[Catch in number of fish estimated from weekly average weights, as determined from the 1939 run. Data combined and arranged by corresponding weeks]

Week ending	Zones 1 and 2	Zones 3 to 5	Total catch below Bonneville	Bonneville estimate and count	Catch above Bonneville	Total catch	Rock Island count	Total run
Feb. 19				4				4
Feb. 26				68				68
Mar. 5				84				84
Mar. 12				0				0
Mar. 19				14				14
Mar. 26				339				339
Apr. 2				402			14	402
Apr. 9				484			28	484
Apr. 16				1,545			70	1,545
Apr. 23				3,359	1,386	1,386	78	3,359
Apr. 30		26,003	26,003	12,936	3,153	29,156	650	38,939
May 7	43,143	11,709	54,852	5,097	1,395	56,247	235	59,949
May 14	15,691	1,724	17,415	3,827	469	17,884	195	21,242
May 21	8,000	621	8,621	205	248	8,869	69	8,826
May 28	4,132	36	4,168	1,981	360	4,528	94	6,149
June 4	2,597	39	2,636	2,932	213	3,849	120	5,568
June 11	3,912	263	4,175	2,230	186	4,361	39	6,405
June 18	5,261	632	5,893	1,240	81	5,974	77	7,133
June 25	7,438	676	8,114	884	46	8,160	450	8,998
July 2	6,856	1,258	8,114	1,855	40	8,154	725	9,969
July 9	10,771	1,565	12,336	1,534	96	12,432	383	13,870
July 16	8,923	1,481	10,404	1,753	70	10,474	419	12,157
July 23	9,402	1,758	11,160	1,327	213	11,373	196	12,487
July 30	15,277	1,086	16,363	4,163	542	16,905	82	20,526
Aug. 6	28,272	2,891	31,163	5,104	1,463	32,626	162	36,267
Aug. 13	54,425	4,024	58,449	10,112	1,377	59,826	171	68,561
Aug. 20	65,145	4,312	69,457	53,753		69,457	209	123,210
Aug. 27	47,758		47,758	80,693		47,758	515	128,451
Sept. 3				63,224	30,109	30,109	344	63,224
Sept. 10		8,942	8,942	12,258	15,915	24,857	344	21,200
Sept. 17	13,520	9,069	22,589	2,057	4,806	27,395	111	24,646
Sept. 24	12,976	933	13,909	994	2,908	16,817	8	14,903
Oct. 1	2,612	436	3,048	489	991	4,039	15	3,537
Oct. 8	993	336	1,329	161	264	1,593		1,490
Oct. 15	1,366	287	1,653	234	247	1,900		1,887
Oct. 22	857	165	1,022	208	62	1,084		1,230
Oct. 29	435	110	545	47		545		592
Nov. 5	214	41	255	29		255		284
Nov. 12	68	16	84	9	1	85		93
Nov. 19	13	3	16	5		16		21
Nov. 26	11		11	21		11		32
Dec. 3	1		1	2		1		3
Dec. 10	4		4			4		4
Dec. 17	1		1	2		1		3
Total	370,074	80,416	450,490	277,665	66,641	517,131	5,803	728,155

TABLE 13.—*Catch and escapement of chinook salmon by selected and corresponding periods*

Period	Catch below Bonneville	Bonneville count	Catch above Bonneville	Total catch	Estimated escapement past Celilo	Rock Island count
To and including Apr. 16	None	2,940	None	None	2,940	112
Apr. 17–May 28	111,059	27,405	7,011	118,070	20,394	1,321
May 29–July 30	79,195	17,918	1,487	80,682	16,431	2,491
July 31–Aug. 27	206,827	149,662	2,840	209,667	146,822	1,057
July 31–Dec. 17	260,236	229,402	58,143	318,379	171,259	1,879
Total [1]	450,490	277,665	66,641	517,131	211,024	5,803

[1] Eliminating duplication in the last 2 periods.

TABLE 14.—*Significant ratios between elements of the chinook run*

Period	Total catch to escapement	Catch below Bonneville to—		Catch above Bonneville to—		Rock Island count to escapement
		Total catch	Bonneville count	Total catch	Bonneville count	
Apr. 17–May 28	5.79	0.941	4.06	0.059	0.256	0.065
May 29–July 30	4.91	.981	4.42	.018	.083	.152
July 31–Aug. 27	1.43	.986	1.38	.014	.019	.007
July 31–Dec. 17	1.86	.818	1.13	.182	.253	.011

For the season prior to April 16 there was, of course, no catch; the estimated escapement was 2,940, and the corresponding count at Rock Island was 112. The percentage of the run going to the upper Columbia River was, therefore, 3.8. (All of these statements and other similar ones to follow are approximations that are affected by errors in the data and in the various assumptions involved. We believe, however, that neither the data nor the assumptions are seriously in error so that these are valid approximations.)

During the period from April 17 to May 28, the period when the first conspicuous peak of the run occurred, the catch amounted to over 1,681,000 pounds (table 1), estimated as representing approximately 118,000 fish. The Bonneville count was 27,400, the catch above Bonneville 7,000, and the estimated escapement 20,400 The Rock Island count was 1,321. The ratio of catch to escapement (catch divided by escapement) is 5.8:1—in other words, it is estimated that 5.8 fish are caught for every one that escapes and is available for reproduction. The percentage of the entire escapement that went to Rock Island was 6.5. The catch that may be attributed to the Rock Island contingent in the run is, therefore, 6.5 percent of 118,000 fish, about 7,650. An estimate of the poundage derived from the Rock Island run during this period may also be had by taking 6.5 percent of the total weight of chinooks in the catch made in the corresponding periods on the lower river. (This includes the catch of the first 4 weeks in Zones 1 and 2, of the first 5 weeks in Zones 3 to 5, and of the first 6 weeks in Zone 6.) The estimate of the poundage derived from the Rock Island run is, therefore, 109,000 lbs. (6.5 percent of 1,681,000 pounds).

For the period from May 29 to July 30, the total catch was 2,242,000 pounds, representing an estimated 80,700 fish. The Bonneville count was only 17,900. The catch above Bonneville amounted to some 1,500 fish, leaving an estimated escapement of 16,400. The Rock Island count was 2,491. The ratio of catch to escapement is 4.9:1—approximately 5 fish are captured for every one that escapes. The Rock Island count was 15.2 percent of the estimated escapement. The catch that may be attributed to the Rock Island run, therefore, is 12,300 fish of an aggregate weight of 341,000 pounds.

It is to be noted especially that the Rock Island portion of the run during this period constitutes over 15 percent of the total and that this is the period during which the run is slack and the catch relatively poor. It is well known that this condition exists each year and it is the general opinion that the populations that characterize this period are the most seriously depleted of any. Certainly it is evident that they are without adequate protection at the present time. By far the greater part of the fish taken in the commercial fishery during these weeks is of high quality and produces the finest of the Columbia River pack. The preservation of so important a part of the run is obviously a matter of the highest importance. This part of the run will be considered in more detail below.

The run from July 31 to August 27 provides a large part of the total catch of the spring season, but the contribution made by the Rock Island runs is relatively small. The total catch for this period during 1938 was 5,640,000 pounds, representing about 207,000 fish. The Bonneville count was approximately 149,600, and the catch above Bonneville was 2,800, giving an estimated escapement of 147,000. The ratio of catch to escapement during this period was, therefore, only 1.4:1, which was undoubtedly reduced by the increased escapement during the last 2 days of the period after the fishing season closed on August 25. The Rock Island count was 1,057, which is only 0.72 percent of the escapement. The catch that may be attributed to Rock Island is, therefore, 1,500 fish with an aggregate weight of 40,600 pounds.

The data last presented (for the period July 31 to August 27) are similar to those given in the original report and are presented here chiefly for comparison with those that follow. We have already stated that this is not a natural subdivision of the run and that, properly, the period from July 31 to the end of the year should be treated as a unit. This larger period takes in the major peak of abundance that occurs in late August and early September and includes completely the closed period, August 25 to September 10, and all catches that may be referred to the stocks of fish affected by the closed season. The total catch was recorded as 8,326,000 pounds, which we estimate included some 318,000 fish. In contrast to the other selected periods, the catch above Bonneville Dam forms a large part of the total and it is of interest to note (tables 1, 12, and 13) that the major part of this catch above Bonneville takes place after the closed period. The total catch during the fall season alone was 2,685,000 pounds (109,000 fish), of which over half, 1,395,000 pounds (55,000 fish) were taken above Bonneville. It is obvious that one important result of the closed period is to permit enough fish to escape the fishery on the lower river so that upwards of a million pounds may be taken above Bonneville Dam.

The Bonneville count during the period July 31 to the end of the year was 229,000 fish. The net escapement (Bonneville count less the catch above Bonneville) was, therefore, approximately 175,000 fish. The ratio of catch to escapement is 1.9:1, which, while still high, is much less than that during the earlier periods. It is to be noted, however, that this ratio is considerably higher than that for the month of August, when the ratio is 1.4:1. This was one of the results of treating the period from July 31 to August 27 as a unit. The facts that this period is not a natural subdivision of the run and that the count at Bonneville for the period is undoubtedly influenced by the incidence of the closed season on August 25 have resulted in this and other differences between the data for the month of August and those for the entire period of the fall run.

The Rock Island count for the period corresponding to that from July 31 to the end of the year was 1,879, or 1.1 percent of the estimated net escapement. Taking this as the percentage of Rock Island fish in the run as a whole, the catch that may be attributed to the Rock Island runs is estimated at 3,500 fish, or 91,500 pounds. This is to be compared with an estimate of 1,500 fish of an aggregate weight of 40,600 pounds for the month of August.

Table 15 presents the more significant figures bearing on the absolute and relative importance of the Rock Island runs of chinook salmon. There are given not only the figures obtained through the basis of estimate adopted in this report, but also, for comparison, those obtained through the two bases used in the original report by Calkins, Durand, and Rich. (The estimates given here for the full season on the bases used in the original report were not, of course, given in that report, which treated the catch only up to August 25.) It is apparent that, in general, the results of all three procedures are of the same order of magnitude so that one may assume with some confidence that no gross errors have been introduced. Although we believe that the estimates based on the average weights obtained in 1939 are the most accurate, and should certainly be used for detailed study of parts of the run, it is clear that simpler methods will give approximate results of real value.

TABLE 15.—*Chinook salmon—comparison of certain estimates as made on the following bases: (1) An average weight of 22 pounds throughout the season; (2) average weights of 15 pounds in May, 20 pounds in June, and 25 pounds for the remainder of the year; and (3) average weights for each week as calculated from the trend lines described in the text. The first two were used in the original report by Calkins, Durand, and Rich*

Basis of estimate	Ratio of catch to escapement	Percentage of Rock Island fish in total run	Catch attributed to Rock Island run—in fish	Catch attributed to Rock Island run—in pounds
April 17 to May 28				
(1)	3.3	5.67	4,300	95,300
(2)	5.2	6.19	6,900	104,000
(3)	5.8	6.50	7,650	109,000
May 29 to July 30				
(1)	6.3	15.46	15,800	346,900
(2)	5.8	15.38	15,700	379,000
(3)	4.9	15.20	12,300	341,000
July 31 to August 27				
(1)	1.8	0.72	1,860	40,900
(2)	1.5	.72	1,600	41,000
(3)	1.4	.72	1,500	40,600
July 31 to December 17				
(1)	2.3	1.16	4,400	96,600
(2)	2.0	1.11	3,700	92,500
(3)	1.9	1.10	3,500	91,500

On the basis of these figures the total catch that may reasonably be attributed to the Rock Island runs is between 500,000 and approximately 600,000 pounds, of which by far the larger proportion was of the valuable spring run. Furthermore, it is of especial importance to note that the Rock Island run forms a particularly large percentage of the seriously depleted and heavily fished June-July run.

RATE OF TRAVEL

These data provide additional information relative to the rate of migration up the river. We have given the reasons for thinking that the interval between the time that the fish appear in Zones 1 and 2 and at Bonneville is approximately 2 weeks. The peak of the run that occurs in late August and early September is obviously an important landmark and should, therefore, provide important evidence on this point—evidence that was not available at the time the original report was prepared.

From the figures of the numbers of fish caught (estimated on the basis of the trend lines of average weights obtained in 1939) it would seem that the peak of the catch in Zones 1 and 2 came 3 weeks before the peak of the count at Bonneville, instead of 2 weeks (fig. 3). The drop in the catch that occurs between the weeks ending August 20 and 27, however, is due, at least in large part, to the fact that there were only 4 days of fishing in the week ending August 27. The spring fishing season closed on August 25. An estimate may be made of what the catch would have been if the full 6 days of fishing had prevailed, instead of 4 days, by multiplying the estimate already presented by 1½. The result is over 71,000 fish; actually a few more than estimated for the week ending August 20. This result indicates strongly that the real peak of abundance in Zones 1 and 2 came not earlier than the week ending August 27—2 weeks earlier than the actual peak in the Bonneville count and quite in agreement with the original assumption. Whether, without the closed period, the peak in the Bonneville count would have come in the week ending September 10 is perhaps somewhat doubtful, and no method has occurred to us whereby that can be independently determined. From the total run (table 12) this would seem to be a reasonable inference, but it has been based on the assumption that 2 weeks are required for the journey from the mouth of the river to Bonneville.

In passing, it should be emphasized for future use in similar situations that the effect of the closed period has been to so increase the Bonneville count immediately following the beginning of the closed period that it has the effect of shifting the peak of the count upward. This would be true even if the final week of the open period had consisted of 6 days instead of 4 days of fishing. In general, the incidence of a closed period will increase the escapement in the following weeks, but in this case the peak of the run happens to coincide so closely with the beginning of the closed period (probably actually preceding it on the lower river) that the effect is to shift the peak of the escapement upward. Also, in this particular case, the fact that the last week of the open season contained only 4 fishing days had the effect of apparently shifting the peak of the catch downward. The combined result was an apparent lag of 3 instead of 2 weeks between the peak of the catch in Zones 1 and 2 and the peak of the count at Bonneville. Similarly, at the beginning of an open period there will be the reverse tendency for the peak of the escapement to be shifted downward and the peak of the catch to be shifted upward. Doubtless the peak of the Bonneville count that occurs during the week corresponding to that of April 30 has been so modified. Actually this count was made during the week ending May 14, and the fish passing Bonneville during that week were doubtless partly through Zones 1 and 2 before the fishing season opened on May 1. These rather confusing effects are, of course, due to the complementary relationship existing between the catch and the count at Bonneville.

Related to these phenomena is the fact that there appears to have been some delay in the passage of fish through Zone 6 following the peak of the run and the closed season. This is shown particularly by the fact that during the weeks ending September 10 to October 15 (almost the entire effective fall season) the catch above Bonneville exceeded the Bonneville count. However, we believe that this does not indicate a general lower average rate of travel, but is due, rather, to the combined influence of individual variation in the rate of travel and a constant reduction in the number of fish passing Bonneville. The anomaly, then, of the existence over a number of weeks of a greater catch above Bonneville than count over the dam is closely related to the fact that the peak of the escapement curve is shifted to an earlier date by the incidence of an open season.

THE JUNE-JULY RUN

As previously mentioned, the June–July run of chinooks is poor compared with that in May or August, and it is rather generally thought that the populations forming this part of the run are the most seriously depleted of any. Some evidence of this was developed at the time the original study was made, but was not included in the original report. It has seemed worth while to pursue the investigation further.

As bearing on the extent to which the June–July run has been depleted, we have examined data secured through the cooperation of the Columbia River Packers Association. These data are in the form of reports of daily deliveries to this company over the period from 1912 to 1937, with the exception of occasional years for which no figures were available. It is unfortunate that similar data are not available for the entire river.

During this long period the catch delivered to the association has averaged nearly 25 percent of the total deliveries on the Columbia River, and has ranged quite consistently between 20 and 30 percent. To test the reliability of these data as an index of changes in relative abundance during different periods, the Pearsonian coefficient of correlation, "*r*," has been calculated between the total annual deliveries to the company and the total deliveries for the entire fishery as given in the report by the Oregon State Planning Board (1938). Between 1912 and 1937 there were 20 years for which complete records were available, and for these the coefficient of correlation is 0.86. The records appear to show, however, that some change took place about 1934, so that the records for the last 3 or 4 years are not consistent with those for earlier years. We have, therefore, calculated "*r*" for the 16 years of record between 1912 and 1928. The value is practically 0.9. Both show such a high degree of correlation that reasonable confidence may be placed in the assumption that the deliveries to the Columbia River Packers Association will serve to indicate long-time (secular) changes in relative abundance of chinook salmon in different parts of the season.

TABLE 16.—*Monthly totals of deliveries of chinook salmon to the Columbia River Packers Association, 1912–37, in thousands of pounds, for the spring fishing season only*

Year	May	June	July	August	Total	Year	May	June	July	August	Total
1912	420	749	1,629	1,628	4,426	1924	609	992	1,270	1,296	4,167
1913	759	683	1,381	918	3,741	1925	703	996	1,100	1,747	4,546
1914	859	1,203	1,935	1,378	5,375	1926	169	732	934	1,680	3,516
1915	1,163	2,194	2,693	1,685	7,736	1927	638	704	794	1,695	3,830
1916	684	496	1,811	3,232	6,223	1928	440	503	702	1,590	3,235
1917	717	578	1,275	2,982	5,552	1931	296	502	680	2,781	4,260
1918	378	643	1,246	3,489	5,756	1932	428	658	714	2,457	4,286
1919	882	665	1,436	2,700	5,683	1933	93	843	456	2,044	3,435
1920	854	1,194	1,271	3,194	6,514	1934	229	616	886	2,783	4,614
1921	468	594	1,143	2,394	4,599	1936	608	701	605	1,970	3,884
1922	727	440	808	2,128	4,103	1937	584	445	676	2,559	4,265
1923	624	973	1,254	1,150	4,000						

NOTE.—The years 1929, 1930, and 1935 are omitted because of incomplete records.

From data given in table 16 we have calculated the trends by the method of averages, and these are shown in figure 4, which has been put on a semilogarithmic grid so that relative changes will be correctly shown and the several trends can be directly compared. It is apparent from this that while a general reduction has taken place, as is shown in each month and also in the total, the reduction in the July catch has been by far the greatest. From a value of nearly 2,000,000 pounds at the beginning of this period (1912), the line of trend of the July deliveries has dropped to only about 600,000 pounds in 1937. The present deliveries are, therefore, approximately one-third of what they were during July 25 years ago. At the same time the totals for the entire spring fishing season have dropped from about 6,000,000 pounds to about 3,500,000 pounds. This graph also shows that the deliveries during May have been seriously reduced. Curiously enough, the trend of the June deliveries is approximately the same as for the spring season as a whole, although those of May and July show evidence of much more serious depletion. Deliveries in August have not suffered nearly so much as those of the other months of the spring season—perhaps because of increased utilization of these later running fish which are not of so good a quality as those of May, June, and July.

Before adopting the policy of treating all of the data on the basis of time units of 1 week, the daily records were examined and it soon appeared that there was, especially in June and July 1938, a very definite weekly cycle of abundance as indicated by the catch in Zones 1 and 2. The Sunday closed season, of course, resulted in

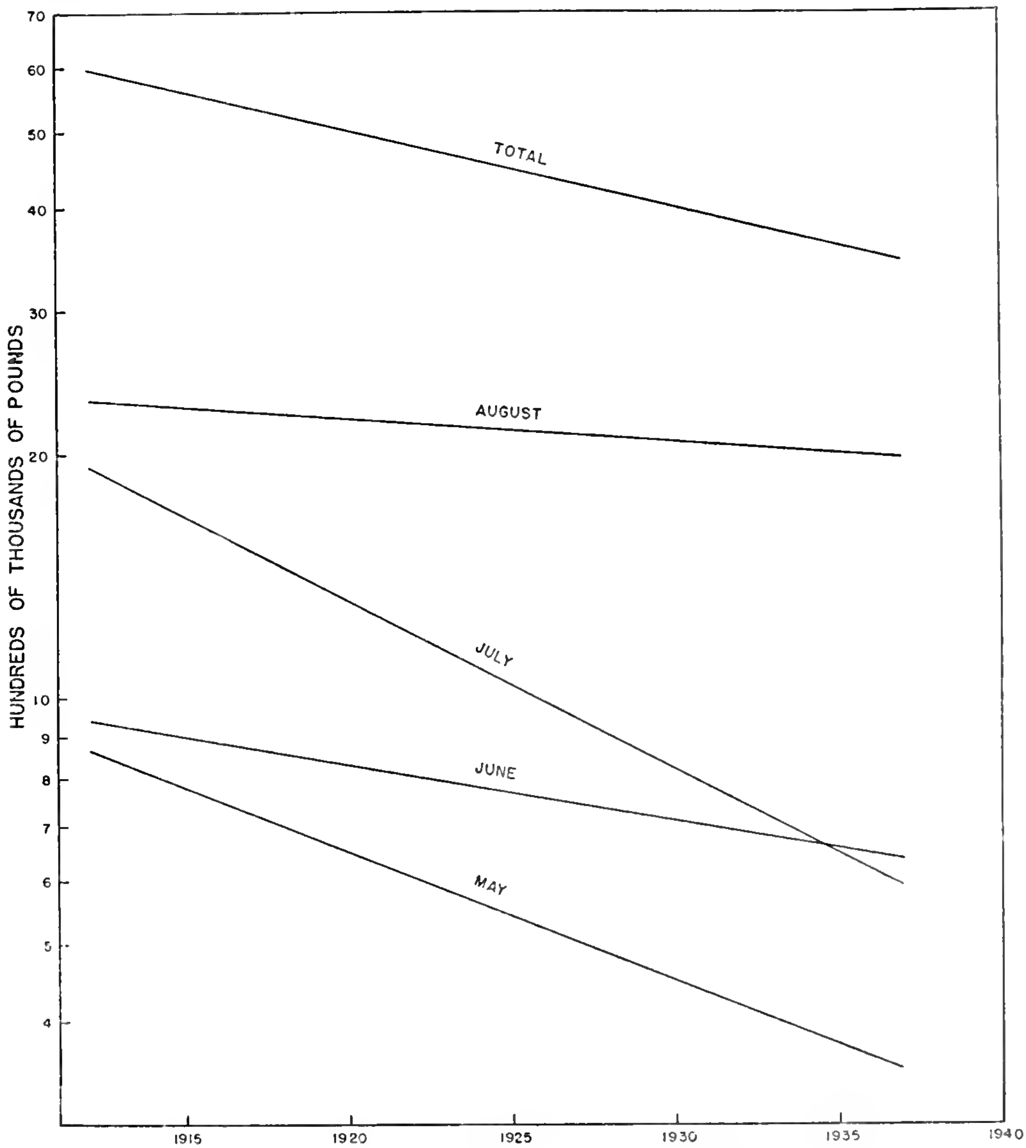

FIGURE 4.—Trends of the total monthly deliveries to the Columbia River Packers Association, 1912-37.

practically no catch on that day, but there was a distinct tendency for the catches to be highest early in the week and to drop gradually toward the end of the week. The natural interpretation was that during the Sunday closed period a body of fish entered the river and on Monday (actually beginning Sunday evening) there were available to the fishermen, in addition to those left at closing time on Saturday, all of the fish that had entered the river and that were free of all commercial fishing during an entire day; 6 pm. Saturday to 6 pm. Sunday. The effect of this accumulation was to increase the catch during the following day or two, but it wore off until, by the end of the week, little if any effect of the closed period remained. The character of the cycle obviously has been determined by the combined influence of a Sunday closed period and a very intensive fishery which, as shown above, takes approximately 80 percent of the fish entering the river during these 2 months.

As an additional line of evidence of a dangerous intensity of fishing we have examined in some detail the daily catches and, for comparison, the daily count at Bonneville Dam for the months of June and July, with attention to the variations in catch and count within weeks; in other words, with respect to the variation that is associated with the day of the week on which the catch or the count was made. The data are presented in table 17, together with certain derived figures. From the figures of catch and count given we have calculated for each week day, excluding Sunday in dealing with catches, (1) the mean of the total deliveries for that day of the week during the 8 weeks under investigation, (2) the mean percentage of the total catch for the week, (3) the mean delivery per gill net, and (4) the mean percentage of the weekly total count at Bonneville. These values are presented in table 18. It is apparent that all three measures relating to the catch show much the same thing; namely, that there is a fairly constant and uniform decrease during the first half of the week, while the catch during the last half is relatively stable and at a much lower level. On the other hand, no such progression is apparent in the count at Bonneville. This is as one would expect in view of the fact that has just been demonstrated—that the intensive fishery takes out of the run during the first 3 days of the fishing week a very large part of the fish that have entered the river during the Sunday closed period.

TABLE 17.—*Daily catch of chinook salmon in Zones 1 and 2, June 5 to July 30, 1938, and Bonneville count for corresponding runs, June 19 to August 13, with derived figures showing fluctuations in catch during the week*

Date	Total, all gear	Total, gill nets only	Number of gill-net deliveries	Mean catch per delivery	Percentage of weekly total	Bonneville count	Percentage of weekly total
	Pounds	*Pounds*					
June 5 Su	605	605	7	86	0.7	260	11.7
June 6 M	17,612	17,612	288	61	19.5	283	12.7
June 7 Tu	16,047	16,047	291	55	17.8	318	14.3
June 8 W	13,499	13,499	244	55	15.0	422	18.9
June 9 Th	15,867	15,867	240	66	17.6	283	12.7
June 10 F	14,353	14,353	246	58	16.0	446	20.0
June 11 Sa	12,139	12,139	235	51	13.5	218	9.8
June 12 Su					0.0	191	15.4
June 13 M	19,462	19,462	335	58	15.1	191	15.4
June 14 Tu	20,542	20,519	336	61	15.8	167	13.5
June 15 W	23,412	23,134	358	65	18.1	159	12.8
June 16 Th	19,502	19,025	324	59	15.1	243	19.6
June 17 F	21,767	20,804	318	65	16.8	159	12.8
June 18 Sa	24,681	21,915	337	65	19.1	130	10.5
June 19 Su	368	368	4	92	0.2	231	24.1
June 20 M	40,894	35,627	416	86	20.8	243	25.4
June 21 Tu	39,249	35,039	429	82	20.0	128	13.4
June 22 W	32,141	26,481	374	71	16.3	113	11.8
June 23 Th	27,200	21,596	332	65	13.8	133	13.9
June 24 F	23,979	19,578	308	64	12.2	36	3.8
June 25 Sa	32,808	23,850	366	65	16.7	[1] 0	7.7
June 26 Su	389				0.2	149	4.2
June 27 M	42,683	37,596	421	89	22.2	79	4.4
June 28 Tu	38,411	34,501	419	82	20.0	[1] 0	17.3
June 29 W	33,043	31,638	391	81	17.2	618	17.3
June 30 Th	27,712	25,871	354	73	14.4	471	26.4
July 1 F	23,605	21,452	328	66	12.3	261	14.6

[1] The ladders were closed this day because of manipulation of the water levels. In calculating the percentage of the weekly total, the count of the following day was divided equally between the two days.

TABLE 17.—*Daily catch of chinook salmon in Zones 1 and 2, June 5 to July 30, 1938, and Bonneville count for corresponding runs, June 19 to August 13, with derived figures showing fluctuations in catch during the week*—Continued

Date	Total, all gear	Total, gill nets only	Number of gill-net deliveries	Mean catch per delivery	Percentage of weekly total	Bonneville count	Percentage of weekly total
	Pounds	*Pounds*					
July 2 Sa.	26, 612	23, 951	370	65	13. 8	277	15. 6
July 3 Su.	1, 413	374	11	34	0. 4	254	16. 5
July 4 M.	49, 636	40, 318	396	102	15. 5	231	15. 1
July 5 Tu.	54, 333	44, 373	435	102	16. 9	206	13. 4
July 6 W.	51, 809	38, 866	419	93	16. 2	239	15. 6
July 7 Th.	59, 254	42, 447	461	92	18. 5	231	15. 1
July 8 F.	54, 530	36, 775	474	78	17. 0	201	13. 1
July 9 Sa.	49, 862	34, 826	496	70	15. 5	172	11. 2
July 10 Su.	3, 697	30	1	30	1. 4	213	12. 2
July 11 M.	72, 215	57, 578	516	111	27. 3	270	15. 4
July 12 Tu.	52, 111	39, 005	492	79	19. 3	288	16. 4
July 13 W.	47, 137	36, 259	476	76	17. 8	209	11. 9
July 14 Th.	36, 822	27, 852	440	63	13. 9	212	12. 1
July 15 F.	29, 583	22, 352	394	57	11. 2	297	16. 9
July 16 Sa.	22, 313	15, 561	328	48	8. 5	264	15. 1
July 17 Su.	2, 591	460	5	92	1. 0	241	18. 2
July 18 M.	49, 528	39, 839	460	87	18. 4	285	21. 5
July 19 Tu.	46, 097	33, 295	440	76	17. 2	189	14. 2
July 20 W.	40, 653	27, 363	410	67	15. 2	201	15. 2
July 21 Th.	32, 998	22, 681	364	62	12. 3	163	12. 3
July 22 F.	40, 156	29, 917	367	82	15. 0	160	12. 1
July 23 Sa.	56, 263	36, 345	378	96	21. 0	88	6. 6
July 24 Su.	6, 021	285	4	71	1. 4	264	6. 3
July 25 M.	87, 161	56, 639	485	117	20. 0	259	6. 2
July 26 Tu.	79, 155	59, 637	470	127	18. 1	476	11. 4
July 27 W.	81, 890	64, 596	545	119	18. 8	445	10. 7
July 28 Th.	60, 369	51, 119	494	103	13. 8	1, 102	26. 4
July 29 F.	63, 156	53, 332	485	110	14. 5	870	20. 4
July 30 Sa.	57, 918	52, 139	530	98	13. 3	747	18. 0

TABLE 18.—*Variation in certain features of the chinook salmon catch in Zones 1 and 2 and of the Bonneville count during June and July, related to the days of the week*

Day of the week	Thousands mean total catch	Mean percentage of weekly total	Mean delivery per gill net	Mean percentage of weekly total of Bonneville count
Sunday				13. 6
Monday	47. 4	19. 8	88. 9	14. 5
Tuesday	43. 2	18. 1	83. 0	14. 2
Wednesday	40. 5	16. 8	78. 4	14. 3
Thursday	35. 0	14. 9	72. 9	17. 4
Friday	34. 9	14. 4	72. 5	14. 2
Saturday	35. 2	15. 2	69. 8	11. 8

The intensity with which the June–July run is being exploited is shown in still another way by comparing the change in the weekly totals of the catch with the weekly totals of the Bonneville count for the corresponding weeks. These data are given in table 12, where the two series may be readily compared. It is seen that the catch below Bonneville during June and July constantly increased from 2,636 fish in the week of June 4, to 16,363 fish in the week ending July 30. At the same time the number of fish passing the Bonneville Dam remained, except for the last week, below the count for the first week of the period. It is obvious that the effect of an increased run entering the river is not felt at Bonneville—a result, without doubt, of a concurrent increase in the intensity of fishing. It is to be noted that the record of the catch above Bonneville Dam agrees with that of the Bonneville count, and thus supports this interpretation. As a measure of this intensity we may take the total number of landings per week derived from the figures given in table 17, and shown in the following statement:

Total number of deliveries per week in Zones 1 and 2 during June and July

Week ending	Deliveries
June 11	1, 551
June 18	2, 008
June 25	2, 229
July 2	2, 283
July 9	2, 692
July 16	2, 647
July 23	2, 424
July 30	3, 013

It is shown by the preceding statement that the number of deliveries practically doubles during the months of June and July—an increase in fishing effort that could readily account for the fact that the count at Bonneville Dam does not increase, although there is better than a fourfold increase in the number of fish taken in the fishery in Zones 1 and 2.

In this connection it has been of interest to determine something of the relationship that exists between the abundance of fish as measured by the average poundage per delivery and the number of deliveries. The number of deliveries may be taken as a fair measure of the number of men fishing. We have, therefore, taken these two series of values from table 17 and calculated the coefficient of correlation. This proved to be +0.75. The interpretation is quite clear that the abundance of fish, as shown by the size of the individual catches, is an important factor in determining the number of fishermen that will fish.

INTENSITY OF FISHING IN GENERAL

The runs of chinook salmon considerably outweigh in importance and value the runs of all other species in the Columbia River fishery combined. Of the entire run the part that enters the river during spring and early summer, April to July inclusive, is the most valuable on account of the fine quality of the fish. This part of the run, perhaps more than any other, has been adversely affected by the reduction of spawning areas and localities suitable for the rearing of the young fish that has attended the utilization of the water resources in the headwaters, especially for power and irrigation. Since the salmon industry began on the Columbia River the chinook has been the mainstay of the fishery and the most relentless exploitation has fallen upon the spring run.

It has been shown above that the present intensity of fishing is such that, in 1938, over 80 percent of the spring run and between 60 and 70 percent of the main fall run of chinook salmon were taken in the commercial fishery. In this connection it is pertinent to recall that in the regulation of the Alaska salmon fisheries the Federal Government, acting through the Fish and Wildlife Service, has adopted the principle that the escapement should be not less than 50 percent of the entire run. There are sound theoretical grounds for thinking that the maximum sustained yield of the salmon fisheries can be maintained with an escapement of this order of magnitude, and the practical results obtained with the Alaska fisheries support this view. It seems reasonably certain that, at least for the spring run of chinooks on the Columbia, the escapement is well below the level that would provide the maximum sustained yield.

Such regulations and restrictions as have been imposed upon the Columbia River salmon fisheries apparently have very little effect insofar as they may act to reduce the intensity of fishing and provide a greater escapement of breeding fish to the spawning grounds. It is to be noted that in the lower river the peaks of both spring and fall runs come within the spring open season so that, insofar as the fishery in the lower river is concerned, the main portions of both runs are exposed to the full force of the exploitation. There is the weekly closed period from 6 pm. Saturday to 6 pm. Sunday that is in force during the spring fishing season, May 1 to August 25, but it has already been shown that this has little value from the standpoint of conservation; its chief effect being to spread the fishery out over a longer stretch of the river. Again it has been shown that whatever effect the closed season, August 25 to September 10, may have in increasing the escapement through the lower river, it is largely offset by the intensive fishery that exists during September and October above Bonneville Dam. In a larger way this closed season acts much the same as does the weekly closed period, and chiefly tends to distribute the fishery over a wider area without materially increasing the breeding population. The effect of the closed season may be seen by examining table 19, which is a diagram representing the passage of a series of stocks of

TABLE 19.—*Effect of a two-week closed period on the stocks of fish passing up the river at the assumed rate*

[Letters represent stocks of fish]

Week	Position of stock		
	Zones 1 and 2	Zones 3 to 5	Bonneville and Zone 6
1	A		
2	B	A	
3	C	B	A
4	D	C	B
5	**E**	**D**	**C**
6	**F**	**E**	**D**
7	G	F	E
8	H	G	F
9		H	G
10			H

NOTE.—Bold-face letters represent closed period.

fish through the fishing district at the rate we have assumed to hold. It is obvious from this diagram that there is no stock of fish that is wholly protected from exploitation by the closed season. For example, stock C is only protected by the closed season from exploitation in Zone 6; stock D is protected in Zones 3 to 6; stock E in Zones 1 to 5; and stock F in Zones 1 and 2 only. But, on the other hand, stock C is open to the very intensive exploitation below Bonneville just before the closed season, and stock D to the fishery in Zones 1 and 2 where a very large part of the total catch is made during the week just before the closed season. Stock E, however, is completely protected from the fishery below Bonneville but is exposed immediately after the closed season to the much intensified fishery above Bonneville. Stock F is protected from the fishery in Zones 1 and 2 only, and also feels the full force of the intensified fishery above Bonneville, while stock G, entering the river at the end of the closed season, is given no protection at all. The closed season undoubtedly does help to increase the escapement to some degree, but it seems very probable that the heavy, concentrated run that enters the river during August and September is actually less intensively fished than is the spring run. This lowered fishing intensity is perhaps due in part to reduced effort by the fishermen, brought about by the lower price received for the fish, and also to the fact that with constant effort the percentage of fish caught when the run is light is probably greater than when the run is heavy. The actual catch per unit of effort is, of course, greater with the heavier run, but the efficiency of the total effort, as measured by the ratio of catch to escapement, is probably inversely related to the intensity of the run.

Within the last few years the use of fish wheels has been entirely eliminated, and the use of traps greatly curtailed. Ostensibly these restrictions were imposed in the interest of conservation, but they could only be effective insofar as they increased the escapement of fish to the spawning grounds, and correspondingly decreased the commercial catch. It seems rather doubtful that these restrictions have actually had this result, although the available data are inadequate either to prove or disprove the point. It may well be, however, that the elimination of these two forms of gear has only resulted in increasing the catch of other forms, without materially increasing the breeding stock.

On the whole it would appear that the chinook salmon runs of the Columbia River are subjected to an exceedingly intensive fishery without any effective protection whatsoever, except such as has been afforded by the elimination of certain forms of gear and by artificial propagation.

PERCENTAGE OF GRILSE

Along with the larger fish that form the bulk of the chinook salmon run there are always some smaller fish, from 2 to 10 pounds in weight, that are commonly designated as "grilse," or, among the Columbia River fishermen, "jack salmon," or simply "jacks." These are practically all males that have become sexually mature 1 or 2 years younger than the average and have, perforce, joined the spawning migration. It has been shown by Gilbert, Rich, and others that most grilse are in their second and third years, while the larger fish are in their fourth, fifth, or sixth years. In counting the fish past Bonneville Dam an effort has been made to record these grilse separately, as shown in table 7, and a study of these records has shown some interesting and significant fluctuations in the percentages of these smaller fish (fig. 5).

It is apparent from this graph that, except for 2 periods during which the percentage of grilse is consistently low, the average is about 20 percent. The fluctuations that involve only individual weeks may be taken as due to "sampling error," but those that extend over several weeks and show consistent change challenge some other explanation.

The 2 periods that show consistently low percentages are those covering the weeks ending June 25 to July 16, and those ending September 10 to September 24. We have already explained the lower percentages of the first period as probably due to confusion of chinook grilse with blueback salmon during the peak of the run of this last species. The second period is that during which the Bonneville count is greatly increased on account of the closed season from August 25 to September 10. The explanation is obvious. A very large part of the total catch of chinooks in the river below Bonneville is made by means of gill nets, and this type of gear is selective—taking more of the larger fish and permitting most of the smaller ones to pass through. During the closed period this selection is not operating, and both large

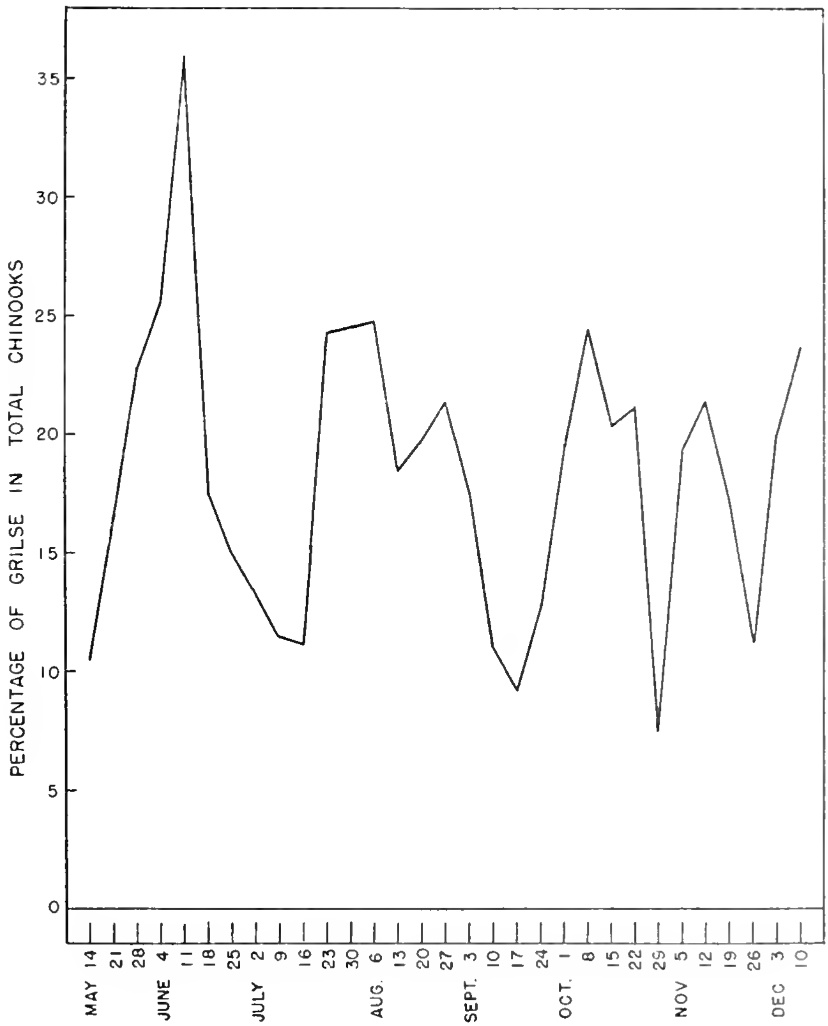

FIGURE 5.—Percentage of grilse in the Bonneville count for 1938, by weeks.

and small fish pass through the lower river and arrive at Bonneville with their proportions practically unmodified.

The grilse passing Bonneville during the 2 weeks ending September 10 and 17 (the weeks in which the run has been least affected by the intensive fishery in the lower river) form approximately 10 percent of the total count, so that it seems probable that this figure is not far from the correct one for the fall run as a whole. This is approximately half of the percentage of grilse found both earlier and later in the season—a fact which supports a previous conclusion based on quite different data, that well over half of the fish that enter the river after the first of August are captured before they can reach Bonneville. If a greater percentage of the larger fish are caught it naturally follows that the percentage of grilse at Bonneville would be approximately doubled.

BLUEBACK SALMON

TABLE 20.—*Blueback salmon run, Columbia River 1938*

[Catch in number of fish estimated on the basis of an average weight of 3 pounds. Data combined and arranged by corresponding weeks]

Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch below Bonneville	Bonneville count	Catch above Bonneville	Total catch	Rock Island count	Total run
Apr. 30				131				131
May 7				572				572
May 14				318				318
May 21	2		2	24		2		26
May 28				153	1	1	2	153
June 4	1		1	1,358	68	69	80	1,359
June 11	21	740	761	5,719	957	1,718	139	6,480
June 18	3,470	7,570	11,040	15,441	5,104	16,144	871	26,481
June 25	28,000	10,470	38,470	16,491	9,123	47,593	8,958	54,961
July 2	25,900	8,715	34,615	21,673	9,774	44,389	4,530	56,288
July 9	15,340	2,960	18,300	7,835	5,916	24,216	1,234	26,135
July 16	3,030	610	3,640	2,770	1,320	4,960	677	6,410
July 23	300	52	352	1,125	375	727	266	1,477
July 30	46	2	48	621	137	185	93	669
Aug. 6	5		5	279	19	24	43	284
Aug. 13		16	16	209	5	21	35	225
Aug. 20				156			37	156
Aug. 27				76			96	76
Sept. 3				71			61	71
Sept. 10				10			0	10
Sept. 17				1			0	1
Sept. 24				0			0	0
Oct. 1				3			1	3
Oct. 8				1				1
Oct. 15				1				1
Oct. 22				0				0
Oct. 29				2				2
Total	76,115	31,135	107,250	75,040	32,799	140,049	17,123	182,290

TABLE 21.—*Blueback salmon run, Columbia River, 1938*

[Catch in number of fish estimated on the basis of an average weight of 3 pounds below Bonneville and of 2½ pounds above Bonneville. Data combined and arranged by corresponding weeks]

Week ending	Catch in zones 1 and 2	Catch in zones 3 to 5	Total catch below Bonneville	Bonneville count	Catch above Bonneville	Total catch	Rock Island count	Total run
Apr. 30				131				131
May 7				572				572
May 14				318				318
May 21	2		2	24		2		26
May 28				153	2	2	2	153
June 4	1		1	1,358	81	82	80	1,359
June 11	21	740	761	5,719	1,149	1,910	139	6,480
June 18	3,470	7,570	11,040	15,441	6,125	17,165	871	26,481
June 25	28,000	10,470	38,470	16,491	10,950	49,420	8,958	54,961
July 2	25,900	8,715	34,615	21,673	11,730	46,345	4,530	56,288
July 9	15,340	2,960	18,300	7,835	7,100	25,400	1,234	26,135
July 16	3,030	610	3,640	2,770	1,580	5,220	677	6,410
July 23	300	52	352	1,125	450	802	266	1,477
July 30	46	2	48	621	164	212	93	669
Aug. 6	5		5	279	23	28	43	284
Aug. 13		16	16	209	6	22	35	225
Aug. 20				156			37	156
Aug. 27				76			96	76
Sept. 3				71			61	71
Sept. 10				10			0	10
Sept. 17				1			0	1
Sept. 24				0			0	0
Oct. 1				3			1	3
Oct. 8				1				1
Oct. 15				1				1
Oct. 22				0				0
Oct. 29				2				2
Total	76,115	31,135	107,250	75,040	39,360	146,610	17,123	182,290

Data on the blueback run are presented in modified form in tables 20 and 21. As previously stated (p. 114), two methods have been applied in changing the poundage records to numbers of fish; (1) assuming an average weight of 3 pounds throughout the season in all zones, and (2) assuming an average of 3 pounds throughout the

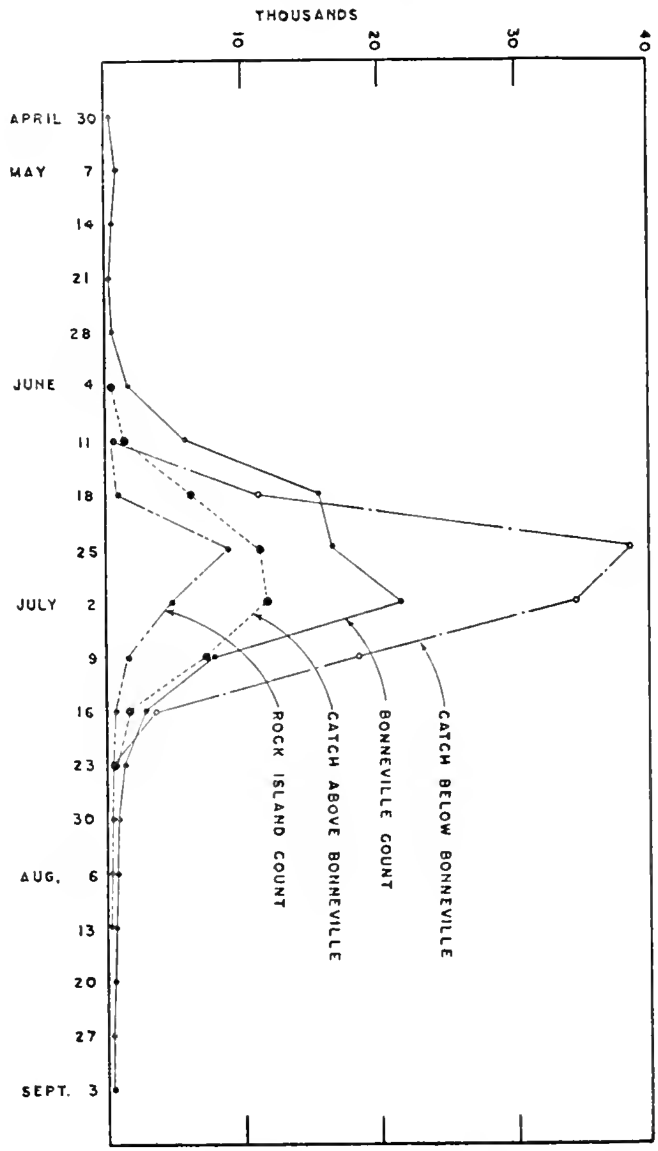

FIGURE 6.—Dominant elements in the 1938 blueback salmon run, by weeks.

season below Bonneville and of 2½ pounds throughout the season above Bonneville. The first method gives the figures of table 20 and the second those of table 21. It is known that the fish caught above Bonneville are smaller than those caught below on account of the selective effect of the gill nets which provide a large portion of the catch below Bonneville, while the catch above Bonneville is made largely by means of dip nets which are not selective. These conversion figures are based on data secured from Harlan B. Holmes, of the Fish and Wildlife Service.

The general features of the run are much simpler than in the case of the chinook salmon just considered. There is a single, well defined peak formed by fish that enter the lower part of the river late in June and early in July. The first fish of this species to appear in the records were in the Bonneville count for the second week in May, and a few were counted past the dam during the next 4 weeks. It was not until the week ending June 18, however, that bluebacks began to show up in large numbers at Bonneville. From that time on for the next 6 or 7 weeks bluebacks were a very important element in the Bonneville count, but after the first of August their numbers dwindled rapidly although a few were recorded as late as the second week in November (table 7). It is to be noted that bluebacks did not appear in the catch of corresponding weeks as early as they were recorded in the Bonneville count, nor as late (tables 20 and 21). This is probably due in part to the use of small-meshed nets especially adapted for catching bluebacks while this species is most abundant; and also in part to inaccurate identification in the Bonneville count. Evidence has been given above to show that during the height of the blueback run there is a tendency to mistake the smaller chinooks (grilse) for bluebacks. It seems not unreasonable to suppose that the same error may also be made while bluebacks are scarce (or even entirely absent) which would account for the very long "tails" to the time-frequency curve given in figure 6, since these tails are formed almost entirely from the fish recorded in the Bonneville count (tables 20 and 21).

There are no complications due to spawning below Bonneville because in all probability all of the fish of this species spawn in streams tributary to lakes far above the upper limits of commercial fishing. The bluebacks of the Columbia undoubtedly represent a number of races, populations, or stocks, each breeding in its "home" lake basin; but so far as the immediate problems are concerned they act from the mouth of the Columbia to Celilo as a unit run. Above Celilo not much is known of the representative races; the available data consist chiefly of the counts made at the Rock Island Dam.

In preparing the modified tables for the blueback run the same rate of migration up the river has been assumed as for chinooks; i. e., that fish that were in Zones 1 and 2 in the first week would be found in Zones 3 to 5 the second week, at Bonneville and between Bonneville and Celilo during the third week, and at Rock Island the fifth week. The data in tables 20 and 21 and figure 6 show that this assumption is well justified, since the conspicuous peaks are made to coincide almost perfectly.

These data have been analyzed by applying methods similar to those used in the study of the chinook salmon. From the totals given in table 20 it may be seen that, for the entire season, the ratio of the estimated number of fish taken in the commercial fishery to the estimated escapement is approximately 3.32:1. In other words, as shown by this estimate, over 3 fish are caught to 1 that escapes, passes through the commercial fishing area, and becomes available on the spawning grounds for perpetuating the run. The Rock Island count was 17,123. Multiplying this by the ratio of catch to escapement gives 56,800 as an estimate of the number of fish caught out of the populations normally spawning in the Columbia River above Rock Island. Reconverting this to pounds by multiplying by 3 gives a total of 170,000 pounds caught that may be attributed to the runs spawning above Rock Island.

These figures are based upon a consideration of the catch and escapement for the entire spring season up to and including August 25, and the total Rock Island count.

For the bluebacks this comprises practically the entire season. But there is evidence that the catch during the central portion of the season constitutes a higher percentage of the run than at the beginning and end of the run—in other words that the fishing is more intense while the fish are most abundant. For the period covered by the weeks ending June 11 to July 16 the estimated number of fish caught is 139,000, while the escapement is 37,600; giving a ratio of catch to escapement of 3.69:1. Applying this ratio to the Rock Island count for the period gives an estimate of 60,500 fish weighing 181,500 pounds that may be attributed to the Rock Island runs during this period only.

The percentage that the Rock Island count constitutes of the total estimated escapement of this species is a measure of the relative importance of the Rock Island runs in the total. On the basis of the entire season the percentage is 40.58, and on the basis of the central, more important period of 6 weeks, the percentage is 43.55. From these figures it appears that approximately four-tenths of the entire run of bluebacks on the Columbia River in 1938 was composed of fish derived from the runs to the upper Columbia River, and that the aggregate commercial catch was approximately 182,000 pounds.

The application of the second method for converting poundage figures into numbers of fish increases the estimate of the number of fish taken above Bonneville, and correspondingly decreases the estimated number in the escapement—since this is derived by subtracting the estimated catch above Bonneville from the Bonneville count. As shown in table 21, it gives an estimate of 39,400 bluebacks taken above Bonneville, instead of 32,800, on the assumption of an average weight of 3 pounds. The estimated escapement is reduced to 35,600 from 42,200; the ratio of catch to escapement is 4.11:1, and the percentage of the total escapement later counted at Rock Island is 48.05. The total catch and poundage attributable to the Rock Island runs can be determined by multiplying separately the catches made above and below Bonneville by the percentage of Rock Island fish in the whole run (48.05 percent). For the number of 3-pound fish caught below Bonneville this gives 51,500, and for the number of 2½-pound fish caught above Bonneville 18,900—a total of 70,400 fish with an aggregate weight of 202,000 pounds. A similar estimate for the period from June 5 to July 16 gives a ratio of catch to escapement of 4.66:1, and the percentage of Rock Island fish in the total run is 52.57. The total catch on the basis of these ratios is 76,500 fish of an aggregate weight of 219,300 pounds.

These estimates show quite conclusively that in 1938 about half of the blueback run was derived from the tributaries above Rock Island; that about four fish were caught in the commercial fishery for every one that was left to propagate, and that the total weight of the fish taken in the commercial fishery and derived from the Rock Island runs was of the order of 200,000 pounds.

STEELHEAD TROUT

TABLE 22.—*Steelhead trout run, Columbia River, 1938*

[Catch in number of fish estimated on the basis of an average weight of 10 pounds. Data combined and arranged by corresponding weeks]

Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch below Bonneville	Bonneville estimate and count	Catch above Bonneville	Total catch	Rock Island count	Total run
Feb. 5				55				55
Feb. 12				158				158
Feb. 19				204				204
Feb. 26				980				980
Mar. 5				1,267				1,267
Mar. 12				84				84
Mar. 19				981			49	981
Mar. 26				7,319			222	7,319
Apr. 2				1,927			143	1,927
Apr. 9				639			243	639
Apr. 16				320			67	320
Apr. 23				138	130	130	55	138
Apr. 30		179	179	3,217	325	504	395	3,396
May 7	718	111	829	1,622	221	1,050	100	2,451
May 14	554	34	588	1,644	120	708	53	2,232
May 21	318	27	345	164	74	419	28	509
May 28	215	4	219	632	50	269	29	851
June 4	120	6	126	652	26	152	8	778
June 11	179	34	213	520	42	255	1	733
June 18	852	195	1,047	641	45	1,092	4	1,688
June 25	3,829	444	4,273	800	83	4,356	12	5,073
July 2	5,880	1,445	7,325	4,061	103	7,428	60	11,386
July 9	15,418	3,010	18,428	7,161	620	19,048	62	25,589
July 16	12,693	3,302	15,995	6,667	352	16,347	57	22,662
July 23	9,354	1,623	10,977	4,886	386	11,363	45	15,863
July 30	9,647	1,304	10,951	6,086	1,578	12,529	25	17,037
Aug. 6	5,292	1,638	6,930	6,457	2,086	9,016	33	13,387
Aug. 13	13,924	2,221	16,145	6,908	1,157	17,302	56	23,053
Aug. 20	10,540	1,783	12,323	17,689		12,323	97	30,012
Aug. 27	6,266		6,266	15,814		6,266	200	22,080
Sept. 3				13,744	12,640	12,640	90	13,744
Sept. 10		2,160	2,160	3,935	9,970	12,130	126	6,095
Sept. 17	920	1,860	2,780	1,204	2,300	5,080	39	3,984
Sept. 24	4,170	750	4,920	857	1,070	5,990	34	5,777
Oct. 1	2,150	300	2,450	604	490	2,940	67	3,054
Oct. 8	730	150	880	230	150	1,030		1,110
Oct. 15	440	110	550	253	290	840		803
Oct. 22	430	80	510	152	130	640		662
Oct. 29	340	110	450	90	8	458		540
Nov. 5	360	140	500	60		500		560
Nov. 12	740	160	900	58		900		958
Nov. 19	830	290	1,120	30		1,120		1,150
Nov. 26	1,060	240	1,300	43		1,300		1,343
Dec. 3	810	180	990	18		990		1,008
Dec. 10	2,090	120	2,210	1		2,210		2,211
Dec. 17	1,070	200	1,270	13		1,270		1,283
Dec. 24	770	170	940			940		940
Dec. 31	1,010		1,010			1,010		1,010
Total	113,719	24,380	138,099	120,985	34,446	172,545	2,400	259,084

TABLE 23.—*Catch and escapement of steelhead trout by selected and corresponding periods*

Period	Catch below Bonneville	Bonneville count	Catch above Bonneville	Total catch	Estimated escapement past Celilo	Rock Island count
Apr. 17–May 28	2,160	7,416	920	3,080	6,496	660
May 29–July 30	69,335	31,474	3,235	72,570	28,239	274
July 31–Sept. 24	51,524	66,608	29,223	80,747	37,385	675
Sept. 25–Dec. 31	15,080	1,552	1,068	16,148	484	[1] 67

[1] Incomplete.

TABLE 24.—*Steelhead trout, significant ratios between elements of the run*

Period	Total catch to escapement	Catch below Bonneville to—		Catch above Bonneville to—		Rock Island count to escapement
		Total catch	Bonneville count	Total catch	Bonneville count	
Apr. 17–May 28	0.48	0.702	0.291	0.298	0.124	0.101
May 29–July 30	2.57	.955	2.200	.045	.103	.010
July 31–Sept. 24	2.16	.638	.773	.362	.439	.017
Sept. 25–Dec. 31	33.35	.934	9.716	.066	.688	.139

Table 22 gives the data relative to steelhead trout in modified form. The catch figures have been converted to number of fish on the basis of an average weight of 10 pounds throughout the season and in all zones. Tables 23 and 24 present some of these data and certain derived figures for selected periods that have particular signific-

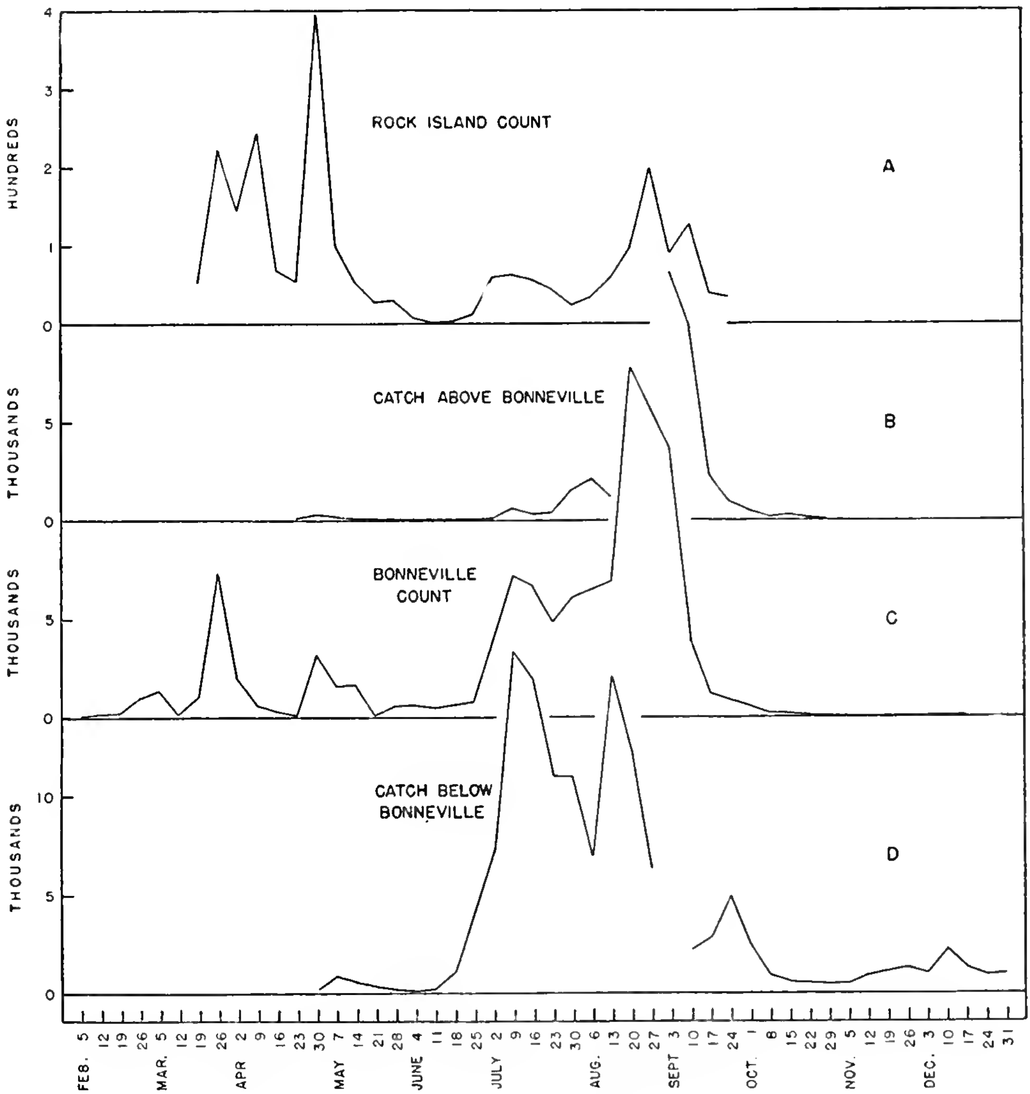

FIGURE 7.—Dominant elements in the 1938 steelhead trout run, by weeks.

ance. In preparing these tables and the graph (fig. 7) the same rate of travel has been assumed as proved satisfactory for the study of the chinooks and bluebacks, and the results appear to justify this assumption.

From table 22 and figure 7 it is apparent that the steelhead run extends broadly over the entire year, although the major part of the run comes during summer and early fall months—from the middle of June to about the first of October. This major portion shows 2 well marked modes, one at the week of July 9 and the other at the week of

August 20. These 2 modes are clearly indicated in each of the component elements into which it has been possible to divide the run as a whole—except possibly the catch above Bonneville Dam (fig. 7). The exact significance of these 2 modes is not apparent, but it is evidently a real phenomenon so far as the run of 1938 is concerned.

In addition to these 2 major modes there are at least 3 minor modes; one centering about the week of March 26, another about the week of May 7, and a third about the week of December 10. It is quite probable that each of these modes, both major and minor, represent races (stocks) or groups of races that dominate the run at those times. Only future observations will show how constant these modes are from year to year, and to which part of the Columbia Basin the fish go for spawning.

The run that centers about the week of March 26 evidently enters and passes through the lower river before the commercial fishing season opens. Up to the week ending April 16 the escapement of steelhead, as shown by the estimate of fish passing Bonneville, amounted to 13,934 fish, of which 724 were later counted over the dam at Rock Island—slightly over 5 percent. This part of the run is practically untouched by the commercial fishery. It should be kept in mind that, for this and the following period, the records of the number of fish of each species passing Bonneville is only an estimate based on "spot counts." It was not until May 7, 1938, that actual counting through gates placed in the fish ladders was begun.

For purposes of study we have separated the portion of the run from which the commercial catch is made into four parts—dividing them, first, at about the center of the period of scarcity that includes the latter half of May and the first half of June; secondly, between the 2 major modes, and finally separating the late fall run from the preceding portion that contained the second major mode. For the first period, April 17 to May 28, the total catch was 30,800 pounds, or 3,080 fish, on the basis of an average weight of 10 pounds. The estimated escapement past Zone 6 was 6,496, and the Rock Island count 660. The ratio of catch to escapement was only 0.48:1, and the percentage of the total run that may be referred to the upper Columbia races is 10.1. The estimated number of Rock Island fish in the total commercial catch is 311, with an aggregate weight of 3,110 pounds.

The second period extends from May 29 to July 30, roughly the months of June and July, and includes the first major mode. The total catch from the fish that entered the river at this time was nearly 750,000 pounds—some 72,500 fish. The estimated net escapement was less than 30,000 fish—the ratio of catch to escapement 2.57:1. Of this escapement only about 1 percent can be referred to the races breeding in the tributaries above Rock Island Dam. By inference only some 7,000 pounds of the total catch for the period can be considered as deriving from these races.

In the period from July 31 to September 24, the ratio of total catch to escapement was 2.16:1. This was not greatly different from that of the preceding period, but the catch was very differently distributed. Whereas, in the period from May 29 to July 30, only 4.5 percent of the total catch was made above Bonneville, in the next period, covering roughly the months of August and September, over 36 percent of the total catch came from the river above the dam. The estimated net escapement was over 37,000 fish. This was an increase of some 9,000 over that of June and July—a little over 30 percent.

It might have been expected that the closed season from August 25 to September 10 would have had a more favorable effect upon the escapement of those stocks of fish that form the second of the two major peaks—roughly those that enter the river during the months of August and September. The count at the Bonneville Dam during these months was over twice that of the preceding 2 months, during which the first of the 2 major peaks appeared. A more complete examination of the data in table 22, however, shows that this improvement in the Bonneville count is by no means indicative of a corresponding improvement in the net escapement because the intensive fishery above Bonneville during September and October takes such a large number of steelheads that the actual escapement past the upper end of the fishing district is, relatively, not much greater than in the preceding period. The ratio of total catch to net escapement during June and July is 2.57:1, and during August and September is 2.16:1. (Both catch and escapement figures are, of course, estimates, and the periods of time are to be referred to the marginal dates of table 22.) It is to be noted that these ratios are considerably higher than 1.65:1, which was the figure given in the original report for the months of June, July, and August. The difference is obviously due to the fact that the data now available are much more complete, containing those for the last half of the main run as well as for the first half.

The steelhead run of the final period to be considered, from September 25 to the end of the year, is much less important than that of the two periods just considered and is characterized particularly by the relatively slight importance of the part of the run that passes Bonneville. The total count at Bonneville was only 1,552 steelhead trout, and the catch in the river below the dam was nearly 10 times as great. It is clearly indicated that the steelheads spawning in the tributaries below Bonneville form a much larger part of the late fall run than of those entering the river previous to September 25. Of the steelheads that do pass Bonneville, however, the data appear to show that a relatively large percentage spawn in the Columbia above Rock Island.

The last column of table 24 shows the percentages of Rock Island fish in the estimated escapement to the river above Celilo Falls for each of the selected periods. The percentage of Rock Island fish in the run up to April 16 was a little over 5; for the period ending May 28 was over 10 percent; for the period ending July 30 and including the first major mode, only 1 percent; for the period of the second major mode, ending September 24, 1.7 percent; but for the late fall period it was nearly 14 percent. Although the figures are not particularly reliable on account of the relatively few fish involved, it is interesting to note the indication of greater importance of the upper Columbia races in the late fall and winter runs and also in the early spring runs. These data at least indicate that a relatively large percentage of those steelheads that pass Bonneville during fall and winter spawn in the main Columbia River and its tributaries above Rock Island Dam, and that the Rock Island contingent in the main part of the steelhead run is, both absolutely and relatively, of much less importance than in fall and early spring months.

These data also provide some evidence that a larger proportion of late fall fish—entering the river after the first of October—spawn in tributaries below Bonneville. This is shown by the ratios of the catch below Bonneville to the Bonneville count for the different parts of the year (table 24). For the first part of the run to be affected by the commercial fishery, April 17 to May 28, this ratio was 0.291:1—only about one-fourth of the fish entering the river were taken below the dam. During the June and July run the ratio was 2.2:1. During the next 2 months, influenced by the closed period, it dropped to approximately 0.8:1. During the last 3 months of the year, however, the ratio rose to nearly 10:1; i. e., about 10 fish were caught in the river below the dam for every 1 that reached the dam. Various explanations might be offered, but it seems most likely that, as suggested above, it is due to the fact that a large percentage of the fish entering the river during the late fall spawn in tributaries that enter the main river below the dam.

We have discussed the importance of the chinook catch above Bonneville during the first few weeks following the closed period, and the fact that the closed period has more effect in spreading the catch out over a longer fishing area than it has in the way of increasing the spawning escapement. Evidently the same effect is apparent in the case of the steelheads. This shift in the relative importance of the fisheries below and above Bonneville is shown somewhat more clearly by the percentages of

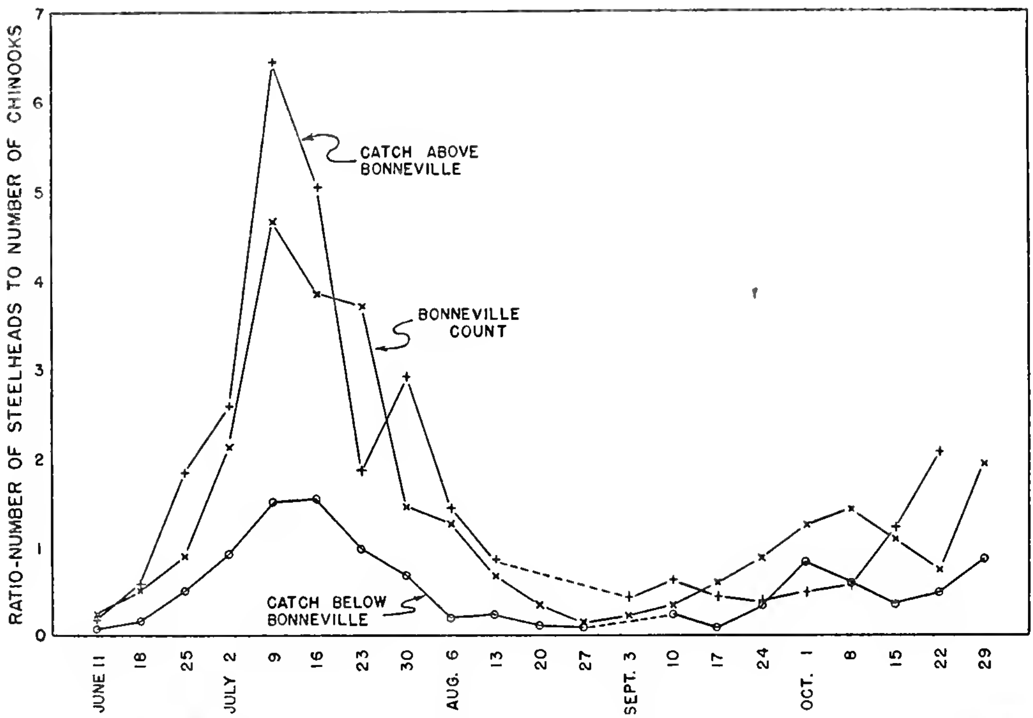

FIGURE 8.—Ratio of steelhead trout to chinook salmon in three important elements of the 1938 run, June 5–October 28, by weeks.

the total catch formed by the catches above Bonneville (table 24). For the months of June and July only 4.5 percent of the total catch was taken above Bonneville, but during August and September the percentage was 36.2. The relation of this to the net escapement also is shown by the percentages that the catch above Bonneville form of the Bonneville count. For the months of June and July only 10.3 percent of the fish counted past Bonneville were later captured in the fishery above the dam. During the months of August and September, however, 43.9 percent was taken.

As with the chinooks, the catch of steelheads above Bonneville during the first few weeks following the closed period of August 25 to September 10 exceeds the Bonneville count. This anomaly has been discussed and there seems to be no reason to doubt that the same factors were operating with the steelheads as with the chinooks. It has seemed possible in the case of the steelheads, however, that this phenomenon might have been the result of misidentification of this species in the Bonneville count—steelheads being mistaken for the much more numerous chinooks. In order to test the possibility of such misidentification on a large scale in the Bonneville count, a study was made of the ratios of the number of steelheads to chinooks in (1) the catch below Bonneville, (2) the Bonneville count, and (3) the catch above Bonneville for each week over the period beginning June 5 and ending October 29. It is to be expected that such series of ratios would vary over the entire period with the relative numbers of fish of the 2 species, but the general trends of the ratios should be similar in the 3 localities in the absence of disturbing factors—such as misidentification in the Bonneville count. Figure 8 is a graph of these ratios wherein ordinary arithmetic coordinates are used, since the absolute values are the significant ones. It is apparent from this that the trends are very similar in the 3 localities; which is evidence that the identification at Bonneville was sufficiently accurate and probably was not responsible for the anomalous fact that more fish were recorded in the commercial catch above Bonneville than were counted over the dam.

The data thus graphed are interesting in themselves in addition to their bearing on this particular problem. It is quite obvious that, in numbers of fish, the steelheads approach the chinooks and, during the June–July period when chinooks are few, greatly exceed them. It is chiefly during the peak of the chinook run in August and September that the ratio is down to about 1:5 in the catch below Bonneville and the Bonneville count. The parallelism in the 3 trends up to about the middle of September is quite striking and is supporting evidence that, for this part of the run, the assumed rate of travel is satisfactory.

SILVER AND CHUM SALMON

As mentioned in the introduction, the purposes of the original report by Calkins, Durand, and Rich were such that consideration of the catches of silver and chum salmon was not important. In this revision, however, it is pertinent to include the data available on these 2 species, and to examine these for whatever light they may throw upon the characteristics of the runs. The general features of the runs of silvers and chums are so similar that it is convenient to treat them together.

The data for these species are given in modified form in tables 25 and 26. In converting poundage to numbers of fish an average weight of 10 pounds per fish has been used for both species. The same rate of migration up the river has been used as with the other species, although the rate of migration of both silvers and chums is more doubtful and of far less significance than in the case of the other species. There is, however, no good evidence that the rate of travel is any different in the case of these 2 species than in the others, although the obvious irregularities in the time at which the main portion of the catches is made in the different zones (tables 4 and 5) lead one to suspect that the rates of travel of these species may be somewhat different. This is a matter that should be investigated, but it is necessary for the present to assume the same rate of travel—which has been done in preparing the modified tables.

TABLE 25.—*Silver salmon run in the Columbia River, 1938*

[Catch in number of fish, assuming an average weight of 10 pounds. Data combined and arranged by corresponding weeks]

Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch	Bonneville count	Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch	Bonneville count
July 30	....	1	1	....	Oct. 29	20, 268	4, 128	24, 396	18
Aug. 6	1	2	3	....	Nov. 5	23, 275	1, 979	25, 254	9
Aug. 13	54	13	67	115	Nov. 12	13, 346	1, 596	14, 942	4
Aug. 20	1, 454	238	1, 692	6, 964	Nov. 19	6, 209	831	7, 040	1
Aug. 27	2, 636	....	2, 636	4, 766	Nov. 26	2, 275	864	3, 139	7
Sept. 3	....	....	....	1, 933	Dec. 3	1, 592	547	2, 139	....
Sept. 10	4	902	906	239	Dec. 10	5, 762	204	5, 966	....
Sept. 17	4, 559	2, 470	7, 029	56	Dec. 17	1, 069	88	1, 157	....
Sept. 24	23, 032	1, 166	24, 198	94	Dec. 24	186	49	235	....
Oct. 1	14, 454	2, 838	17, 292	389	Dec. 31	154	....	154	....
Oct. 8	10, 578	5, 951	16, 529	240					
Oct. 15	32, 410	5, 346	37, 756	212	Total	195, 232	34, 329	229, 561	15, 185
Oct. 22	31, 914	5, 116	37, 030	138					

NOTE.—No catch was recorded for Zone 6.

TABLE 26.—*Chum salmon run in the Columbia River, 1938*

[Catch in number of fish, assuming an average weight of 10 pounds. Data combined and arranged by corresponding weeks]

Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch below Bonneville	Bonneville count	Catch in Zone 6	Week ending	Catch in Zones 1 and 2	Catch in Zones 3 to 5	Total catch below Bonneville	Bonneville count	Catch in Zone 6
Sept. 24	3	....	3	2	....	Nov. 26	6, 074	1, 210	7, 284	46	....
Oct. 1	117	284	401	68	....	Dec. 3	1, 083	440	1, 523	13	....
Oct. 8	334	293	627	179	....	Dec. 10	2, 286	57	2, 343	1	....
Oct. 15	4, 839	1, 538	6, 377	945	7	Dec. 17	453	23	476	....	....
Oct. 22	15, 960	2, 931	18, 891	174	365	Dec. 24	44	8	52	....	....
Oct. 29	22, 370	5, 361	27, 731	236	28	Dec. 31	15	....	15	....	....
Nov. 5	51, 458	7, 235	58, 693	225	195						
Nov. 12	41, 601	5, 084	46, 685	202	297	Total	162, 694	27, 576	190, 270	2, 117	892
Nov. 19	16, 057	3, 112	19, 169	26	....						

For both silver and chum salmon it is quite apparent that such a small part of each run goes above Bonneville that the same sort of analysis that was made of the data for the other species would be meaningless for these. Obviously the chief spawning areas are in the tributaries that enter the main river below Bonneville—an inference that is in entire accord with the known facts of the distribution of these species. Not only in the Columbia River but generally throughout their entire range, both silver and chum salmon tend to spawn in the lower tributaries of the larger rivers or in the shorter coastal streams. The same is true of the pink salmon, which do not appear in the Columbia in commercial quantities. Under such circumstances it is not possible even to approximate the number of fish in the entire run because the sum of the fish taken below the dam and those counted past Bonneville do not form a sufficiently large percentage of the whole, and without at least approximate information as to the total number of fish in the run it is impossible to make the sort of analysis that has been done with the chinooks, bluebacks and steelheads.

The silver salmon first appeared in the river about the first of August, but the catch did not amount to much until after the closed period from August 25 to September 10. On the other hand, a very large part of the total count past Bonneville was made during the 2 or 3 weeks that were chiefly affected by the closed season. (In table 25, the weeks ending August 20, August 27, and September 3.) Several factors, alone or in combination, may account for these facts. First it appears that a much larger percentage of the earlier fish than of the later ones pass above the dam to spawn in the upper tributaries. Secondly, the intensity of fishing for this species may be greater after the closed period than before. This may be due in part to a change in the gear used on the lower river after the height of the fall run of chinooks has passed. The silvers, being smaller fish, may be more readily caught with gill nets of smaller mesh than is most effective for the larger chinooks. However this may be, it seems reasonably certain that in 1938 there was a small but fairly well separated run of silver salmon that entered the river late in August.

The main part of the run of this species comes from about the middle of September to about the middle of November. There is some evidence of separate modes in the run during this time, but it is not conclusive or even very strongly marked. The height of the entire run in the lower river comes close to the middle of October.

Chum salmon do not begin to enter the river much before the first of October. From that date on the run gradually increases to a peak that comes about the first week in November. After this the run as gradually decreases to terminate late in December. There is no evidence of significant minor modes. As in the case of the silver salmon, comparatively few of these fish pass Bonneville Dam, although a small catch was recorded from Zone 6. It is clear that the majority of the fish of this species spawns in the tributaries below Bonneville Dam.

SUMMARY

1. Exceptional data are available for the study of the salmon runs of the Columbia River for 1938. For the first time the catch data for Oregon and Washington were given in similar form so that they could be combined. As a result, the daily catch in pounds of each species in each of 6 zones (corresponding to the parts of the river bounding the 6 contiguous counties of Washington) is available for study. Coincident with this the Bonneville Dam was closed and fish ladders were constructed, by means of which the fish surmounted the dam. On their way through the ladders the fish were conducted through narrow passages and over white surfaces, and the number of each species was recorded. There have also been available for study the counts of salmon passing through the fish ladders at the Rock Island Dam, on the upper Columbia River near Wenatchee, Wash.

2. By using appropriate conversion factors the catch in pounds has been converted into numbers of fish, so as to make these data directly comparable with the counts at Bonneville and Rock Island dams. Tables have been prepared in which are given (1) the weekly catch for each of 3 major areas representing natural groups of zones, (2) the total catch, (3) the Bonneville count, and (4) the Rock Island count. For each major area the data have been appropriately "lagged" so that, as nearly as possible, those for the same part of the run will lie on the same line as the table is read from left to right. This lag has assumed that fish entering the river and to be found in Zones 1 and 2 one week will be found in Zones 3, 4, and 5 the second week, at Bonneville and in Zone 6 the third week, and at Rock Island the fifth week. These modified tables form the basis for study and analysis.

3. The general course of the run of each species is shown so far as possible by the available data. The chinook salmon enter the river throughout most of the year, but two quite distinct peaks are shown: One near the end of April, the so-called "spring" run, and the other the latter half of August. There is a period of marked scarcity during June and July. The blueback run is of much shorter duration, the main portion lasting only 6 or 8 weeks and showing a marked peak toward the end of June. Steelhead trout enter the river throughout the year but the chief run is during the

months of June to September. There are 5 modes: minor ones about the end of March, the first of May, and the first of December, and major modes early in July and about the middle of August. The run of silver salmon extends from early in August to the end of the year, but centers rather broadly from the middle of September to the middle of October. The chum salmon run attains a well marked maximum about the first week in November, but extends from about the first of October to about the middle of December.

4. The main parts of the chinook, blueback, and steelhead runs spawn above Bonneville, but silvers and chums spawn chiefly in the tributaries below the dam.

5. There is some evidence of error in the identification of species in the Bonneville count.

6. The importance of the runs to the river above Rock Island (largely affected by the dam at Grand Coulee) is shown by the ratio of the Rock Island count to the estimated escapement. Some 4 percent of the very early chinooks passing Bonneville previous to the first of May appear later at Rock Island. Of the May run of this species, about 6 percent apparently went to this portion of the river. Of the June–July run, which is poor and apparently seriously depleted, some 15 percent is attributable to these races. During the remainder of the year only about 1 percent of the estimated escapement appeared here. Approximately 40 percent of the blueback run spawns above Rock Island. In the case of the steelheads, the early and late runs contain 10 percent or more of fish spawning above Rock Island; but during the main portion of the run, June through September, only about 1 percent of these fish go to this portion of the river.

7. The intensity of the fishery for chinooks, bluebacks, and steelheads is measured by the ratio of the commercial catch to the escapement, as calculated from the data given in the modified tables. For the May run of chinooks it is shown that only about 1 fish out of 7 escapes the commercial fishery and is available for the future maintenance of this run. During June and July, a period of great scarcity, only about 1 fish in 6 escapes, and during the remainder of the run, August through December, the escapement is considerably better but even at this time about twice as many fish are taken in the commercial fishery as remain to reproduce. These figures do not take into consideration the effect of the intensive oceanic fishery which would materially increase the catch–escapement ratio. In the case of the blueback salmon the ratio of catch to escapement is approximately 4:1, indicating that only about 1 fish out of 5 of this species escapes the fishery. The ratio for the steelheads varies with the season, but for the main part of the run, June to September, it is somewhat greater than 2:1; i. e., more than 2 out of 3 steelheads are taken in the fishery. Similar ratios for the silvers and chums cannot be determined because few fish of these species pass Bonneville; consequently no estimate of the net escapement can be made.

8. The weekly closed period, 6 p. m. Saturday to 6 p. m. Sunday, in force during the spring fishing season, May 1 to August 25, is almost entirely ineffective insofar as it may tend to increase the number of breeding fish on the spawning grounds. Its chief effect is to spread the fishing over a longer stretch of the river. This is the result of an intensive fishery conducted over a long area. The closed season from August 25 to September 10 is designed to protect the peak of the chinook run and a portion of the steelhead run, but it acts, in a larger way, much the same as does the weekly closed period in that it chiefly tends to extend the fishing areas. The effect of an increased escapement of fish through the fishing area below Bonneville is almost

entirely offset by the very intensive fall fishery that is concentrated in Zone 6, above Bonneville Dam.

9. The closed period of March and April protects from the commercial fishery the run of chinooks that enters the Willamette River during April and early May, but this run is subjected to an intensive sport fishery below the falls at Oregon City. Unfortunately there are no data on the sport catch or on the Willamette run as a whole. This closed period also protects a small run of chinooks to the main river, the principal portion of which passes through the commercial fishing area before the season opens on May 1.

10. The main runs of all species of salmon to the Columbia River are practically unprotected from exploitation. If all existing restrictions were removed, it is doubtful whether the catch would be materially increased, or, conversely, that the remaining brood stock would be materially decreased. The only present aids to the conservation of these runs are apparently those afforded by artificial propagation, stream improvement, and, possibly, the restrictions that apply to the use of traps and wheels.

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UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

FISH AND WILDLIFE SERVICE
Ira N. Gabrielson, Director

Fishery Bulletin 38

BIOLOGY OF THE ATLANTIC MACKEREL (*Scomber scombrus*) OF NORTH AMERICA

Part I: Early life history, including the growth, drift, and mortality of the egg and larval populations

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ABSTRACT

This portion of a comprehensive study on the Atlantic mackerel (*Scomber scombrus*) treats of the early life history from spawning up to about the time the schooling habit develops, with emphasis on the quantitative aspects.

Spawning takes place along the Atlantic coast, mostly 10 to 30 miles from shore, from Chesapeake Bay to Newfoundland, with perhaps 9/10 of the volume between the Chesapeake Capes and Cape Cod; 1/10 in the southern half of the Gulf of St. Lawrence, and negligible amounts elsewhere. Embryological development at the temperature usually enconntered occupies about 1 week. The pelagic eggs are confined to a surface stratum 15–25 meters thick. Hatching at 3 mm. of length, larvae grow to 10 mm. in about 26 days, and to 50 mm. in an additional 40 days, by which length they approximate the typical form for adult mackerel, and assume the schooling habit.

In 1932, it is estimated, 64,000 billion eggs were produced south of Cape Cod by a spawning population estimated at 100 million individuals. That year dominant northeasterly winds (which were abnormally strong) drifted one concentration of larvae, originating off northern New Jersey, and another concentration, originating off southern New Jersey, in a southwesterly direction, to localities abreast of Delaware Bay and Chesapeake Capes, respectively. A reversal of dominant winds, consequently of drift, returned both groups to northern New Jersey, by the 9-mm. stage of growth.

Mortality during most of the developmental period was 10 to 14 percent per day, but was as high as 30 to 45 percent per day during the 8- to 10-millimeter period when fin development was rapid. Survival from spawning of the eggs to the end of the planktonic phase of life (50 mm.) was in the order of 1 to 10 fish per million eggs spawned. This rate of survival is an abnormally low one since the fish from this spawning season were abnormally scarce in the adult populations of subsequent years. The low survival rate is ascribed to the abnormal amount of southerly drift, coupled with a general scarcity of plankton in the spring of 1932.

BIOLOGY OF THE ATLANTIC MACKEREL *(SCOMBER SCOMBRUS)* OF NORTH AMERICA. PART 1: EARLY LIFE HISTORY, INCLUDING GROWTH, DRIFT, AND MORTALITY OF THE EGG AND LARVAL POPULATIONS

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CONTENTS

INTRODUCTION

The common mackerel, *Scomber scombrus*, is found on both sides of the Atlantic Ocean, approximately between the 30th and 50th parallels of north latitude. Although American and European representatives are very much alike in appearance, life history, and habits, their ranges are discontinuous, so that the two populations may be regarded as separate races with no intermigration. Consistent with this view is the observation (Garstang, 1898, p. 284) that the two stocks differ in morphological characters.

The American race has from colonial times been caught and marketed in large volume.[1] In the nineteenth century the annual yield occasionally reached 200,000,000 pounds. The present yield is about 60,000,000 to 80,000,000 pounds annually, of which the United States fishery takes about three-quarters and the Canadian fishery the remainder (Sette and Needler, 1934, p. 43).

[1] The European race, too, is the object of an important commercial fishery, but appears never to have been held as high in esteem or occupied so high a rank among the commercial fishes of Europe as has its American relative among the fishes of this side of the Atlantic. Fishery Bulletin 38. Approved for publication May 15, 1939.

Among the commercial fishes, the mackerel is remarkable for its spectacular changes in yield. To illustrate this, only a few records need be selected (Sette and Needler, 1934, p. 25). From 116,000,000 pounds in 1834 the United States catch dropped to 23,000,000 pounds in 1840, only to rise again to 137,000,000 pounds in 1848. From its peak of 179,000,000 in 1884, the catch dropped to 30,000,000 in 1886, only 2 years later. More recently it increased from 13,000,000 pounds in 1922 to 68,000,000 pounds in 1926. For the United States and Canada together the largest catch, 234,000,000 pounds, was landed in 1884, the lowest, 12,600,000 pounds in 1910.

Although these fluctuations had profound effects both on the economic welfare of the fishermen and on the business of the fish markets, and although speculation, both popular and scientific, as to the causes of these sharp changes in returns from the fishery, has been indulged in for many years, no satisfying explanation has been forthcoming. This is not particularly surprising, for the scientific research concerning work on this species has been of desultory nature and unsuited to the solution of a problem as intricate as is presented by the fluctuations in fish populations. Nonetheless, from the fragmentary records then available, Bigelow and Welsh (1925, pp. 198–199) found evidence suggesting that the mackerel, like the Norwegian herring, was subject to marked inequalities in the annual success of reproduction or of survival to commercial size of the various year classes, and attributed the intermittently good and poor years of fishing to intermittently good and poor seasons of spawning or survival.

This hypothesis, being the most reasonable one thus far advanced, determined the method of approach in the present investigation. Obviously, its pursuit required two basic series of observations: (1) An estimate of changes in abundance, and (2) determination of changes in age composition. Carried through a number of years, these observations should provide material for measuring the relative numerical strengths of year classes arising from each season's spawning, for tracing the influence of the annual increments afforded by each year class and their subsequent mortality on the success of the commercial fishery, and conversely for examining the influence of the commercial fishery both on the reproductive success and on the mortality.

Accordingly, after some preliminary field work in 1925 at Woods Hole and Boston, Mass., in which various techniques of sampling and measuring were developed, a routine program of observations was commenced at the principal mackerel fishing ports. For the estimation of changes in abundance, pertinent details covering the landings by mackerel vessels were recorded to form the basis for computing catch per unit of fishing effort; and for the determination of age-composition, samples of mackerel were drawn daily from each of a number of the fares landed. These basic observations began in 1926 and have continued to the present time. In addition, inquiries were pursued into the natural history and habits of the mackerel, since more adequate knowledge of these was required for interpretation of the data derived from the commercial fishery.

During the 10 years, 1926 to 1935, sufficient material has accumulated to provide substantial contributions to the understanding of the life history of the mackerel, with special reference to its fluctuations in abundance; and, accordingly, a series of papers, of which this is the first, is to be published.[2] The present paper deals with features of the early life history, with particular reference to the understanding of variations in the annual replenishment of the commercial stock. It summarizes present knowledge

[2] Results, of preliminary nature, previously published are to be found in Sette, 1931, 1932, 1933, and 1934. Also see Sette and Needler, 1934.

of the course of events from the time the eggs are spawned until the young mackerel attain the juvenile phase and closely resemble the adults in form and habits. Other papers in this series, now in course of preparation, deal with (1) habits and migrations, (2) age and rate of growth, and (3) fluctuations in abundance of the commercial stock.

Acknowledgments.—The entire portion of the mackerel's life considered in this paper is passed suspended in the waters of the sea, hence as a member of the plankton community. Accordingly, the data were secured by towing fine-meshed plankton nets through the waters of the spawning grounds. A preliminary cruise in Massachusetts Bay was taken in 1926 on the U. S. Fisheries steamer *Gannet,* Captain Greenleaf, commanding. Cruises in succeeding seasons 1927 to 1932 were on the U. S. Fisheries research steamer *Albatross II*, Captain Carlson, commanding. In June 1932 the *Albatross II* was taken out of service and completion of that season's program was made possible by the kindness of the Woods Hole Oceanographic Institution in putting at our disposal for two cruises during June and July the ketch *Atlantis,* Captain MacMurray, commanding.

Numerous persons assisted in the scientific work aboard ship. Of these, E. W. Bailey, Wm. C. Neville, and Herbert Ingersoll took part in many cruises. Wm. C. Herrington's suggestions contributed greatly to the development of the use of current meters to measure flow through the plankton nets.

In the separation of eggs and larvae from the other planktonts, numerous persons assisted, but the major portion of the responsibility rested on Mildred Moses, whose vigilance insured a constant level of accuracy in removal of the desired material. Her performance of subsequent numerical computations was also an important contribution to the present results.

To C. P. Winsor I am indebted for suggestions relating to the statistical treatment of the mortality curves.

Certain tabulations and the graphs used herein were products of W. P. A. official project No. 165–14–6999.

Throughout the investigation, and in all of its many phases, the constantly available encouragement and advice of Henry B. Bigelow has been invaluable. To the extent that this account proves readable, the reader may thank Lionel A. Walford whose editorial suggestions have been freely followed.

ACCOUNT OF FIELD WORK

As before mentioned, when work began in 1925 it was strongly suspected that the fluctuations were due mainly to annual variations in the comparative success of survival through the larval stages (Bigelow and Welsh, 1925, pp. 198–199). Accordingly, work on the early life history was begun at the outset of the investigation in 1926. At that time, it was not known where most of the spawning took place or where the nursery grounds for larvae were located. The literature recorded the occasional finding of eggs in the sea south of the Gulf of St. Lawrence, but no larvae; yet the spawning population apparently favored the southerly waters off the United States coast as much as the northerly waters off the Canadian coast. Massachusetts Bay was a spring mackerel fishing ground well known to be visited at this season by numerous ripe adult individuals, so the first search took place there. Towing in various parts of the bay yielded large numbers of eggs, especially in that portion of the waters partially enclosed by Cape Cod. Not only were the eggs abundant, but numbers of larvae in various stages of development were found.

Encouraged by this success in waters south of the previously known distribution of larvae, search was in 1927 extended south of Cape Cod. Here eggs were found in abundance from the offing of Cape Cod nearly to the mouth of Chesapeake Bay. As in Massachusetts Bay, larvae were present in abundance also.

To determine whether this was the usual condition, the survey was repeated in a single cruise during May of 1928, when approximately the same conditions were found.

These three seasons of prospecting for mackerel eggs and larvae completely altered the previous notion that spawning was more successful in the northwest portions of the range of the species. Not only were specimens regularly obtained from Massachusetts Bay to Chesapeake Bay, but the numbers of individuals per tow were greatly in excess of those taken by similar methods in the Gulf of St. Lawrence during the Canadian Fisheries expedition of 1914–15. Evidently this southerly region was far more important than previously supposed, and hence a suitable one in which to study variations in the survival rate during early stages.

However, it was still necessary to determine the length of the spawning season and the duration of the period of larval development. For this purpose, successive cruises were made during the spring and early summer months of 1929. These proved that in the area between Cape Cod and Cape Hatteras spawning began in early April, and larval development had nearly run its course by the end of July.

In 1930 and 1931, such successive cruises during the spawning season were repeated and every opportunity was taken to devise methods of estimating the abundance of the various young stages.

This development of quantitative technique required the determination of vertical distribution so that the proper levels would be fished; determination of the incubation and growth rates so that cruises might be planned at proper intervals to include all the important events; and finally, it required devising a reliable method of measuring the amount of water strained by the tow nets so that hauls would be comparable from time to time and place to place. By 1932 knowledge and techniques were advanced sufficiently for the survey of that season to provide adequately quantitative data for the more important sections of this report dealing with growth, drift, and mortality. Toward the close of this season, the *Albatross II* was withdrawn from service as a Government economy measure. This prevented continuing the research into its next phase, that is, the measurement of mortality and its accompanying hydrobiological conditions through a series of seasons, to see how mortality is affected by particular conditions in seasons of good survival contrasted with other conditions in seasons of poor survival. Since the hoped-for resumption of surveys has not yet been possible, the present available results are now reported.

SYNOPSIS OF RESULTS

Most mackerel reach reproductive maturity when 2 years old. Some precocious individuals, usually males, first spawn a season earlier and others of both sexes a year later. The percentage of the latter is higher among the females than the males.

Mackerel are said to spawn 360,000 to 450,000 eggs in a season, but this is a point needing further study. Doubtless smaller individuals spawn fewer and larger individuals more eggs than this. The eggs are ripened in successive batches; it is not known how many batches or what interval of time intervenes between their discharge.

Spawning takes place over nearly the entire spring and summer range of the species, from off Chesapeake Bay to Newfoundland. By far the most important ground is between the Chesapeake capes and Cape Cod; second in importance, with perhaps one-tenth as much spawning, is the southern half of the Gulf of St. Lawrence. Other stretches of the coastal waters may at times receive negligible amounts of spawn, but it is safe to say that the entire Gulf of Maine (excepting Cape Cod Bay), and the entire outer coast of Nova Scotia, the northern two-thirds of the Gulf of St. Lawrence and the waters around Newfoundland are not regular spawning grounds of any importance.

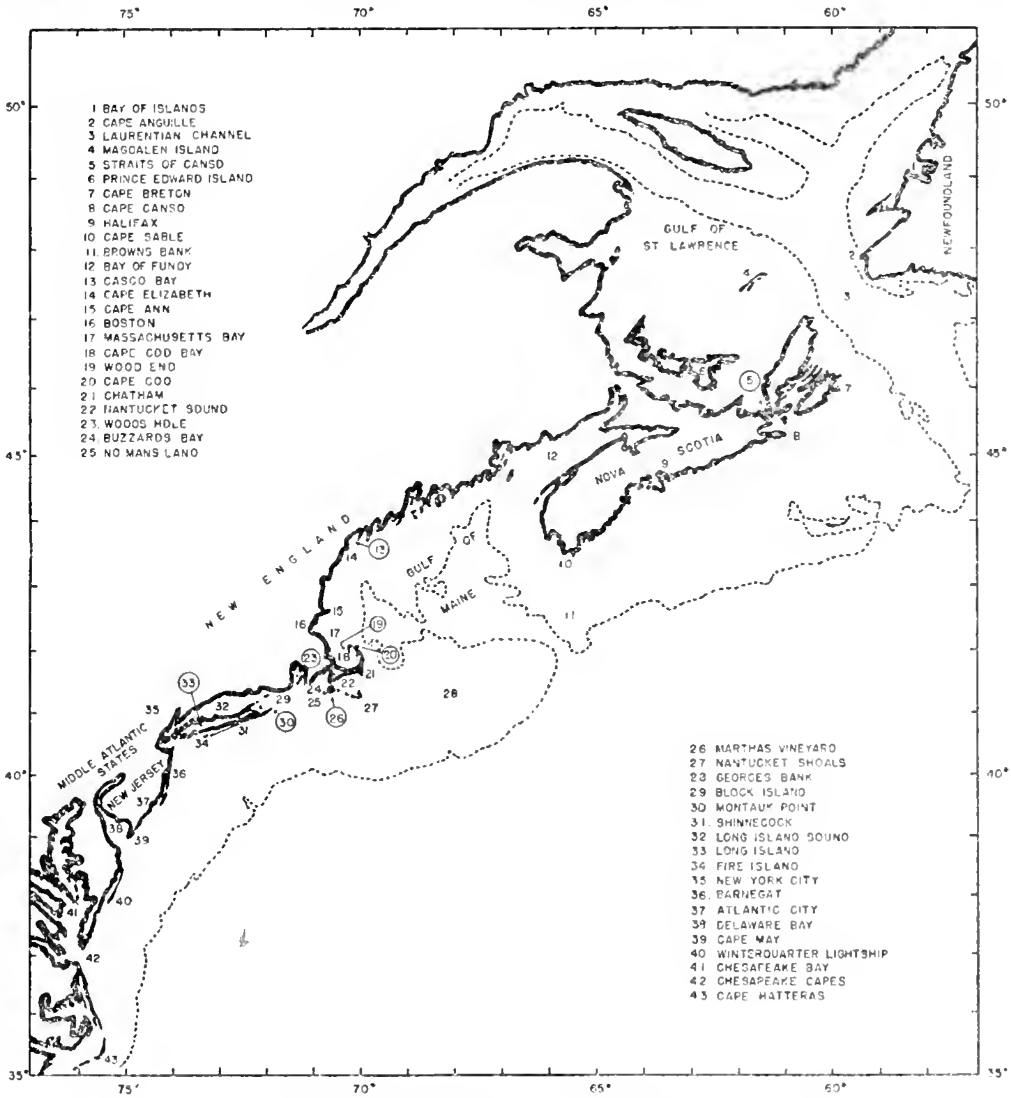


FIGURE 1.—Geographical features and landmarks mentioned in the text.

Spawning takes place in open waters in some places close to shore, in others as far as 80 miles to sea, but mostly 10 to 30 miles from shore. Open bays, such as Cape Cod Bay and Casco Bay, are spawning sites of minor importance while well-enclosed bays and sounds, especially those receiving considerable river water, such as Chesapeake Bay, Delaware Bay, and Long Island Sound, are neglected by the spawning mackerel.

Spawning occurs at any time of day or night, and probably near surface.

Embryological development is similar to that of other teleost fishes. It progresses more rapidly in warm water than in cold, eggs hatching in 2 days at 21° C. (70° F.) and in 8½ days at 10° C. (50° F.). The prevailing temperatures on the spawning grounds at the height of the spawning season are between 9° and 12° C., so that in nature the incubation period usually occupies about a week.

During incubation the eggs are suspended in the sea water between its surface and the thermocline, which is usually 15 to 25 meters (8 to 13 fathoms) deep in the area studied. They have a tendency to sink gradually as development proceeds, so that the late stages are found at deeper levels than the early ones, but even so, not below the thermocline.

After hatching, the young mackerel passes through three phases of development, conveniently designated as yolk sac, larval, and post-larval stages. During the yolk sac stage—a matter of about 5 days—the fish is about 3 mm. (⅛-inch) long and subsists on the yolk. During this period, the mouth and digestive organs develop into usefulness and the yolk sac is absorbed. During the period occupied by the larval stage, that is, between yolk sac absorption and development of fins, which lasts about 26 days, the fish grows from a length of 4 mm. (⅙-inch) to 10 mm. (⅜-inch) in length. Then, when the fins have appeared, the post-larval stage begins. It continues about 40 days and during this time the fish grows to a length of about 50 mm. Toward the end of this stage, while growing from 30 to 50 mm., the body assumes the trim fusiform shape of the adult. At that time, the fins, relative to the body, are even larger than in the adult, and the coloration includes shiny, silvery iridescence, though still lacking the characteristic wavy black bands of the adult.

During the yolk sac stage, movements are feeble, not even serving to keep the fish right side up. Swimming faculties increase during the larval stage and are exercised in performing vertical diurnal migrations, the larvae ascending toward the surface at night and descending toward the thermocline at day. But they do not swim any considerable distances during this stage; instead they drift with the water masses in which they are suspended. In post-larval stages, true swimming takes place, the young fish at times moving in a direction opposite to the prevailing drift of water. The schooling habit probably begins to assert itself toward the end of this stage and thereafter is followed in much the same fashion as by the adults.

In 1932, the larvae were drifted initially in a southwesterly direction, and the main body was transported about 80 miles down the coast, one subgroup drifting from the offing of northern New Jersey to the offing of Delaware Bay; another, from the offing of southern New Jersey nearly to the Chesapeake capes. Then, a reversal of drift returned both groups to the offing of northern New Jersey by the time they had reached the end of the larval stage, and were 9 mm. long. The southwesterly drift coincided with the predominance of northeasterly winds, and the northeasterly return with a reversal of dominant winds.

Compared with other seasons,1932 had an abnormally large northeasterly wind component, which left the 9-mm. larvae farther to the southwest and farther offshore than in other seasons. After the post-larval stage of active swimming commenced, the direction of travel was toward southern New England, and by the latter part of July, some of the largest of the post-larvae had even passed Nantucket Shoals and were taken off Cape Cod.

In 1932 the mortality over most of the developmental period was 10 to 14 percent per day. There was a notably higher mortality of 30 to 45 percent per day during the 8- to 10-mm. period, when fin development was rapid. Other departures from the general rate, of doubtful significance, were during egg stages, when about 5 percent per day was indicated, and during the yolk sac stage (3-mm. larvae), when about 23 percent per day was suffered.

The indicated total mortality, from the spawning of the eggs to the end of planktonic existence (50 mm. or 2 inches long), was 99.9996 percent. That is, the survival was in the order of magnitude of only 1 to 10 fish per 1,000,000 of newly spawned eggs.

This mortality was not due to sharply higher death rate at the yolk-sac stage—a theory of year-class failure holding favor among fishery biologists. Mortality was substantial in all stages. It was greatest during fin development in the transition phase from larval to post-larval stages. The higher mortality at this time appears to have been connected with the particular pattern of drift caused by the dominant wind movement, which in 1932 left the larvae farther than usual from their nursery grounds along the southern New England coast. This, together with a general scarcity of plankton, is considered the cause of failure of the 1932 year class.

SIGNIFICANCE OF RESULTS

Most conservationists lay particular stress on the maintenance of adequate spawning reserves. It is important to do so. If an annual commercial crop is to be constantly obtained, the spawning stock must be kept large enough to produce as many young as are needed to replace the fish caught by man and other predators. This can be done, in most cases, only by controlling the annual yield. From this springs an obvious, but not universally appreciated, fact that accumulating a surplus of spawners is a wasteful practice, for it means holding the annual yield below the amount that the resource is capable of producing. It would be simple, for instance, to insure an adequate spawning reserve by allowing no fish to be caught. But this would be more futile than to allow all to be caught. The latter would utilize one crop, the former none. Obviously, efficient exploitation calls for an intermediate course of action, one that would permit taking the maximum annual yield commensurate with the maintenance of an adequate spawning reserve; no more and no less.

But what is an adequate spawning reserve? It can be defined as one large enough to reproduce the young needed to recruit the commercial stock. Its determination is a matter of observing the numbers of recruits produced by spawning stocks of different sizes. Thus, the answer rests on knowledge of recruitment.

Two things affect recruitment: First, the numbers of spawners; second, the mortality in young stages—"infant mortality." The latter is tremendous and variable. Its variability is so great that it could readily obscure such correlation between number of spawners and number of recruits as might be present intrinsically. For example, under a given quality of survival conditions a large spawning population may produce a large number of recruits and a small population a small number of recruits, but with variable survival conditions a large number of spawners might produce only a small number of recruits if infant mortality be relatively high; and conversely, a small number of spawners might produce a large number of recruits if infant mortality be relatively low. As long as one can observe only the changes in numbers of spawners and numbers of recruits, the relation between the two cannot be seen, for it is obscured by the intervening infant mortality. Therefore, as long as the effect of infant mortality is unknown, so long will the size of an adequate spawning reserve be unknown.

Thus the measurement of infant mortality is the key to the problem. In the course of this study, a technique for making this measurement has been devised, and was applied during the season of 1932. With similar observations in enough additional seasons, it should be possible to determine what recruitment can be expected from given sizes of spawning stocks for particular infant mortality rates. Thus there will be determined an adequate spawning reserve, for it will be one that produces the needed average recruitment over the observed range of infant mortality rates.

LIFE HISTORY

REPRODUCTIVE AGE

According to information formerly available (Bigelow and Welsh, 1925, p. 205), "Some few females ripen when still not more than 11 inches long; most of them, and all males, at 12 to 13 inches." Present observations indicate first attainment of maturity at somewhat larger sizes, the difference possibly being due to the manner of measurement. The lengths given below were from snout to tip of the middle rays of the caudal fin, whereas the earlier measurements may have excluded the caudal fin.

Of 1,116 mackerel sampled from catches of traps in the vicinity of Woods Hole, Mass., and at three localities on the shores of Massachusetts Bay between June 24 and July 21, 1925, the smallest male with mature gonads was 26 cm. (10¼ inches) long and the smallest female 29.5 cm. (11½ inches). At 30.5 cm. (12 inches) 30 percent of the males and a negligible percentage of females were mature. At 34 cm. (13½ inches) about two-thirds of the males and one-half of the females were mature; and at 37 cm. (14½ inches) nine-tenths of both sexes were mature. (See fig. 2.)

It is possible that our data may not be typical because they were taken somewhat after the peak of spawning, which usually falls in May and June, and some individuals which had spawned early, and whose gonads had somewhat recovered, might have been mistaken for immature individuals. The number so mistaken cannot have been large for there was little difficulty in recognizing the two categories, "ripe" and "spent," which make up our class of "mature." The mistakes, if any, because the spawning of some individuals was too long past, should have been mostly among the larger sizes, because they are usually first to appear along the coast and presumably the earliest to spawn. But among these (52 specimens over 38 cm. in length were examined) only 1 individual appeared immature, hence the error, if any, must have been small.

By means of size and age relations to be published in another paper of this series, it may be concluded that only a few males, and even fewer females, spawn as yearlings. Four-fifths of the males and two-thirds of the females spawn when 2 years old, and virtually all of both sexes when 3 years old.

FECUNDITY

Various statements have appeared in the literature purporting to give the numbers of eggs spawned by individual mackerel. Brice (1898, p. 212) in "The Manual of Fish Culture" states that the average number of eggs at one stripping is about 40,000, that a 1⅜ pound fish gave 546,000, and that the largest fish yielded probably a full 1,000,000 eggs. Bigelow and Welsh (1925, p. 208) say, "Mackerel is a moderately prolific fish, females of medium size producing 360,000 to 450,000 eggs, but only a small part of these (40,000 to 50,000 on the average) are spawned at any one time." But Moore, whose report appears to be based on more intensive study than others, more cautiously states (J. P. Moore, 1899, p. 5) "seldom 50,000 and frequently a much lesser number of ova are produced at one time, but the aggregate number matured (in a spawning season) in one female of average size is several hundred thousand." This is probably as precise a statement as is warranted at the present time.

Moore (loc. cit.) has shown that there are successive batches of eggs ripened by an individual female during the course of the season. This introduces the uncertainty as to whether any particular enumeration has included, on the one hand, all batches destined to be spawned during the current season and, on the other hand, none that were destined to be spawned during a following season. The difficulty of making a correct decision is amply portrayed by the thorough study by Clark (1934) on the California sardine, *Sardinops caerulea*, a species which, like the mackerel, spawns successive batches. Clearly this subject requires additional study to provide statisti-

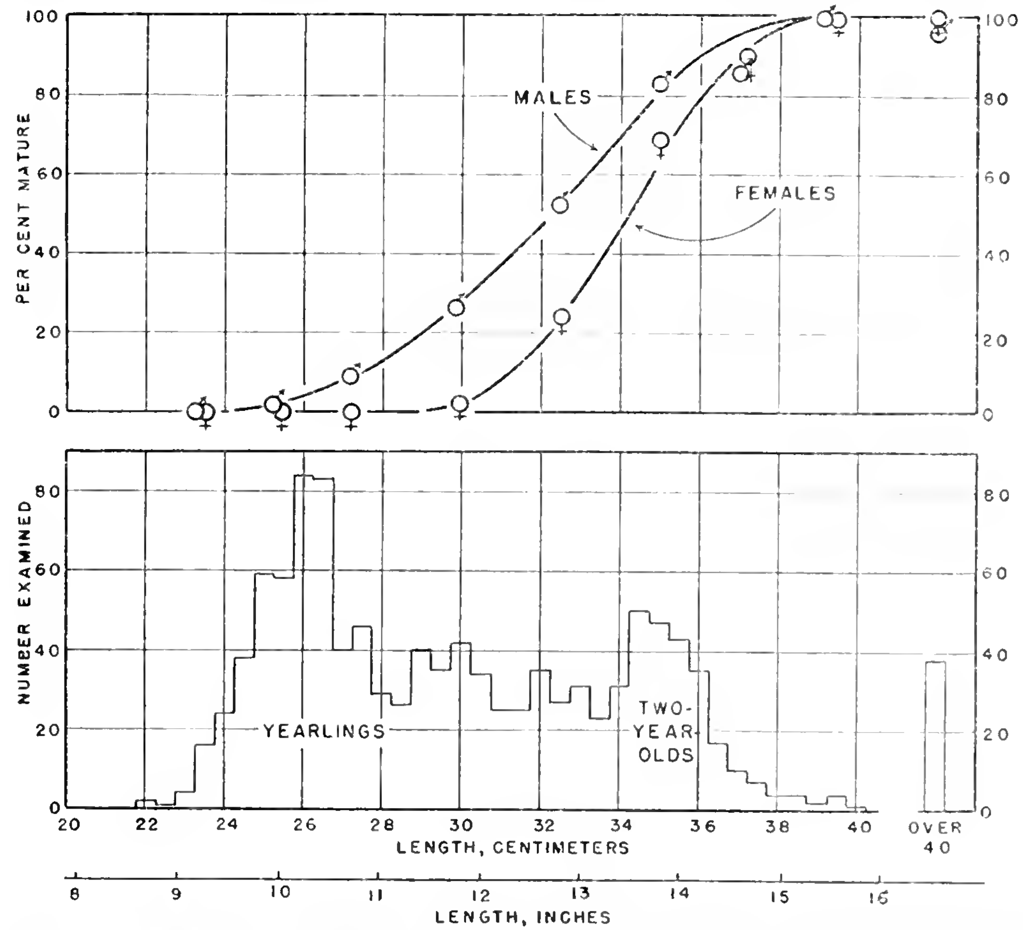


FIGURE 2.—Length and age at which mackerel reach reproductive maturity. The upper panel shows, by 2½ cm. length groups, the percentage of each sex matured. The lower part shows by half cm. length groups, the numbers examined for determination of percentage of maturity.

cally adequate data, and deserves such study because the ability to compute the number of eggs that can be produced by a population of known size-composition or, conversely, to compute the size of a parent population of known size-composition from the known numbers of eggs found in a spawning area would provide useful, if not indispensable, data for elucidating several perplexing problems connected with the fluctuations of fish populations and the management of fish resources. See pages 164 and 165 for an example of the uses of such data.

SPAWNING GROUNDS AND SPAWNING SEASONS

Bigelow and Welsh in 1925 (pp. 206–208) summarized the information available on the spawning of the mackerel. Apart from the generalization that mackerel spawn along the American Atlantic coast from Cape Hatteras to the Gulf of St. Lawrence mainly in spring and early summer, most of the conclusions reached at that time are now subject to revision. Their statement (p. 206) "* * * a much greater production of mackerel eggs takes place east and north than west and south of Cape Cod, with the Gulf of St. Lawrence far the most productive nursery for this fish," is particularly at variance with present available facts, as will appear from the following account of the numbers of mackerel eggs found in the various parts of the spawning range.

Coast of the Southern New England and Middle Atlantic States

Numbers and distribution.—Until the present investigations there was little known about the spawning in the great bight bordered by the shores of southern New England and the Middle Atlantic States. Although ripe individuals are commonly taken in the fishery in this area, no appraisal had been made of the egg concentrations to be found there; nor was it known whether larvae hatched from such eggs as were spawned there could survive; in fact it was suspected that reproduction was unsuccessful, for no larvae of the mackerel had been captured there.

As a result of information gained from the surveys of the present investigation during the seasons 1927–32, this region now appears to contain the most important spawning grounds of the mackerel. In horizontal tows at the surface, i. e., in the stratum of densest concentration, a meter net has taken, in 20 minutes, as many as 185,000 eggs. In 1929 the average catch per positive tow [3] of this kind was 2,600 eggs during the cruise of May 10 to 18, and 5,000 eggs during the cruise of May 28 to 31. These numbers may be taken as fairly typical of concentrations at the surface when and where spawning is active, and will be useful for comparison with other regions where similar data are available. More informative, in the absolute sense, are the results of oblique tows of 1932, which sampled all levels and covered systematically the entire region between Cape Cod and the Chesapeake Capes. The average catch of such tows, including all between May 2 and June 21, i. e., the major portion of the spawning season, and including both positive and negative tows, was slightly over 1,100 eggs. Since these tows strained 17 cubic meters of water per meter of depth fished, the average concentration was 65 eggs per square meter of sea surface.

Within this region eggs have been consistently most abundant along the inner portions of the continental shelf. The area of densest distribution occupies about the inner half of the shelf off New York with the zone narrowing and trending somewhat offshore southerly, and also narrowing but trending inshore northeasterly. By far the greatest concentrations have been found regularly somewhat southerly of the Fire Island Lightship, and this undoubtedly marks the usual center of greatest spawning activity.

So far as is now known, no spawning takes place in the enclosed waters of the bays and sounds west and south of Block Island. A few eggs are spawned in the southern part of Buzzards Bay and Vineyard Sound, but these are negligible in quantity compared with the spawning in open waters.

[3] Positive here indicates a tow in which mackerel eggs were caught.

Season.—Spawning begins in the southern end of this region during the middle of April about as soon as the mackerel appear in the offing of Chesapeake Bay. Thence it proceeds northeastward along the coast, taking place during the month of May off the New Jersey and New York coasts and extending into June off southern Massachusetts. In 1932, spawning in this region reached its climax about the middle of May. (See table 5.) Surveys of other spawning seasons indicate that this is the usual time of maximum spawning.

Temperature at spawning.—In this region we have found mackerel eggs in water as cool as 7.3° C. (45° F.) and as warm as 17.6° C. (64° F.). In 1932, the greatest numbers of eggs (98 percent) were found in water of 9.0° to 13.5° C. (48° to 57° F.) and this may be regarded as the range in which the bulk of mackerel eggs are usually spawned in this region.

Gulf of Maine

Numbers and distribution.—On visits to the western portions of the Gulf of Maine during the present investigation, eggs were found only in Cape Cod Bay. There the concentration was only slightly less than in waters south of Cape Cod but practically none were found in waters off the outer face of Cape Cod and the coast between Boston and Cape Elizabeth. Moore (1899) found them in the outer portions of Casco Bay in 1897, but the numbers were few. Bigelow and Welsh (1925, p. 206) occasionally found a few in various parts of the Gulf of Maine. The maximum haul was recorded by them as "200 plus."

Although Bigelow and Welsh (1925, p. 207) say, "That Nantucket Shoals, Georges Bank, and Browns Bank, like the Scotian banks to the east, are also the sites of a great production of mackerel eggs is proven by the ripe fish caught there * * * ", it now hardly appears likely that these banks around the periphery of the Gulf of Maine can be the site of important spawnings. The records of eggs taken by Bigelow and Welsh did not include any from these banks and during the present investigation the waters about Nantucket Shoals were visited repeatedly, and the western half of Georges Bank occasionally, without finding more than negligible numbers there. It is likely that the ripe fish caught on these grounds were a part of schools destined to spawn elsewhere, presumably the Gulf of St. Lawrence, and were taken during the course of migration to that area. This is in harmony with the results of investigations on migration which are to be reported on in another paper of this series.

Thus it appears that the only spawning ground regularly important in the Gulf of Maine is Cape Cod Bay. This body of water is so small compared with the grounds south of Cape Cod or with those of the Gulf of St. Lawrence that reproduction in the Gulf of Maine must be negligible compared with that of the other spawning regions.

Season.—Spawning probably takes place somewhat later in the Gulf of Maine than south of Cape Cod in consequence of later vernal warming and later incursion of mackerel into the waters of this region. It evidently was on the increase and perhaps near its maximum in Massachusetts Bay between June 9 and June 14 of 1926, when hauls taken on a line of three stations running out from Wood End Light toward the middle of Cape Cod Bay averaged 700 and 1,200 per tow on June 9 and 14, respectively. A more precise determination of the time of maximum spawning awaits the sorting of additional hauls made in 1926 and 1930.

Coast of Nova Scotia

Numbers and distribution.—Information on the occurrence of mackerel eggs along the coast of Nova Scotia is limited to the results of a survey in 1922 reported by Sparks (1929, pp. 443–452).[4] Stations were occupied along the entire coast from Cape Sable to the Straits of Canso during the period May 31 to September 18, but no eggs were taken after the middle of July. For the most part the hauls yielded very few eggs, the average number taken being 14 per station, which presumably represents the sum of three tows.[5] Although Sparks stated neither the dimensions of his nets nor the duration of his tows, it may be presumed that at least the surface net was a meter in diameter at the mouth and that the tows were 15 to 30 minutes in duration. If so, the egg concentration was exceedingly low compared with the other regions. Furthermore, the occurrence of eggs even in this low concentration was limited to a relatively narrow band along the coast (table 1). Thus the waters along the Nova Scotian coast are poorer in mackerel eggs than any others within the known habitat of the species.

Season.—Spawning occurs along the Nova Scotian coast from about the last of May to the middle of June.

Table 1.—*Number of mackerel eggs taken per station in Nova Scotian waters at various distances from shore*

Station	Distance	Number of eggs	Station	Distance	Number of eggs
	Miles			*Miles*	
380	1	2	381	7	14
384	2	6	386	9	0
383	6	19	382	11	6
385	6½	11			

Gulf of St. Lawrence

Numbers and distribution.—The Canadian Fisheries Expedition of 1914–15 explored the Gulf of St. Lawrence during the spring and summer of 1915 (Dannevig, 1919, pp. 8–12). Their surveys were made with a meter net hauled at the surface for 10 to 15 minutes, supplemented in many instances by vertical hauls, which, however, took few mackerel eggs. The average catch in horizontal tows was 324 eggs per positive haul, and the largest catch was 3,800 eggs. Since eggs were taken at almost all stations south of the 100-fathom contour marking the southern border of the Laurentian Channel, it may be presumed that mackerel spawn over this entire area. The numerous larvae taken there indicate that this area not only is the site of considerable spawning, but also that conditions there are suitable for the development of the larva. The largest larva taken measured 9 millimeters in length.

In addition to the catches in the southern part of the Gulf of St. Lawrence, a few larvae were taken near Cape Anguille on the southwestern coast of Newfoundland. Also, there was a number of mackerel eggs in a sample of fish eggs collected from the Bay of Islands by the Newfoundland Fishery Research Commission and referred to the Bureau of Fisheries for identification. It thus appears that spawning takes

[4] In addition to Sparks's results there is the listing by Dannevig (1919, p. 60) of two mackerel eggs taken off Halifax and one egg (listed with a question mark) near Sable Island.

[5] According to Sparks, three tows were taken at each station: No. 5 net, about 7 meters deep; No. 0 net, 0–2 meters deep; No. 0 net, 23–27 meters deep.

place occasionally on the western coast of Newfoundland, but probably only in bays in which the water warms up to 10° C. (50° F.); perhaps it is of irregular occurrence and it is certainly of minor importance.

Season.—In the southern half of the Gulf of St. Lawrence, eggs were present as early as May 29 and as late as August 12. The maximum catches were taken on June 30, July 7, and July 8, and it may be presumed that the height of the season was in the latter part of June and early part of July.

Relative Importance of the Several Spawning Regions

Because it is important to know which grounds are mainly responsible for recruitment of the mackerel population, an appraisal of the relative amounts of spawning in the four regions will be attempted, even though the available information is not adequate for precise treatment. Since these four regions are roughly equal in size and each is sufficiently large to constitute a major spawning area, it will suffice to examine only average concentration of eggs in each region. The pertinent data, in terms of average or usual number of eggs taken per positive surface tow with a meter net are as follows:

Continental shelf between Cape Cod and Cape Hatteras	3,000 to 5,000
Gulf of St. Lawrence	About 300.
Gulf of Maine (exclusive of Cape Cod Bay)	Less than 100.
Coast of Nova Scotia	About 14.

Of course, these numbers cannot be taken at their face values for there are many factors affecting their comparability. However, the last two items in the list are so low that it may be concluded that the coast of Nova Scotia and the Gulf of Maine are of negligible importance as mackerel spawning areas.

On the other hand, the Gulf of St. Lawrence and the continental shelf between Cape Cod and Cape Hatteras are both grounds of evidently some importance, and their comparison with each other deserves more careful consideration. The two things that might affect most obviously the comparability of the data on them are: (1) the technique of towing, including the distribution of stations, (2) the fact that the Gulf of St. Lawrence survey took place more than a decade earlier than the townetting over the continental shelf between Cape Cod and Cape Hatteras.

The techniques employed in the Gulf of St. Lawrence by the Canadian Fisheries Expedition obviously were not intended for quantitative purposes. According to Dannevig (1919, p. 3) "The duration of the surface hauls varied somewhat, as a rule between ten and fifteen minutes; * * *" and Huntsman (1919, p. 407) states, "The tow hauls (as distinguished from the vertical hauls) are the most unreliable, owing to lack of information in the records as to the manner in which they were taken * * *. The tow hauls were taken in a great variety of ways." Further, Huntsman's table (loc. cit., p. 419) of hauls by the C. G. S. *No. 33*, which contributed most of the mackerel eggs, shows that some of these hauls in reality were oblique and that towing periods varied between 5 and 20 minutes, with the time not given for certain of the hauls containing important numbers of mackerel eggs.

Furthermore, the stations were closely spaced in some portions of the Gulf and widely spaced in others. They may have chanced to be concentrated where the eggs were thickest or the contrary. Similarly, the distribution with respect to time may have been favorable to the taking of abnormally large numbers of eggs, or the contrary. On the other hand, the coverage, both as to space and time, was far from haphazard. The *Princess* occupied stations in the Gulf of St. Lawrence during June 9 to June 15 and again during August 3 to 12, and, in the meantime, *No. 33* was making net hauls in the southern half of the Gulf during June, July, and August, the two boats together making about 50 net hauls in the productive southern half of the Gulf during the mackerel spawning season (Dannevig, 1919, charts and tables).

While it cannot be said whether more intensive work over a more uniform pattern of stations would have revealed substantially a greater or less number of eggs than was taken by the Canadian Fisheries Expedition, the fact remains that only one of their hauls yielded more than a thousand eggs and only a few, more than a hundred. Experience in the area between Cape Cod and Cape Hatteras indicates that a similar coverage, with similar techniques, would have resulted in many more hauls containing thousands of eggs, and the conclusion appears inescapable that eggs were much less abundant in the Gulf of St. Lawrence in 1915 than in the area between Cape Cod and Cape Hatteras during 1927 to 1932.

It is difficult to determine how much the decade of difference in the time that the Gulf of St. Lawrence and the area between Cape Cod and Cape Hatteras were investigated affects the comparability of the data on egg numbers, but at least two obvious features may be considered—annual fluctuations and long-term trends in volume of spawning. In the area between Cape Cod and Cape Hatteras the numbers of eggs were consistently high during the years 1927 and 1932. Though the methods of towing varied too much and the coverage in some years was too deficient to permit mathematical demonstration of this, in every year the eggs were sufficiently abundant to be taken by the several thousand per surface tow at favorable times and in favorable places; and it may be concluded that annual fluctuations were not sufficient to alter the general magnitude of egg production. It appears also that the numbers of spawners, judging from catch statistics, did not fluctuate by orders of magnitude during this period. Thus, experience suggests that the egg yield does not fluctuate markedly as long as the number of spawners does not.

Referring now to the catch statistics in the Canadian and the United States fisheries (Sette and Needler, 1934, p. 43) it appears that the trend in Canada was nearly horizontal between 1915 and the late 1920's, but that in the United States the general level was about three times as high in 1929 as in 1915. If it may be assumed that the spawners are, in general, proportional to the catch and that the numbers of eggs are proportional to the number of spawners, both of which are admittedly questionable premises, then it could be argued that the 1915 Canadian data on eggs would roughly hold for recent times and the comparison justified as indicating relative amounts of spawning in the two areas in recent times. On the other hand, comparison as of 1915 might be expected to reduce by two-thirds the numbers of eggs in the Cape Cod to Cape Hatteras area, and thus indicate relatively greater importance for the Gulf of St. Lawrence. Even so, the change would not be one of order of magnitude.

All available information considered, it appears most likely that the spawning in the area between Cape Cod and Cape Hatteras is distinctly more important than in the Gulf of St. Lawrence, and though it is possible that the difference is one of an order of magnitude, with eggs so concentrated in the Cape Cod to Cape Hatteras region as to be available in the thousands per tow, and so scarce in the Gulf of St. Lawrence as to be available in the hundreds per tow, it is also possible that the true divergence is less marked and that the numbers are really in the upper and lower levels of the same order of magnitude. The diagrammatic representation of relative egg numbers in the various regions given in figure 3 should be considered with this reservation. Although the collection of more adequate data on the subject is greatly to be desired, present information supports the view that the present survey has covered the most important spawning ground.

The existence of large regions with little spawning near the middle of the spawning range of the species is a peculiarity that may be explained by hydrographic conditions. It will be noted from the diagrammatic representation of relative intensity of spawning in figure 3 that the regions of greatest intensity are the southern and northern quarters of the spawning range. That of the least intensity is the middle half of the range. The places of intense spawning, that is, the great oceanic bight between Cape Cod

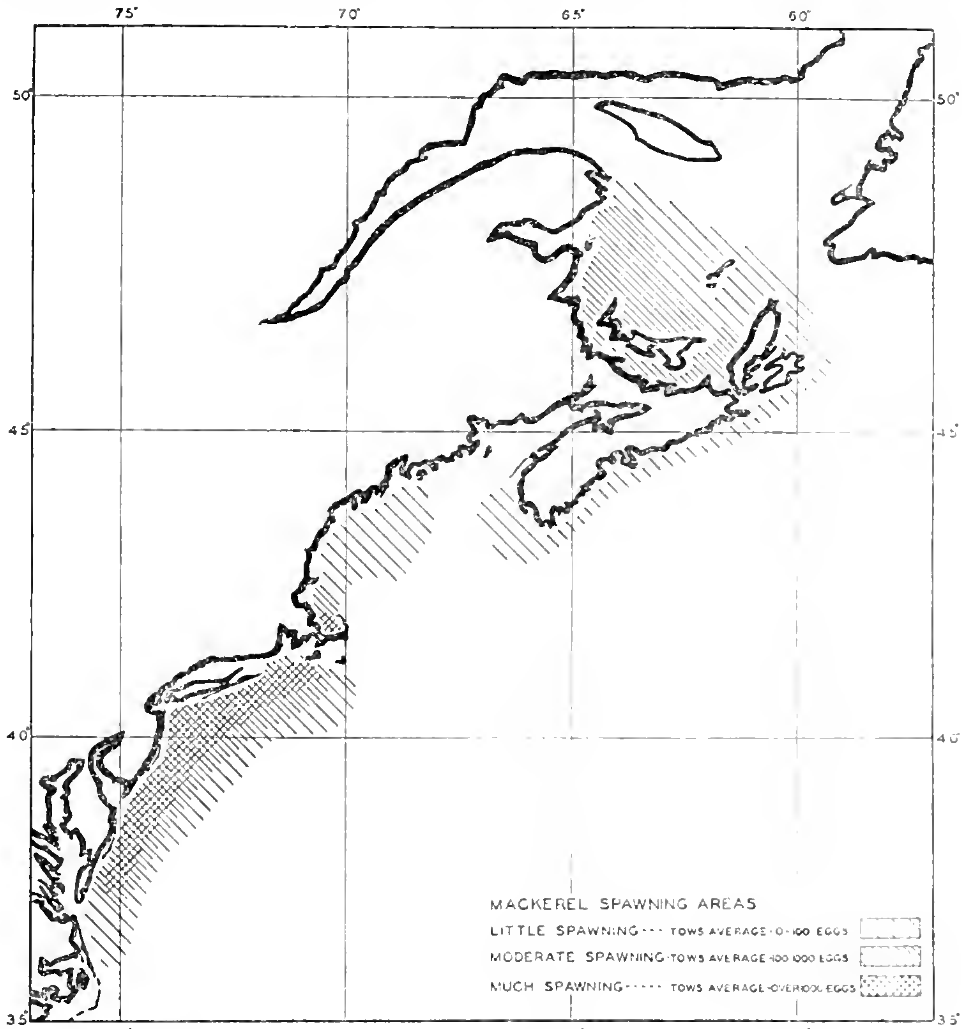


FIGURE 3.—Relative intensity of mackerel spawning in various regions along the Atlantic coast of North America, as indicated by the average number of eggs caught in plankton nets.

and Cape Hatteras, Cape Cod Bay, and the southern half of the Gulf of St. Lawrence, have this in common: they are all bodies of relatively shoal water overlying relatively flat bottom, where topography and circulation favor vertical stability, and vernal warming of the upper strata proceeds rapidly, producing temperatures suitable for mackerel spawning earlier than in the intervening areas. On the other hand, the places of least intense spawning are areas with broken bottom where tidal and general circulation produce extensive vertical turbulence, drawing cold water from the depths to the surface, thereby delaying the vernal warming of the upper strata, as a rule, until the mackerel spawning season is over. As nearly as may be determined from the information on hydrographic conditions (Bjerkan, 1919, pp. 379–403, Bigelow, 1928, pp. 550–585) and on spawning times and places (see above), the dividing line between good and poor spawning areas may be drawn at a vernal temperature of about 8° C., (46° F.). The areas that receive little or no spawn are, during the spawning season, usually colder, and those that receive much spawn are usually warmer than this temperature.

NUMBER OF EGGS SPAWNED AND SIZE OF SPAWNING STOCK

A rough estimate of the total number of eggs spawned in the region between Cape Cod and Cape Hatteras can be made from the data of the 1932 survey of spawning. The average catch during the first seven cruises was about 1,000 eggs per 17 square meters of sea surface (table 19), or an equivalent of about 200 million eggs per square nautical mile. Taking 25,000 square miles as the areas surveyed, this would amount to a total of 5,000 billion eggs. Since this figure is based on the average concentration during a 50-day period, and since the period of incubation would average about 7 days at the prevailing temperature, there must have been about 7 renewals or approximately 35,000 billion eggs spawned to maintain this average concentration. From a curve of numbers of eggs taken in successive cruises, it appears that perhaps one-seventh should be added to allow for the fact that the cruises did not begin early enough or extend late enough to include all the spawning. This raises the figure to 40,000 billions eggs. These are in all stages, and it may be computed from mortality rates of eggs (table 7) that this would be equivalent to 1.6 times as many newly-spawned eggs. Applying this factor, the final estimate of eggs spawned in this area in 1932 becomes about 64,000 billion.

It is difficult to appraise the reliability of this estimate because of the uncertainty of its components. Judging these as well as may be, it appears that at best it may be within 25 percent of the true value and at worst only within the true order of magnitude. But this is only personal judgment, and since it is impossible to study statistical probabilities, there is utility in testing the result by deriving a related statistic from an entirely different source.

During 1932 the catch of mackerel on or near spawning grounds during the spawning season; that is, in area XXIII (Fiedler, Manning, and Johnson 1934, p. 96), and in area XXII, west of Nantucket Shoals during April, May, and June, was about 13,000,000 pounds. From unpublished records on size composition of this catch, it appears that about 10,000,000 pounds of it consisted of fish of spawning size, and that their average weight was nearly 1.9 pounds. Thus, a take of about 5,000,000 spawners is indicated.

To estimate from this the size of the spawning stock it is necessary to know what percentage this was of the spawning stock in 1932. This may be done only in an indirect manner. The 1923 class of mackerel, after reaching spawning age, declined at a rate of 20 percent per year as measured by the catch per purse seine boat during the four seasons, 1928 to 1931 (Sette, 1933, p. 17). This decline was so steady that it probably should be ascribed to mortality rather than to other causes, such as changes in availability. Of course one cannot be sure that the spawning population in 1932 was subject to the same mortality as the 1923 class during the previous years, but as far as the intensity of fishing is concerned, there was no significant change between 1931 and 1932. The fleet numbered 112 seiners in 1931 (Fiedler, 1932, p. 211) and 114 in 1932 (Fiedler, Manning, and Johnson 1934, p. 97).

Views may differ as to the relative part played by catch mortality and by natural mortality in causing total mortality, but by taking divergent views, say three-quarters catch mortality on the one hand and one-quarter catch mortality on the other hand, one would arrive at 15 and 5 percent, respectively, as catch mortality; or, taking a middle ground, it would be 10 percent. Similarly divergent views may be taken as to the fraction of annual mortality suffered during the spawning season. Perhaps three-quarters and one-quarter, respectively, may reasonably be taken as the extremes and one-half (or 10 percent) as the middle ground. These would give as extremes 11 and 1.25 percent that the catch during the spawning season was of the total spawning stock. The middle view would be 5 percent.

This results in an estimated total population between 45,000,000 and 400,000,000, with a middle ground estimate at 100,000,000 individuals in the spawning population on the spawning grounds as derived from catch statistics.

It will now be recalled that the estimate derived from tow net hauls was 64,000 billion eggs spawned, and if 400,000 eggs are produced by the average female (p. 156) the indicated spawning population would be 160,000,000 females, or 320,000,000 fish of both sexes. This is within the extremes computed from the catch data and about halfway between the middle and largest figures. Considering the approximate nature of some of the elements in the estimates, this is a remarkable agreement between the two methods of computing the size of the spawning stock, and strengthens the view that the total estimate of eggs is sufficiently reliable to warrant the conclusion that the egg production was in the order of 50,000 billion in 1932.

This, of course, refers only to the spawning in the region south of Cape Cod, and it has been pointed out (p. 160) that important spawning occurs also in the Gulf of St. Lawrence. Since spawning in the latter region seemed to be of lesser magnitude than south of Cape Cod, it is probable that the entire spawning off the east coast of North America would not be more than double the estimated 64,000 billion, or, since the latter is an uncertain figure, let us say in the order of one hundred thousand billion eggs.

SPAWNING HABITS

According to Bigelow and Welsh (1925, p. 208), "Mackerel spawn chiefly at night." If this be true, the earliest egg stages should be relatively more abundant at certain times of the day than at others. From material collected at a number of stations in 1929, the eggs in "early cleavage" and "late cleavage" were counted, representing respectively the first and second 10 hours of development at the temperatures prevailing at the time. If spawning took place chiefly at night the early cleavage eggs should predominate between midnight and 10 a. m. and be in the minority during the remainder of the day. At the 14 stations from each of which more than 10 eggs of both stages were examined, the average percentage of early cleavage in the midnight to 10 a. m. group was 45 and in the 10 a. m. to midnight group 33. The difference between the two groups was not statistically significant ($t=0.91$ and $P=0.3+$, according to the method of Fisher, 1932, p. 114) and it may be concluded that the diurnal variation in percentage of early stage eggs does not indicate a tendency toward more spawning by night than by day. Tabulation of percentages according to the hours of the day did not indicate that any other particular part of the day was favored.

THE EGG

Description.—According to published descriptions, (Ehrenbaum, 1921, p. 4 for the European mackerel; Dannevig, 1919, p. 11, and Bigelow and Welsh, 1925, p. 208, for the American mackerel) the mackerel egg is 0.97 to 1.38 mm. in diameter and contains an oil globule 0.28 to 0.35 mm. in diameter. Measurements of eggs taken at sea during this investigation had a similar range in dimensions. By far the commonest dimension (modal) was 1.2 to 1.3 mm. for the egg and 0.31 to 0.32 mm. for the oil globule.

There is a tendency toward a decrease in size of mackerel eggs as the season advances. Data given by Ehrenbaum (1921, p. 4) show the same tendency in the egg of the European mackerel. This could be due to the seasonal trends of either temperature or salinity, but the experiments of Fish (1928, pp. 291–292), who found cod eggs fertilized in cold water to be larger than those fertilized in warm water, suggest that temperature alone could be responsible. Whatever its mechanism, the phenomenon of decrease in size as the season advances probably holds true for all species occuring in the tows of the present investigation. It was my practice to make scatter diagrams in which oil globule diameter was plotted against egg diameters for all eggs in hauls containing troublesome mixtures. Invariably, when mackerel eggs were near the limits of the over-all range of their dimensions and thus might be expected to overlap the range of the eggs of other species, the latter were also near the corresponding limits of their respective over-all range and the groups remained discrete, showing that tendencies for smaller or larger than average size were shared simultaneously by all species. Thus, in individual collections the range in dimensions was much less than the relatively large range of all collections, and a feature that might have been a hindrance in identification was in reality not very troublesome.

In the collections made during the course of this investigation there were eggs of four species whose dimensions approached those of the mackerel. The egg of the common bonito (*Sarda sarda*) is 1.15 to 1.33 mm. in diameter, but in its early stages it has a cluster of small oil droplets instead of a single large one. In its late stages, these droplets often become united into a single oil globule. In this condition there might be some difficulty in distinguishing the two, were it not that bonito eggs occur later in the season (in areas we have prospected) when the mackerel eggs are considerably smaller. For instance: Mackerel eggs taken in Cape Cod Bay, July 19, 1929, were 1.00 to 1.12 mm. in diameter while bonito eggs taken July 25, 1929, in the offing of No Man's Land were 1.12 to 1.27 mm. in diameter. The eggs of the cusk (*Brosmius brosme*) and the tilefish (*Lopholatilus chamaeleonticeps*) are similar in size but have oil globules distinctly smaller (0.19 to 0.23 mm.) than those in the mackerel's eggs. Closer to the mackerel egg in its dimensions was that of a species not yet identified. Although overlapping the mackerel egg in dimensions, its modal size was distinctly smaller and the oil globule somewhat larger, and in its late stages the embryonic pigment was arranged in bars unlike the diffuse arrangement in the embryo of the mackerel. Inasmuch as eggs of this type were found only at the edge of the continental shelf, their distribution was discontinuous with that of the mackerel; and since no mackerel larvae were later found in the same or neighboring localities this egg caused no confusion.

Rate of embryonic development.—Although mackerel have never been observed in the act of spawning, it is generally supposed that both eggs and sperm are discharged into the surrounding water, where fertilization takes place. Observations have shown that thereafter, during the period of embryonic development,[6] the eggs are suspended in the sea water mostly near the surface and all above the thermocline.

As is true with most cold-blooded organisms the rate of development depends on the temperature at which it takes place, being slower at low temperatures and faster at high temperatures. According to Worley (1933), who examined this feature of the development at the U. S. Fisheries Biological Station, Woods Hole, Mass., the time elapsing between fertilization and hatching was 50 hours at 21°, 70 hours at 18°, 95 hours at 16°, 115 hours at 14°, 150 hours at 12°, and 208 hours at 10°. There is no reason for believing that the rates differ at sea, though this is difficult to demonstrate.

According to Worley (1933, p. 857), "Experiment showed that typical development (and survival) could be realized only between 11° and 21°." At sea in 1932, however, eggs were most abundant at temperatures below 11°, as appears from the following average numbers taken at each degree (centigrade) of surface temperature encountered in the survey:

7	0	14	150
8	111	15	555
9	2, 117	16	44
10	3, 360	17	5
11	2, 432	18	74
12	1, 390	19	0
13	1, 380	20	0

The embryos in eggs from water below 11° C. differed in no perceptible way from those found in warmer water, and there is no reason for believing that development was not proceeding as "normally" at the lower as at the high temperatures.

Worley also found (loc. cit.) that "The total mortality during the incubation period was least at 16° C. where it amounted to 43 percent." He had three experiments at this temperature with mortalities of 37, 40, and 53 percent respectively (loc. cit. p. 847). At sea, in 1932, the average mortality was 59 percent (from interpolation to the hatching point from the data of the 5th column in table 7), or only a little greater than in the least favorable of the laboratory experiments. The weighted mean temperature of the water from which these sea-caught eggs were taken was 10.9° C. Worley's laboratory eggs suffered 90 and 95 percent mortality in his two experiments at 11°.

Obviously, both the range for normal development and the point of maximum survival were at lower temperatures at sea than in the laboratory experiments of Worley. The explanation for this disparity between results in the laboratory and observations at sea probably lies in the fact that Worley's experiments took place at a time when temperatures of the sea water from which he took his fish were in the neighborhood of 16° C. The lesser mortality at and near this temperature was connected no doubt with the lesser change involved in bringing the eggs from the temperature of the parent to the temperature of the experiment. It is obviously desirable that laboratory experiments be repeated on material taken from water of lower temperature.

Vertical distribution.—Although it has been known that mackerel eggs are suspended in the sea, usually near the surface, there has been in American waters no previous determination of vertical distribution, apart from the general observation

[6] For the minutiae of the embryology of mackerel, the reader is referred to Moore (1899, pp. 5–14), and to Wilson's (1891) description of the sea bass, which the mackerel in its embryology closely resembles.

that surface hauls take more eggs than deeper hauls. The present determination is based on a series of horizontal hauls at different depths in 38 meters of water in the offing of the Fire Island Lightship on May 19, 1929.

Four series were taken: one at dawn, another at noon, another in the evening, and the final series at midnight. The net was one-half meter in diameter at the mouth and rigged with a closing device actuated by a messenger. It was lowered while open, towed for 20 minutes, then closed and hauled to the surface. Each series included hauls at the surface and at the 5-, 10-, 20-, and 35-meter depths. The courses of the nets were kept as nearly horizontal as possible by periodical estimation of depth based on measuring the towing warp's angle of stray and paying out or hauling in the line as needed to keep the net at the proper level. Since the net was lowered while open, and since the tripping mechanism failed on several occasions, there was some contamination of the haul during its passage through the water overlying the stratum fished. Correction for this contamination was estimated on the basis of the average concentration of eggs in the overlying water and the time it took the net to pass through the overlying water in an opened condition. An additional correction for variations in speed of towing, based on the angle of stray of the towing warp, was applied to all catches on which data adequate for this purpose were available.

TABLE 2.—*Vertical distribution of mackerel eggs at station 20498, May 17, 1929*

Depth	Numbers taken per haul				Numbers per haul adjusted to standard [1]			
	Dawn	Noon	Sunset	Midnight	Dawn	Noon	Sunset	Midnight
Surface	12,080	34,600	27,900	13,320	[2] 12,080	[2] 32,900	[2] 27,900	[2] 13,320
5 meters	10,810	13,210	21,600	13,200	13,880	17,900	[2] 22,850	[2] 13,145
10 meters	11,120	8,850	8,750	8,260	7,550	8,210	11,480	[3] 7,600
20 meters	5,120	1,070	380	694	[3] 2,960	750	0	[3] 418
35 meters	1,182	20	124	285	0	0	0	[3] 15

[1] Adjusted for time (20 minutes); speed (to cause stray of 28.5° in towing wire); and for contamination in passing through overlying strata in paying out and hauling in.
[2] Not adjusted for speed.
[3] Adjustment for contamination was large and probably inaccurate.

As may be seen from figure 4, the numbers decrease rapidly with depth. When the numbers from the several hauls at each level (exclusive of certain unreliable subsurface hauls designated as questionable in the figure) are averaged, the distribution is as follows: surface, 22,000 per haul; 5 meters, 13,000; 10 meters, 8,000; 20 meters, 700; 35 meters, 0. Except for the surface hauls which were not adjusted for towing speed, and certain of the subsurface hauls on which reliable corrections were impossible, the successive hauls at each level yielded nearly the same numbers, indicating at once the reliability of the method of sampling and the stability of the vertical distribution.

Comparing the distribution of eggs with physical conditions, it is obvious that eggs were abundant from the surface down to a depth of 10 meters, the range in which temperature, salinity, and therefore density were approximately uniform. Between 10 and 20 meters the temperature decreased sharply, the salinity increased sharply, and therefore the density increased sharply. In this zone of increasing density, the mackerel eggs rapidly diminished in number so that at 20 meters few were taken and below 20 meters, none. At this station, therefore, the distribution of mackerel eggs was limited to the stratum above the pycnocline (zone of sharp increase in density).

While this has been demonstrated in detail at only this one station, that it is a general rule is indicated by subsequent experience with oblique hauls, where, with several nets on the line, the deeper nets, when towed entirely below the thermocline, took very few eggs that were not otherwise accounted for (by the contamination correction based on the average catch of the upper net and on the time taken to pass through the upper stratum). It is safe to conclude therefore, that the pycnocline forms a barrier to the downward extension of mackerel eggs. Further, the pycnocline is sufficiently well indicated by the thermocline in this region so that the latter may be used an an indicator of the lower limit of mackerel eggs.

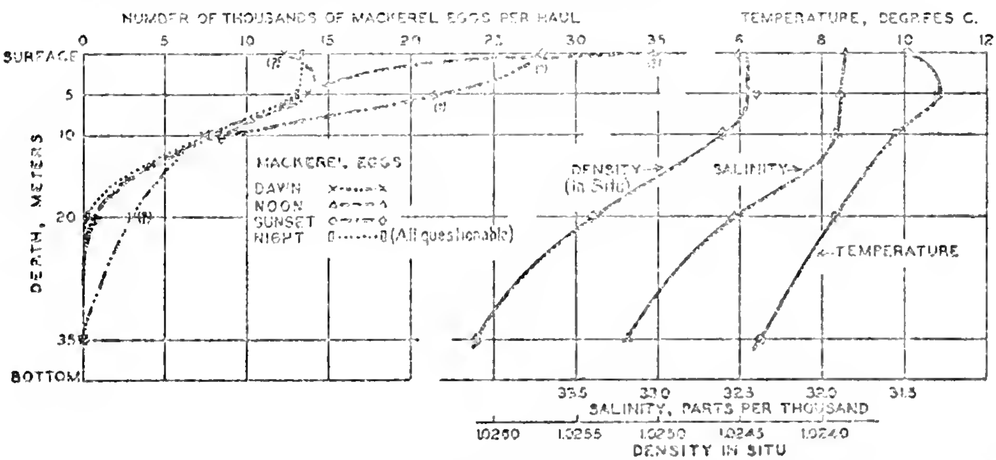


Figure 4.—Vertical distribution of mackerel eggs in relation to temperatures, salinity, and density of water. Observations were adjusted to the basis of standard speed of towing, except those indicated as questionable.

The serial tows of May 17, 1929, also illustrated significant differences in the vertical distribution of eggs in different stages of embryonic development. When the eggs were separated into three stages of development occupying approximately equal periods of time, it was found that those of the early stage (A) were mostly near the surface, those of the late stage (C) mostly between the 5- and 10-meter levels, and those of the intermediate stage (B) intermediate between A and C in their vertical distribution (table 3). Too few eggs were taken at greater depths to indicate reliably the proportionate numbers at each of the three different stages of development.

Table 3.—*Vertical distribution of various stages of mackerel eggs according to noon series, station 20498, May 17, 1929*

[Stage A is from fertilization to complete epiboly; stage B is from complete epiboly to embryo extending three quarters around the circumference of the egg; stage C is from this point to hatching]

Depth	Number taken				Number adjusted to standard [1]			
	Stage A	Stage B	Stage C	Total	Stage A	Stage B	Stage C	Total
Surface	30, 250	4, 250	100	34, 600	29, 630	4, 170	100	33, 900
5 meters	3, 960	5, 690	3, 560	13, 210	5, 280	7, 760	4, 860	17, 900
10 meters	980	2, 950	4, 920	8, 850	800	2, 750	4, 660	8, 210

[1] Adjustments the same as in table 2.

The differential vertical distribution of the several egg stages could result either from a decrease in specific gravity of the water after the eggs were spawned or an increase in the specific gravity of the eggs as embryonic development proceeded. Moore (1899, p. 14) concluded that the eggs increased in specific gravity during development when he noted that mackerel eggs which he was incubating in the laboratory sank during the third day. But he gives neither the specific gravity of his 3-day-old eggs [7] nor that of the sea water either at the beginning or end of his experiment. Since he was working before rigid control of temperature was customary, it is likely that the specific gravity of the water in his experiment may have been changed by warming.

In the present example, at least, it is known that the temperature of the water was increasing at the time station 20498 was visited. At the temperature of the water in which the eggs were found on May 17, it takes about 5 days for incubation (p. 167), and it may be estimated that stage C eggs were spawned at least 3 days prior to stage A eggs, hence on May 14, when unfortunately this station was not visited. However, from interpolation (linear) both in space and time between the temperature at station 20498 on May 17 and temperature at neighboring stations on May 12, it appears that the density of the water at the surface on May 14 could have been very nearly the density of the water at the 10-meter level on May 17. Hence it is preferable to ascribe the sinking of the late stages to the warming of the water with attendant decrease in density, rather than to an increase in the density of the eggs.

THE LARVA [8]

Yolk-sac stage.—The newly hatched larva [9] is slightly less than 3 mm. in length, well covered with scattered black pigment spots which tend to be denser dorsally than ventrally. The eyes are colorless. The region of the gut is occupied by the yolk sac with its oil globule. Both sac and globule are about the same size as they were in the egg. The mackerel is readily distinguished from other similarly marked larvae with which it is found, by its larger size, stouter shape, coarser pigment spots, and its 30 myomeres.

As development proceeds, the pigment becomes localized on top of the head and along dorsal and ventral edges of the body, the eye becomes black, the yolk sac absorbed, the mouth and gut formed. These changes are completed at a length of 4 mm.

As seen in the laboratory and hatchery, the mackerel swim very feebly during the yolk-sac stage, with short, spasmodic, random movements. Their balancing faculty is undeveloped, their position being indifferently upside down, right side up, and at various angles. At sea they must be totally at the mercy of the water movements.

Larval stage.—As used herein, this stage represents the period beginning after yolk-sac absorption and ending after fin formation, and it includes individuals between 4 and 8 mm. in length. In this stage, the mackerel is readily distinguished from other species by the row of black spots of irregular size and spacing along dorsal and ventral edges of the body, beginning about midway between snout and tail and extending almost to the end of the notochord (but not into the fin fold). Those in the dorsal row are less numerous and more widely spaced than those in the ventral. Other species which were found with the mackerel, and which have also such dorsal and ventral rows of pigment, are the winter flounder (*Pseudopleuronectes americanus*), which differs from the mackerel by its greater number of myomeres (37–40) and its

[7] But he does give the specific gravity of newly spawned eggs as between 1.024 and 1.025, a figure very close to that of surface water at our station 20498. (See fig. 4.)

[8] While the term larva may be applied to the entire planktonic existence, it is convenient to recognize three subdivisions: yolk-sac stage, larval stage, and post-larval stage.

[9] This description is based on formaldehyde preserved specimens because this is the form commonly available for study. In life, the newly-hatched larva is longer, measuring 3.1 or 3.2 mm. (distortion and shrinkage decrease the length of preserved specimens), and in addition to the black pigmentation, have yellow and greenish pigment on each side of the head between the eye and otocyst, and on the surface of the oil globule (Ehrenbaum, 1905 p. 31).

strongly, laterally compressed body; the bluefish (*Pomatomus saltatrix*), which differs by its fewer myomeres (24); and the rosefish (*Sebastes marinus*), which has the same number of myomeres (30) and in the 4- to 5-mm. stage could be confused with mackerel. With both the rosefish and mackerel available for comparison, the former is readily distinguished by the closeness of the spots in the dorsal and ventral rows, those in the rosefish forming almost a continuous black streak, whereas those of the mackerel are discrete. Other differences, less useful, are the more slender shape and the greater relative length of the post-anal region in the rosefish larva. After passing the 5-mm. stage, the rosefish larva is readily separated from the mackerel larva by its prominent preopercular and cranial spines. An additional character of use in separating the mackerel larva from the others is its strong teeth, which are readily visible in specimens of the 7-mm. size but less so in smaller individuals.

Inability to keep larvae alive in the laboratory or hatchery during this stage precluded direct observation on their activity, but, as is shown in a later section, their movements are sufficiently well-directed for performance of diurnal vertical migrations of 20 to 30 meters but not sufficiently sustainable for migrations of miles in extent.

Transition phase.—Intervening between larval and post-larval stages is a transition phase including individuals 9 and 10 mm. long whose fins are in various states of completion.[10] Fin formation is a gradual process, neither beginning sharply at 9 mm. nor ending sharply at 10 mm. At the former length, the caudal fin already shows a number of rays, and at the latter length, the laggard first dorsal fin does not yet show any of its spines. But the tail fin makes its greatest changes, the second dorsal fin and finlets and the anal fin and finlets are all developed within this size range, hence it is most appropriately designated as a transition phase.

Post-larval stage.—This stage includes the latter part of planktonic existence beginning at about completion of fin formation and lasting until the young fish are nimble enough to evade the plankton nets. It is comprised of individuals 11 to 50 mm. long.

Since all the vertical fins except the first dorsal are complete, identification by adult characters is simple. The larvae enter this stage somewhat laterally compressed, and by its end fill out to the trim fusiform shape of the adult. At the beginning of this stage the color pattern is typically larval, but by its end the dark pigment has spread over the dorsal portions, and in live specimens the silvery hue is apparent, though the black wavy bands characteristic of the adult are yet to form. The appearance is in general like a miniature adult with somewhat oversized head and fins.

As appears in a later section, the post-larvae are capable of extensive swimming. Furthermore, as they near the end of this stage the schooling instinct asserts itself. The transition from a primarily planktonic habit to a primarily swimming and schooling habit probably is gradual, in the sense that all individuals may not experience the change at the same size. The available evidence is that it involves individuals between about 30 and 50 mm. in length. This evidence is from two sources. First, the survival curve (fig. 17) has a substantially uniform trend from 11 to 30 mm., from which it may be inferred that there was no change of trend within this size range sufficient to indicate a loss of larvae such as could be expected if some had begun to

[10] The present description of lengths at which fins appear differs from published figures (Ehrenbaum, 1921, figs. 1 to 7, and Bigelow and Welsh, 1925, fig. 92) probably because the latter give lengths inclusive of finfold or caudal fin, though this is not definitely stated; whereas our measurements were taken to the end of the notochord, i. e., exclusive of the finfold in early stages; and to the base of the caudal fin rays, i. e., exclusive of the caudal fin in later stages. This was necessary on account of frequent distortion or injury to the caudal appendage.

school and were no longer susceptible to capture in plankton nets. Second, a school of small mackerel was observed and sampled in Woods Hole Harbor in July 1926, containing individuals between 35 and 65 mm. in length (table 21). The first evidence shows that the schooling habit did not involve fish under 30 mm. in length; the second proves that some fish, at least, begin schooling as soon as they exceed that size.

Vertical distribution.—From series of horizontal hauls at 0, 5, 10, 20, and 35 meters at early morning, midday, evening, and midnight, at a station (*Albatross II* No. 20552) southeast of Fire Island Lightship (latitude 40°20′ N., longitude 70°57′ W.) visited on July 13 and 14, 1929, there is evidence that the larvae of the mackerel do not descend far below the surface, probably being limited by the thermocline, and that they perform a diurnal vertical migration (fig. 5).

TABLE 4.—*Vertical distribution of mackerel larvae at various times of the day as indicated by horizontal tows with a closing half-meter plankton net at Station 20552 (Albatross II), latitude 40°20′ N., longitude 72°59′ W., July 13 and 14, 1929*

Depth of haul	Time [1]	Length of larvae (millimeters)						Total	
		4	5	6	7	8	9		
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
Dawn:									
Surface	2.53 a. m.			2	2		2	6	93
5 meters	3.27 a. m.	1						1	7
10 meters	3.54 a. m.							None	
20 meters	4.20 a. m.							None	
35 meters	6.03 a. m.							None	
Total		1		2	2		2	7	100
Noon:									
Surface	11.33 a. m.							None	
5 meters	12.08 p. m.							None	
10 meters	12.24 p. m.							None	
20 meters	12.52 p. m.							None	
35 meters	1.17 p. m.							None	
Evening:									
Surface	6.26 p. m.		2					2	14
5 meters	6.51 p. m.							None	
10 meters	7.17 p. m.	1	10	13	1			25	86
20 meters	7.44 p. m.							None	
35 meters	8.12 p. m.							None	
Total		1	12	13	1			27	100
Midnight:									
Surface	11.30 p. m.		1	4	5	1	1	12	38
5 meters	11.54 p. m.	1	13	2	1			17	53
10 meters	12.22 a. m.		2		1			3	9
20 meters	12.47 a. m.							None	
35 meters	1.13 a. m.							None	
Total		1	16	6	7	1	1	32	100

[1] Midpoint of the 20-minute haul is given.

In detail it will be noted (table 4) that in any one series of hauls the larvae were caught mostly at only one or two levels; indicating that they were confined to such thin strata that the entire population could easily, at times, be situated between the levels of the hauls, and hence at those times be missed. Accordingly, it is probable that in the evening the larvae were nearly all at the 10-meter level, probably traveling upward, and by midnight some had reached the 5-meter level and some the surface. The deeper ones probably continued upward so that nearly all reached the surface shortly after midnight; and by 3 a. m., when the next series began, they had begun to descend so that they were between the surface and the 5-meter level, and few were taken in the hauls at either level. By noon, they probably had descended beyond 10 meters and were located between the 10 and 20 meter hauls, and none was caught.

It is improbable that the daytime descent was beyond the 20 meter level at this station or was ever beyond the thermocline. During 1930, 1931, and 1932, when the nets were hauled obliquely below as well as above the thermocline, the lower tows seldom caught larvae that could not be accounted for as contaminants resulting from passage through the upper layers.

From the length-distribution of the larvae it appears (table 4) that the larger individuals (6 to 9 mm.) were more stongly inclined to migrate, reaching the surface at night, while the smaller ones (4 to 5 mm.) tended to stay in the intermediate 5- to 10-meter levels.

Though these observations do not provide a precise description of vertical distribution and migration, they do demonstrate the necessity of sampling all levels down to the thermocline to get the representative statistics needed for the studies on growth and mortality to follow.

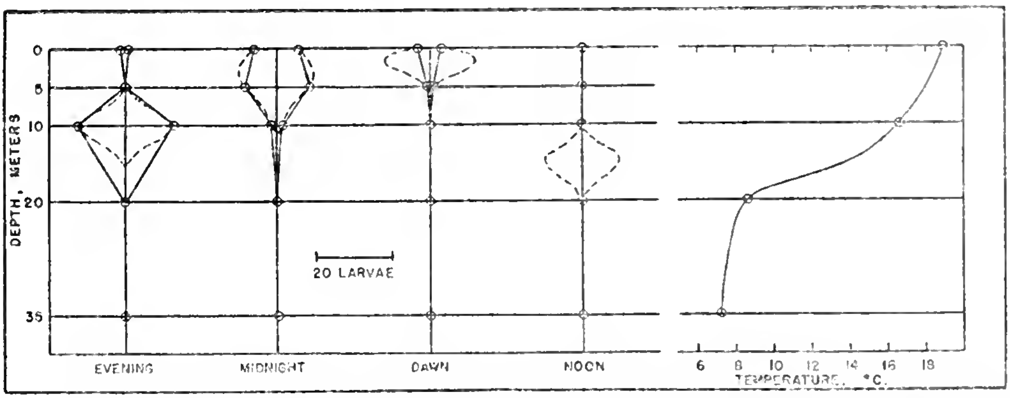


FIGURE 5.—Vertical distribution of mackerel larvae at several points of time in the diurnal cycle in relation to temperature. The solid lines connect observational points. The broken lines indicate the probable vertical position of the bulk of the population of larvae.

GROWTH

Very little has been published on the growth of marine fishes during that early period of the life history spent in the plankton community, and nothing on the growth of the mackerel during this stage. Of the data collected during the present investigation, only those of 1932 were collected in a manner sufficiently quantitative and at short enough intervals of time to be used in deducing growth rate.

The method of analysis consists, essentially, in following the advance in position of the mode of homologous groups of larvae by comparing sizes collected in successive cruises. But this cannot be done in a simple and direct manner. Mackerel eggs are spawned over a period of several months. The larvae are subject to high mortality. As a result, almost always there are vastly more small larvae than large ones, and the predominance of small larvae is so great during most of the season that the groups of larger ones do not form distinct modes. Instead, in ordinary arithmetic frequency distributions they are apparent principally as a lengthening of the "tail" of the distribution at its right-hand side (table 5).

TABLE 5.—*Number of eggs and larvae taken on each cruise in 1932, classified according to stages of eggs and lengths of larvae*

[During cruises 1 to 7, tow nets 1 meter in diameter at mouth were used, and during cruises 8 and 9, tow nets 2 meters in diameter were used; all hauls were obliquely towed and numbers caught were adjusted to represent an equal amount of towing per meter of depth fished]

Egg stages and lengths of larvae in millimeters	Cruises								
	I May 2-6	II May 9-16	III May 19-23	IV May 24-28	V June 1-5	VI June 5-8	VII June 15-21	VIII June 25-July 1	IX July 16-24
A	11,415	21,563	22,294	12,172	2,907	2,815	851	(1)	(1)
B	7,895	13,585	13,519	15,287	2,057	1,161	1,303	(1)	(1)
C	4,667	18,228	5,266	21,712	6,011	1,562	2,733	(1)	(1)
3	4,017	6,310	7,338	18,392	5,215	9,214	8,805	[1] 0.3	[1] 1.6
4	1,690	838	2,207	[2] 4,462	1,243	8,236	734	[1] 0 4	[1] 12.5
5	239	751	1,607	[2] 751	1,049	2,371	546	[1] 5.6	[1] 8.9
6	38	311	544	[2] 200	1,132	501	208	[1] 15.9	[1] 11.4
7	12	21	151	[2] 25	911	399	55	36.6	8.9
8	4	2	40	[2] 48	200	470	19	30.1	17.2
9	1	1	18	[2] 28	54	186	13	16.6	8.2
10	-----	-----	7	[2] 3	7	41	12	9.6	3.4
11	-----	-----	5	[2] 2	6	12	5	5.8	1.9
12	-----	-----	-----	-----	2	4	9	3.8	1.2
13	-----	-----	-----	-----	1	4	7	.8	.1
14	-----	-----	-----	-----	2	2	8	1.1	.4
15	-----	-----	-----	-----	-----	1	5	.6	.3
16	-----	-----	-----	-----	-----	-----	2	.5	.8
17	-----	-----	-----	-----	-----	-----	3	.2	.1
18	-----	-----	-----	-----	-----	-----	5	.1	-----
19	-----	-----	-----	-----	-----	-----	3	.2	.1
20	-----	-----	-----	-----	-----	-----	1	.3	.3
21	-----	-----	-----	-----	-----	-----	1	-----	.5
22	-----	-----	-----	-----	-----	-----	1	.1	.3
23	-----	-----	-----	-----	-----	-----	-----	-----	1.3
24	-----	-----	-----	-----	-----	-----	-----	-----	.3
25	-----	-----	-----	-----	-----	-----	-----	-----	.8
26	-----	-----	-----	-----	-----	-----	-----	-----	1.0
27	-----	-----	-----	-----	-----	-----	-----	-----	1.3
28	-----	-----	-----	-----	-----	-----	-----	-----	1.3
29	-----	-----	-----	-----	-----	-----	-----	-----	-----
30	-----	-----	-----	-----	-----	-----	-----	-----	.3
37	-----	-----	-----	-----	-----	-----	-----	-----	.3
51	-----	-----	-----	-----	-----	-----	-----	-----	.1
Total	29,978	61,610	53,006	73,082	20,797	26,979	15,329	128.6	84.8

[1] Eggs and larvae below 7 mm. were not retained in their full numbers by the coarse-meshed nets used on cruises 8 and 9.
[2] The numbers given in this class are deficient, due to failure to occupy the usual number of stations at the southern end of the area of survey where many of the larvare of this size were to be found at this time. For revised data see footnote on p. 192.

The groups of more than average abundance were brought into prominence by a modification of the conventional deviation-from-average-frequency method. The average numbers per cruise of the larvae at each length ("observed values" of table 6) were converted to logarithms and plotted against logarithms of lengths. Straight lines were fitted to these observed values (figure 6) from which the theoretical values were derived. These were subtracted from the logarithms of the frequencies of each cruise, giving remainders which represent the relative amounts by which the number of larvae of particular sizes deviated from the average number at particular times in the season (last 9 columns of table 6).

Since the average curve was, in effect, an estimate of mortality by sizes, the deviations may also be regarded as frequencies from which the effect of mortality was removed, leaving only the effects of rate of hatching, rate of growth, and, of course, the random variations of sampling. Fluctuations of hatching (resulting from fluctuations in spawning) give rise to modes, and growth causes the modes to progress from one cruise to the next. If early growth of the mackerel is exponential as in many animals and plants, the progress of modes should be along straight lines when the deviations are plotted against logarithms of length, as in figure 7. This idea influenced the selection of homologous modes marked by corresponding letters R, S, and T, in the figures.

That each series includes truly homologous groups is indicated by several criteria, independent of the straight-line conformity. In the R series, the modes all tend toward peakedness. In the S series, they all tend to be broad. In the T series they are intermediate in shape. The progress in each series is reasonably consistent and the course of growth is roughly parallel in the three series; moreover, the slight departure from parallelism is in the expected direction, the later series having the higher growth rates consistent with their development in the warmer water to which they are subjected. Furthermore, the modes are consistently present in the material from each cruise with only two exceptions, R in cruise III and S in cruise IV. The absence of S in cruise IV is plainly due to failure on that cruise to visit certain stations in the southerly end of the spawning area, where previous cruises would lead one to expect

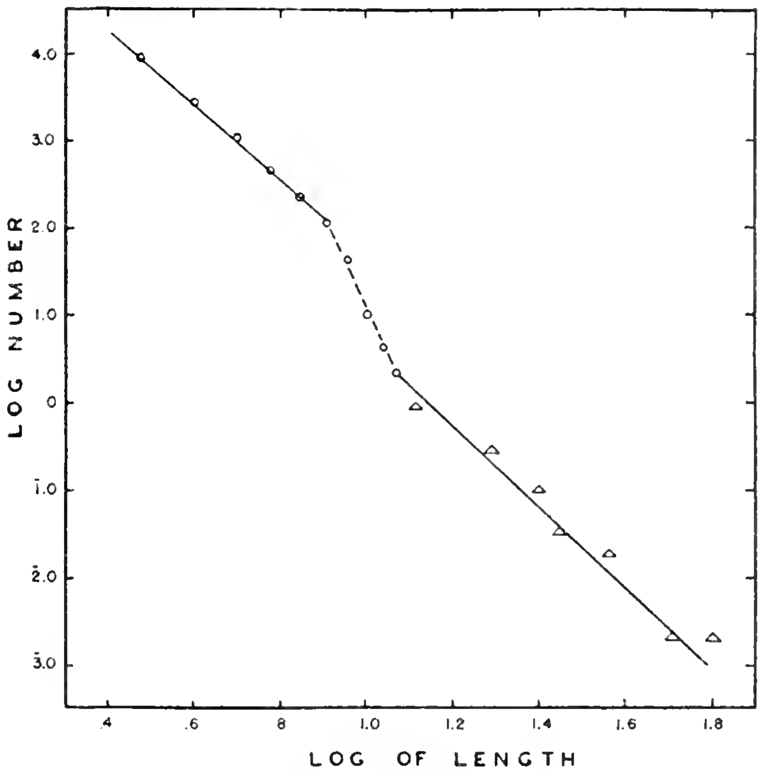


FIGURE 6.—Frequency distribution of lengths of larvae plotted logarithmically.

to find larvae of sizes appropriate for this series (fig. 13, IV). Absence of R in cruise III has no such simple explanation, and can be explained only as chance sampling fluctuation.

Only one other reasonably sensible alternative to the series of homologies in figure 7 is possible. According to this alternative, R of cruises I and II would be considered forerunners of the 9- and 10-mm. larvae of cruise III; S of cruise III considered the forerunner of R of cruises V and VI; the 3- and 4-mm. larvae of cruise IV, the forerunner of S of cruise V; S of cruises V and VI, the forerunner of R of cruise VII; and T of cruise VI, the forerunner of S of cruise VIII. But, this would not account for the presence of such prominent modes as R of cruise IV, S of cruise VII, or T of cruise VIII; and there are other objections to this alternative set of homologies which will be considered later.

TABLE 6.—*Deviations of individual cruise frequencies of lengths of larvae and postlarvae from the average frequency [1] of the 9 cruises of the season of 1932*

Length		Average number per cruise			Cruises								
		Observed values [2]		Theoretical values [1]	I	II	III	IV	V	VI	VII	VIII	IX
Mm.	*Log*	*Number*	*Log number* [3]	*Log number* [3]	*Dev.*	*Dev.*	*Dev.*	*Dev.*	*Dev.*	*Dev.*	*Dev.*	*Dev.*	*Dev.*
3	0.477	8,470	13.93	14.00	−0.40	−0.20	−0.13	+0.26	−0.28	−0.04	−0.06	--------	--------
4	.602	2,773	13.44	13.41	−.18	−.49	−.07	+.24	−.32	+.51	−.54	--------	--------
5	.699	1,045	13.02	12.98	−.60	−.10	+.23	−.10	+.04	+.39	−.24	--------	--------
6	.778	421	12.62	12.63	−1.05	−.14	+.11	−.33	+.42	+.07	−.31	--------	--------
7	.845	225	12.35	12.36	−1.28	−1.04	−.18	−.96	+.60	+.24	−.62	−0.80	−1.41
8	.903	112	12.05	12.05	−1.45	−1.75	−.45	−.37	+.25	+.62	−.77	−.57	−.81
9	.954	43	11.63	11.55	−1.55	−1.55	−.29	−.10	+.18	+.72	−.44	−.33	−.64
10	1.000	10	11.00	11.10	--------	--------	−.25	−.62	−.25	+.51	−.02	−.12	−.56
11	1.041	4.29	10.63	10.72	--------	--------	−.02	−.42	+.06	+.36	−.02	+.04	−.44
12	1.079	2.14	10.33	10.33	--------	--------	--------	--------	−.03	+.27	+.62	+.25	−.26
13	1.114	1.44	10.16	10.15	--------	--------	--------	--------	−.15	+.45	+.70	−.24	−1.11
14	1.146	1.49	10.17	10.00	--------	--------	--------	--------	+.30	+.30	+.90	+.03	−.43
15	1.176	.77	9.89	9.82	--------	--------	--------	--------	--------	+.18	+.88	−.01	−.40
16	1.204	.36	9.56	9.72	--------	--------	--------	--------	--------	--------	+.58	−.06	+.18
17	1.230	.37	9.57	9.61	--------	--------	--------	--------	--------	--------	+.87	−.31	−.53
18	1.255	.57	9.76	9.48	--------	--------	--------	--------	--------	--------	+1.22	−.53	--------
19	1.279	.37	9.57	9.35	--------	--------	--------	--------	--------	--------	+1.13	+.01	−.31
20	1.301	.17	9.23	9.27	--------	--------	--------	--------	--------	--------	+.73	+.15	+.15
21	1.322	.17	9.23	9.16	--------	--------	--------	--------	--------	--------	+.84	--------	+.55
22	1.342	.16	9.20	9.08	--------	--------	--------	--------	--------	--------	+.92	+.07	+.34
23	1.362	.14	9.15	9.00	--------	--------	--------	--------	--------	--------	--------	--------	+1.11
24	1.380	.03	8.48	8.90	--------	--------	--------	--------	--------	--------	--------	--------	+.52
25	1.398	.09	8.95	8.83	--------	--------	--------	--------	--------	--------	--------	--------	+1.06
26	1.415	.11	9.04	8.75	--------	--------	--------	--------	--------	--------	--------	--------	+1.23
27	1.431	.14	9.15	8.67	--------	--------	--------	--------	--------	--------	--------	--------	+1.44
28	1.447	.14	9.15	8.60	--------	--------	--------	--------	--------	--------	--------	--------	+1.51
29	1.462	--------	--------	8.50	--------	--------	--------	--------	--------	--------	--------	--------	--------
30	1.477	.03	8.48	8.45	--------	--------	--------	--------	--------	--------	--------	--------	+.97
37	1.568	.03	8.48	8.00	--------	--------	--------	--------	--------	--------	--------	--------	+1.42
51	1.708	.01	8.00	7.35	--------	--------	--------	--------	--------	--------	--------	--------	+1.65

[1] Deviations were taken from the theoretical rather than observed values. The theoretical values were derived from the observed values by fitting straight lines to the points resulting from the plot of logarithm of numbers against logarithm of lengths in fig. 6.

[2] From 3 to 12 mm., inclusive, the average was of the first 7 cruises; from 13 to 51 mm., inclusive, it was of 9 cruises.

[3] 10 was added to the logarithm of each number in order to simplify notation in the case of decimal numbers.

There is, in addition, external evidence that the chosen series of homologies is correct and the alternate series incorrect.

The geographic distribution of successive stages needed to fit the alternate series would not be in harmony with any possible system of drifts. The 3- and 4-mm. larvae of cruise IV were off Long Island and the 6- to 8-mm. larvae of cruise V were mainly in the offing of the southern coast of New Jersey by the next cruise. To assume that these were homologous would require drifting at an average rate of 25 miles per day, which is far too fast for non-tidal currents in this area, comparing rather to such swift ocean currents as the Gulf Stream (Iselin, 1936, p. 43). On the other hand, the system of homologies indicated by the letters in figure 7 requires no fantastic assumptions as to drift. In fact, it will be shown below (p. 183) that the movements of larvae designated by this system of homologies follow a pattern closely and definitely related to wind-impelled drifts.

Furthermore, the growth rate of the larvae that would be indicated by the alternate series is not consistent with the lengths of the smallest post-planktonic stages. The range in size and the modal lengths of small post-planktonic mackerel taken in July and August of certain years have been indicated in figure 8. Unfortunately, the earliest available sample of such material in the 1932 measurements was drawn August 30, nearly 50 days after the latest tow net material. It lies close to the projected S–S and T–T lines of the chosen homologies and far from the projected line that would result from the alternative homologies. That this does not result by coincidence from altered growth rates intervening between cruise material and post-planktonic material is shown by the range and modal sizes from earlier dates in 1926 and 1927 when several samples were secured by dip net early in summer.[11] Their lengths (table 21) agree closely with the terminal position of the growth curves described by the chosen homologies, and are far below a growth curve predicated on the alternatives. Hence it may be concluded that the chosen series consist of truly

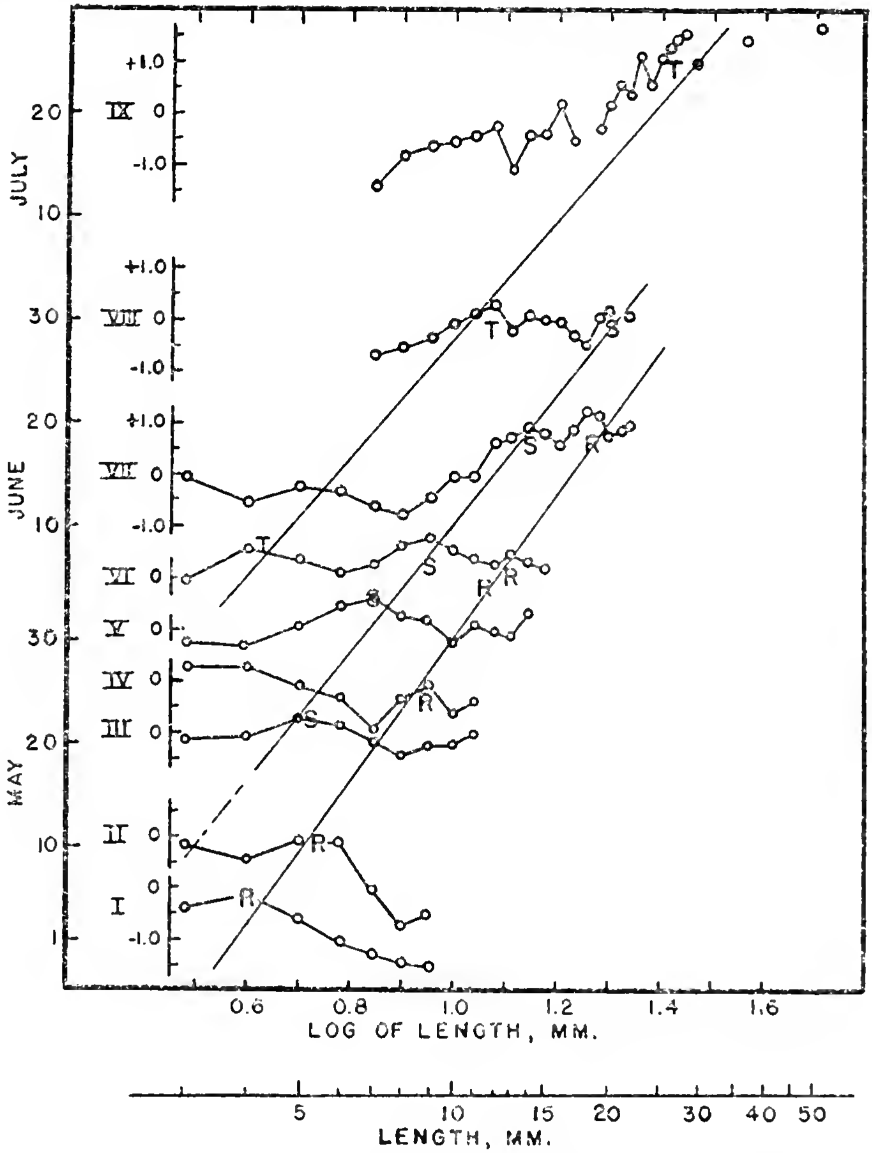


FIGURE 7.—Growth of mackerel larvae and post-larvae as indicated by the progress of modes in the deviations of numbers of specimens in each size-class taken on individual cruises from the average number taken on all cruises. The letters R, S, and T mark the positions of homologous modes referred to the scale of dates; and the straight lines are fitted to the homologous series. The vertical interior scale is the scale of deviations in logarithms. Roman numerals are cruise numbers.

homologous modes, and that the straight lines fitted to the respective series correctly describe the larval and post-larval growth in 1932.

[11] Schools of very small mackerel wander into pound-nets from which they can be removed by dip net if the pound-nets are visited before hauling. Once hauling commences they are frightened and usually escape through the meshes. In addition to samples so collected, one was taken from a school which wandered into the boat basin at the U. S. Fisheries Biological Station, Woods Hole.

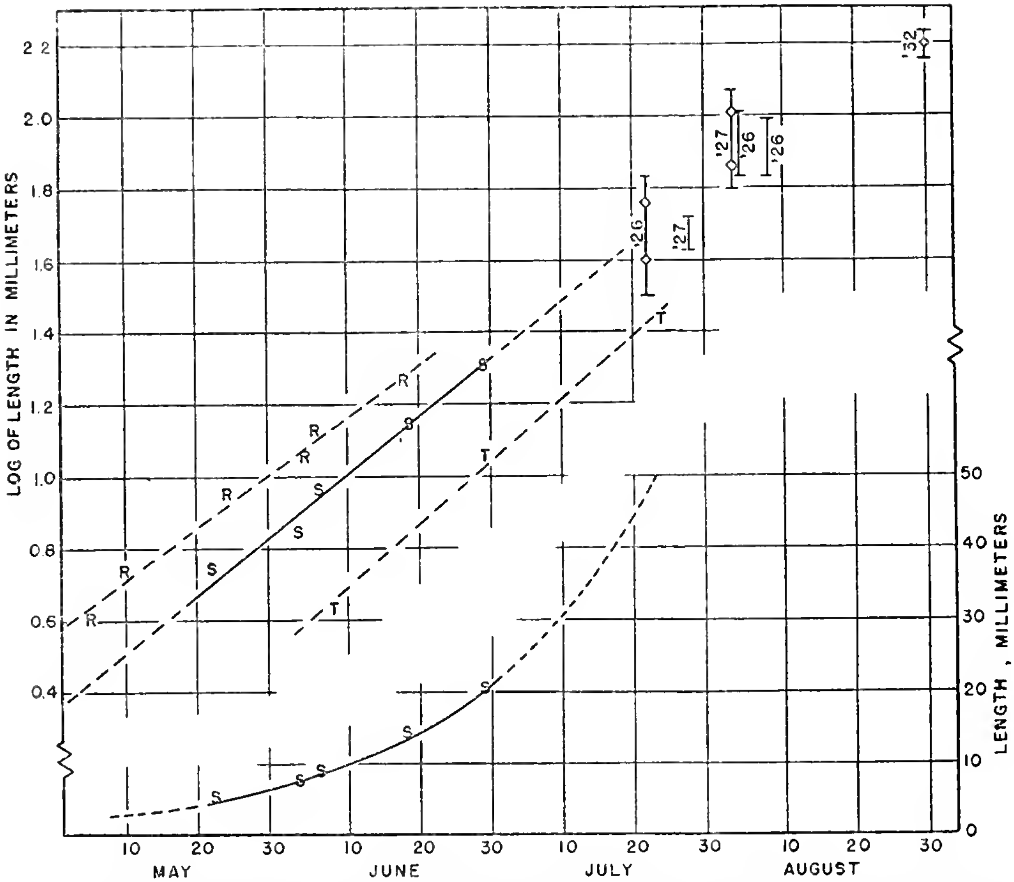


FIGURE 8.—Growth of mackerel larvae and post-larvae derived from the progression of modes of figure 7. The vertical lines at the upper right represent the range of sizes and position of modes (diamonds) of young mackerel collected by dip net from pound nets in the vicinity of Woods Hole, Mass., in the years designated. The straight lines in the upper part of the graph are on the logarithmic scale. The curved line in the lower part represents the actual growth of the S series being plotted on an arithmetic scale.

Inasmuch as the S series had its origin in the area and near the time of maximum spawning and formed the most distinct mode in the deviation curves, it may be taken as most nearly typical of the growth of larvae in the season of 1932. In the lower part of figure 8, the growth of this series has been plotted on an arithmetic scale from which it is readily seen that mackerel hatching in early May attain a length of 4 mm. by about May 20, 7 mm. by June 1, 12 mm. by June 15, and 22 mm. by July 1. This rate projected to the 22nd of July reaches 48 mm. (nearly 2 inches), which closely agrees with the largest larva of the final cruise and also with the length of individuals in the dip net sample of July 22, 1926, which ranged from 35 to 65 mm. (1.4 to 2.5 inches).

From the above relationship of sizes and ages, and from Worley's (loc. cit.) data on rates of incubation, it is possible to compute the duration and average age of each of the egg stages and of each size-class of larvae. Apart from its value *per se*, this is of use in further computations of mortality rate.

This was calculated as follows: the weighted mean temperature in which the stage A eggs were found during the cruises of 1932 was 10.9° C. At this temperature the incubation period occupies 7.23 days (Worley 1933, fig. 5). Stage A, representing the development from fertilization to complete epiboly constitutes 35 percent of the incubation period, stage B, from complete epiboly to embryo ¾ around the yolk mass constitutes 32 percent, and stage C from embryo ¾ around the yolk mass to hatching constitutes 33 percent (Worley 1933, fig. 5). The average time occupied by these three egg stages was therefore 2.53, 2.31, and 2.39 days, respectively, and the average age of each stage was derived by simple arithmetic.

The duration of each larval length-class was computed from the formula:

$$\text{duration (in days)} = \frac{\log l_2 - \log l_1}{0.01591}$$

where l_1 is the lower boundary of the length class interval in mm., l_2 the upper boundary of the length class interval in mm. The constant 0.01591 is the increase per day of the logarithm of lengths computed from the straight line fitted to the points of the S series (fig. 8).

The average age of each length-class was computed by the formula:

$$\text{age (in days)} = \frac{\log l_2 - \log l_1}{0.01591} + 7.23$$

where l_1 is the length of newly hatched larvae (2.8 mm.) and l_2 the midvalue of the length class interval. The constant 7.23 is the average age of newly hatched larvae.

The boundaries of class intervals were as follows: for 3-mm. larvae, 2.9 to 3.5 mm.; for 4- to 25-mm. larvae, the designated length ±0.5 mm.; for 30- to 50-mm. larvae, the designated length ± 5.0 mm. The mid values of class intervals were: for 3-mm. larvae, 3.2 mm.; for all others, the designated lengths.

Accuracy of determination.—The resulting values for duration of egg stages and of larval-length classes are given in table 7 to hundredths of days, thus expressing a smooth curve that gives the most probable relationship for the body of data from which they are derived. Purely from the standpoint of instrumental and sampling accuracy, they have no such high degree of precision. The durations may be accurate to the nearest tenth of a day for the egg stages, and of lesser accuracy for the larval-length classes. The duration of the 3-mm. class, derived by extrapolation, is especially in doubt, and may be in error by as much as a day. The other classes probably are within several tenths of a day of true values.

From the standpoint of variability in growth itself, the values are even more approximate. While growth obviously follows a curve of percental increase, there must be fluctuations about this curve due to local variations in environment affecting accessibility of food and rates of metabolism. Furthermore, the particular curve of growth given pertains only to the S group, which developed under a particular set of environmental conditions. From figure 8 it appears that the earlier hatching R group, developing, on the whole, in cooler water, grew more slowly than the S group, while the later hatching T group grew faster in the generally warmer water in which it developed. Thus the R group took 56 days, the S group 50 days, and the T group 47 days in growing from a length of 4 to a length of 25 mm., a divergence from the S group of 12 percent in one instance, and 6 percent in the other. This is by no means the extreme variation to be anticipated, for it is conceivable that temperature or other influences might vary more widely than happened in these three instances, and correspondingly greater differences of growth would follow. On the other hand, the S group developed from eggs spawned somewhat early in a season that was slightly warmer than average (Bigelow, 1933, p. 46) and thus in temperatures that would likely be reproduced in the middle portion of less unusual seasons, and therefore the rates computed from the S group must be near the usual rate, probably within 10 percent.

Discussion of growth.—Having determined the rate of growth of the mackerel through its early life, it would be interesting to have comparisons of the early growth of other fishes, particularly to see if logarithmic growth is the general rule. Unfortunately, there is a paucity of data on this subject, most of the material on growth of fishes being confined to the portion of life following the larval or post-larval stages. From various sources, however, it has been possible to assemble material on the early growth of three other species: the herring (*Clupea harengus*) in the Clyde Sea area, the haddock (*Melanogrammus aeglifinus*) in the waters off the northeast coast of the United States, and the northern pike (*Esox lucius*) of North American fresh waters.

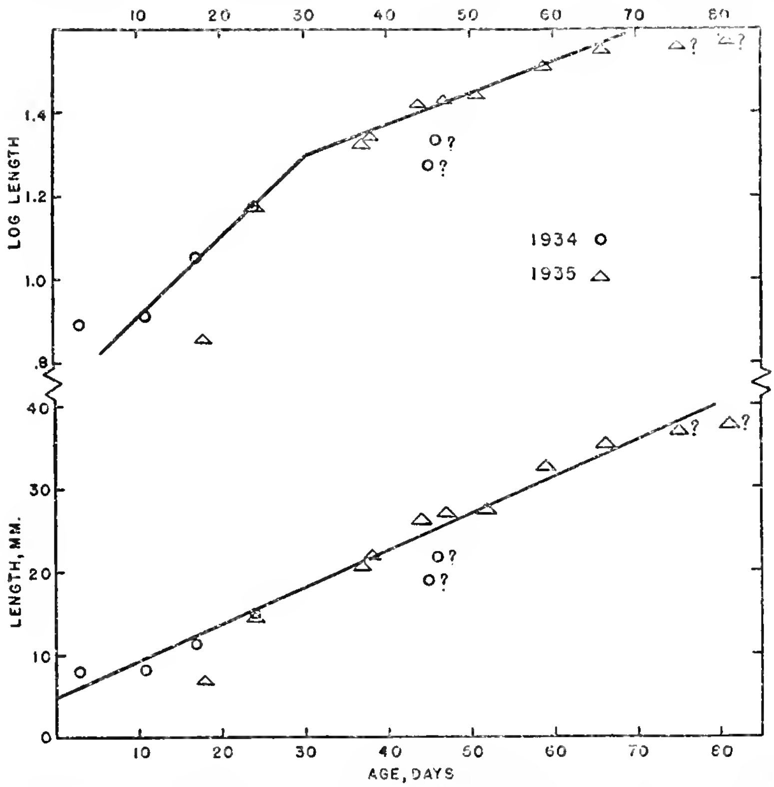


FIGURE 9.—Growth of pre-metamorphosis herring on the Clyde Sea area, after Marshall, Nicholls, and Orr, plotted logarithmically (upper part) and arithmetically (lower part).

Since the data on these need to be formalized for comparison with the mackerel, each will be presented in turn.

For pre-metamorphosis herring caught by tow net and sprat trawl in the Clyde Sea area in 1934 and 1935, Marshall, Nicholls, and Orr (1937, pp. 248–51) determined the median lengths at successive intervals of time. Plotting the median values against age, they concluded that "The points do not lie on a straight line but it is obvious that, apart from four points, a straight line expresses the relationship best." Their curve is reproduced in the lower part of figure 9, and the four exceptional points thought by them not to have represented the main shoals are indicated by question marks. When the same data are plotted logarithmically, as in the upper part of figure

9, it is seen that logarithmic curves with a change in slope at 30 days of age, or length of 19.5 mm., fit the points as well or better than does the straight line in the lower part of figure 9.

The observations on haddock (Walford, 1938, p. 68–69) were taken in a manner similar to those on mackerel. In fact, the material consisted mainly of haddock larvae caught on our mackerel cruises. Walford summarized these by months, giving frequency distributions for each of the four months: April, May, June, and July. From these polymodal frequency distributions, he selected modes that he considered to be homologous, recognizing three such series. Taking his middle series as perhaps the most typical, the modal values, as nearly as can be read from his figure 50, were

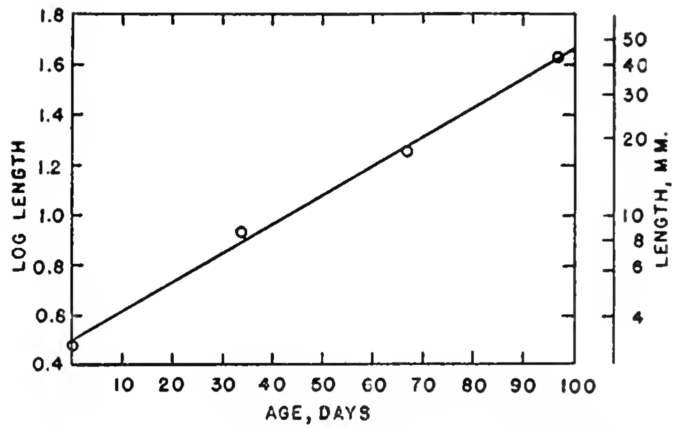


FIGURE 10.—Growth of haddock during early life. Data from Walford, 1938.

3, 3.5, 18, and 43 mm. on the mid-dates, April 11, May 15, June 17, and July 17, respectively. According to Walford, the 3 mm. mode of the first cruise consisted of recently hatched individuals. Assuming this size to be zero days old, the logarithms of the modal sizes were plotted against age in figure 10, whence it is apparent that the growth of the haddock was logarithmic as in the mackerel.[12]

Data on the northern pike (Embody, 1910) consisted of the average length in samples of two or more specimens drawn from a population reared in the laboratory at water temperatures of 65° to 72° F. Since the data are not readily accessible, they are repeated below: [13]

Age in days after hatching:	*Total length in millimeters*	Age in days after hatching:	*Total length in millimeters*
0	7	5	13
2	9. 25	7	[1] 14
3	10. 5	9	15. 25
4	11. 5	11	16

[1] Sac absorbed.

[12] Another of the series of modes selected by Walford also becomes logarithmic with slight re-interpretation of his fig. 49. The new interpretation involves the assumption that the group in question was under-represented in the April sample, an assumption that is reasonable in view of the fact that his samples for this month were from a more easterly area than that subsequently sampled. (This is true also of the central mode, above discussed, but the group forming this mode could have drifted into the area subsequently sampled, whereas the time sequences were such that the group here under consideration in all probability could not have so drifted). It further involves taking the mode for May at 12 instead of 17 mm. and for June at 30 instead of 33 mm. These selections are of prominences on the curve, which are equal to those selected by Walford, and by reason of parallelism with the middle group, seem more reasonable than the points given in Walford's figures 49 and 50. Walford's third series obviously consists of a younger group not present enough months to repay study.

[13] I am grateful to the late Professor Embody for communicating these data to me by letter.

Plotted on a logarithmic scale, these values describe the curve given in figure 11. It is interesting to note that the change in slope approximately coincides with yolk sac absorption.

For ready comparison the growth curves of mackerel and of these other species are assembled in figure 12. In all of them, length was used as an index of size. Mass or volume would be a more nearly true index. However, if there is no change in form, length would serve well to test for logarithmic growth since a certain power of length would be proportional to the mass or volume, and in logarithmic plots the only difference between the two would be a difference in vertical scale. Since the mackerel and haddock undergo little change in form during early life history, a simple logarithmic curve well fits their growth as indicated by length. The herring larva, on the other hand, is slender and almost eel-like when young, growing stouter as development proceeds. This being true, length overestimates size early and underestimates it later. This may be the reason for the nearly linear arrangement of points when lengths are plotted directly against age. Further, the change in slope when the logarithms of lengths are plotted against age suggests that the change in form is greatest at about 30 days of age when the herring is about 18 mm. long. The growth of the northern pike, too, shows a change in slope. In this instance it approximately coincides with yolk sac absoption, hence this might as easily be a real change in growth rate due to difference in food availability or assimilation rather than an apparent change due to altered form. Evidence from the information available on these several species supports the view that growth in the early life of other fishes, as well as the mackerel, is logarithmic in character and at a uniform percental rate throughout this stage of life except when there is a change in mode of living (e. g., yolk sac absorption) and that the use of length as an index of size may complicate interpretation of growth rates when there is considerable change in form.

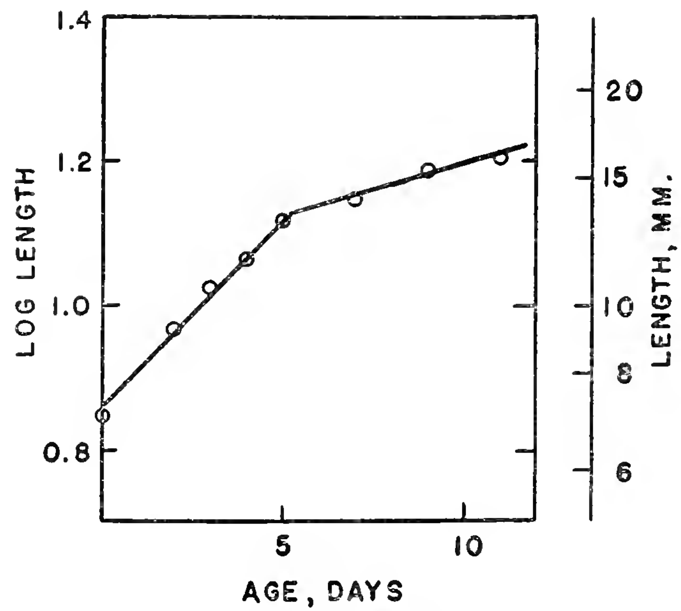


FIGURE 11.—Growth of northern pike during early life. Data from Embody, 1910.

DRIFT AND MIGRATION

The current system in the waters overlying the continental shelf between Cape Cod and Cape Hatteras has yet to be studied. Evidences collected during this investigation from releases of drift-bottles and computations of dynamic gradients, the latter subject to large errors of interpolation, were not sufficiently conclusive to deserve publication. They indicated slight tendency for movement in a southwesterly direction parallel to the coast, probably not strong enough to transport eggs and larvae of the mackerel important distances.

On the other hand, evidence from the distribution of mackerel eggs and larvae themselves leads to definite conclusions. From the growth curve of larvae, figure 8, or from the position of homologous modes in the deviation curves, figure 7, it is possible

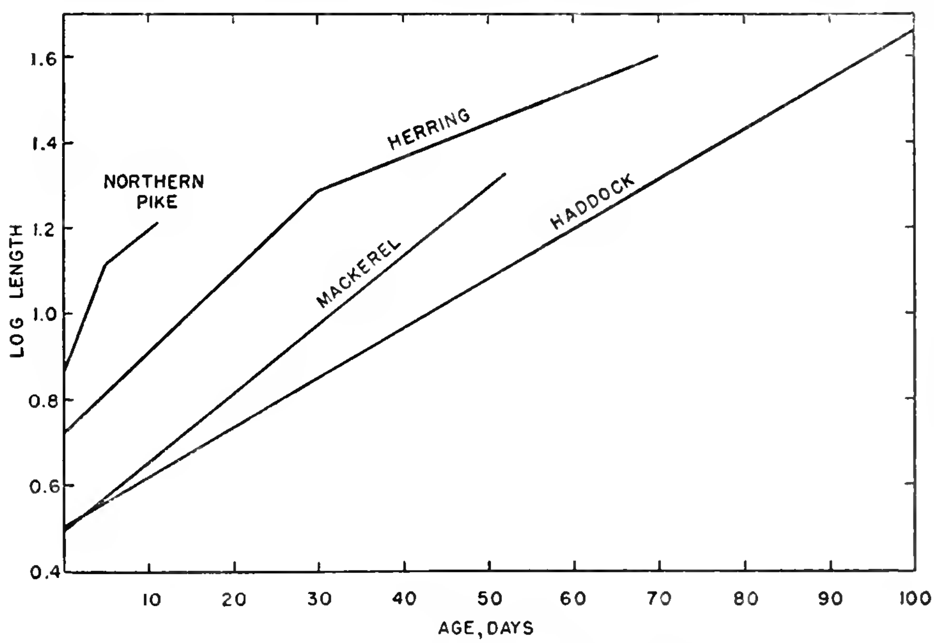
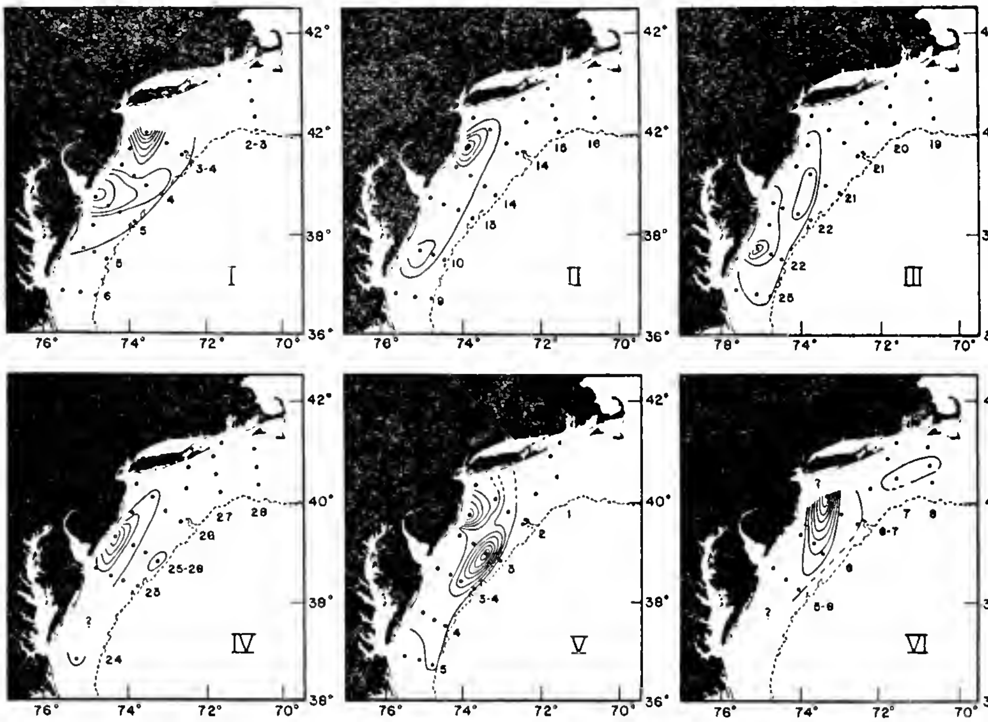


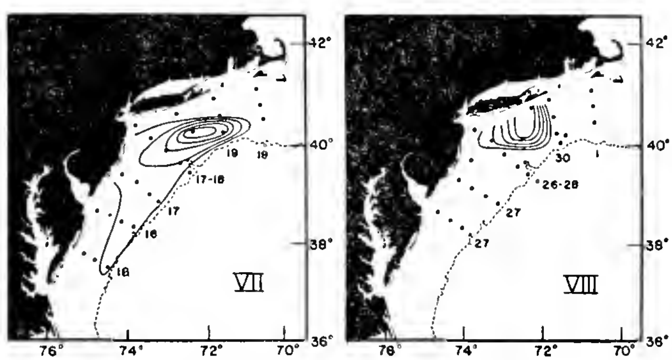
FIGURE 12.—Growth of northern pike, herring, mackerel, and haddock.

to ascertain the lengths attained by certain groups of larvae at each successive cruise. By plotting the geographical distribution of larvae of these particular lengths in successive cruises, as in figure 13 based on the S series, their movements may be followed.

In general, this series represents a population spawned over the continental shelf off the New Jersey coast. Larvae hatched from these eggs remained in this area until they reached a length of 8 mm. about a month later. Thereafter, there was a northeasterly shift which brought the population to the region just south of Long Island at the end of their second month when they were about 20 mm. long. Movement toward the northeast probably persisted still longer, for the only individuals large enough to have been members of this series were taken at stations along the east coast of Massachusetts (Chatham II and Cape Anne II in table 20) during the cruise of July 14 to 28. Although there is local spawning in Massachusetts Bay, it is unlikely that it was responsible for these large individuals, because spawning usually is later in Massachusetts Bay, and the locally produced larvae could not have grown to as large a size as the 37- and 51-mm. post-larvae taken on July 22.

Examining in greater detail the distribution in the successive cruises, two concentrations were evident within the area over which the larvae of this series were distributed. One may be called the northern center; the other, the southern center. The northern center was off the northern part of New Jersey (New York II) [14] in the





CRUISE	DATE	STAGE	CONTOUR INTERVAL
I	MAY 3-5	A & B	1000
II	MAY 10-14	3 MM	750
III	MAY 21-23	4-6 MM	300
IV	MAY 24-26	5-6 MM	150
V	JUNE 2-5	6-8 MM	100
VI	JUNE 5-8	8-10 MM	50
VII	JUNE 16-19	13-15 MM	2
VIII	JUNE 25-JULY 1	19-22 MM	0.05

FIGURE 13.—Location on successive cruises during 1932 of the population of mackerel comprising the S group, as indicated by the relative concentration of larvae of appropriate sizes. The Arabic numerals at the ends of rows of stations give the day of month on which each row was occupied.

early egg stages. In the successive cruises it may be traced to the north central coast of New Jersey (Barnegat I), to the southern part of New Jersey (Cape May II, III, Atlantic City II), back to the south central portion of the New Jersey coast (Atlantic City I), to the north central portion (Barnegat I), to the northern portion (New York II), to the offing of Long Island (Shinnecock II and Montauk III), to the Long Island coast (Shinnecock I and II), and finally to the offing of eastern Massachusetts (Chatham II and Cape Anne II).

[14] For location of this and below-mentioned stations see fig. 14.

The southern center shifted southward from off Delaware Bay (Cape May II) half way to the Chesapeake Capes (Winterquarter I) where it remained during the following cruise and possibly the next one also, though these stations were not visited on the fourth cruise. During the fifth cruise it was found farther north and seaward in the offing of the southern New Jersey coast (Atlantic City III and Cape May IV). Next it appeared to join the northern center and was apparent as a tongue extending from this center to the offing of the middle of the New Jersey coast (Atlantic City II). Thereafter its location apparently coincided with the northern center.

During the time that the two centers were separate they moved in essentially identical directions (fig. 15). Both moved southward from May 3 to May 22 and then northward until June 7, apparently under a common impulse. If the resultants of wind direction and force during the cruises be plotted,[15] as in figure 15, it is seen that the strong winds blew in essentially the same direction as the larvae moved, southerly until May 22 and then northerly until June 7. Obviously the wind, by drifting the surface water, was responsible for the transport of the larvae. After June 7, however, the movements of larvae did not correspond so closely with the movements of the wind (fig. 16) and must have been to some extent independent of them. Thus the movements of the population of mackerel larvae may be divided into two phases, an early passive phase and a later active phase. The break between the two came, as might be expected, when the larvae, at a length of 8–10 mm., developed fins (p. 171) and graduated from the larval state to the post-larval stage. The movements in the two stages will be considered in detail separately.

During the passive phase, although the movements of the two centers of larvae are essentially similar and both correspond to that of the wind, there are minor differences worthy of note. The southern center was found at the same place on cruises II and III in spite of considerable sustained wind from the northeast and corresponding movement of the northern center in the interim between the cruises. Later there was the great shift of the southern center between cruises III and V without correspondingly great wind movement and without correspondingly great drift of the northern center. To some extent these discrepancies may be due to failure precisely to locate centers of distribution with the stations as far apart as of necessity they were.[16]

But it is more likely that the peculiarity in the relation of the drifts of the northern and southern centers has a physical rather than statistical basis. The outstanding peculiarity was that the northern center traced a course in a southerly direction almost equal in distance to its return in a northerly direction (up to cruise VI) whereas the southern center moved southerly a much shorter distance and then returned northerly a much greater distance. Considering now the topographical features, it is noticeable that at the northern and middle portions of the area the continental shelf is broad and the water relatively deep, while at its southern end the shelf narrows sharply and the water is much shoaler. A water mass impelled by the wind could move in a southerly direction freely until it reached the narrow, shoal southerly end where it must either: (1) stream very rapidly through the "bottle neck" at the southern extremity; (2) turn out to sea; or (3) pile up temporarily.

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15 Records of the Winterquarter Lightship, 8 a. m. and 4 p. m., including only those winds of force 3 (Beaufort Scale) or higher, were plotted in vector diagrams to determine the resultants.

16 The true position of the northern center at the time of cruise III (fig. 13) was particularly uncertain. On the chart of movement (fig. 15) it seemed logical to plot it at the center of gravity between the three northern stations with largest catches, that is, Atlantic City II, Cape May I, and Cape May III, but its true position most likely was between stations, there or elsewhere, and hence missed. This accounts also for the almost complete obliteration of mode S on this cruise, to which attention was earlier called in discussing progress of modes as indicating growth.

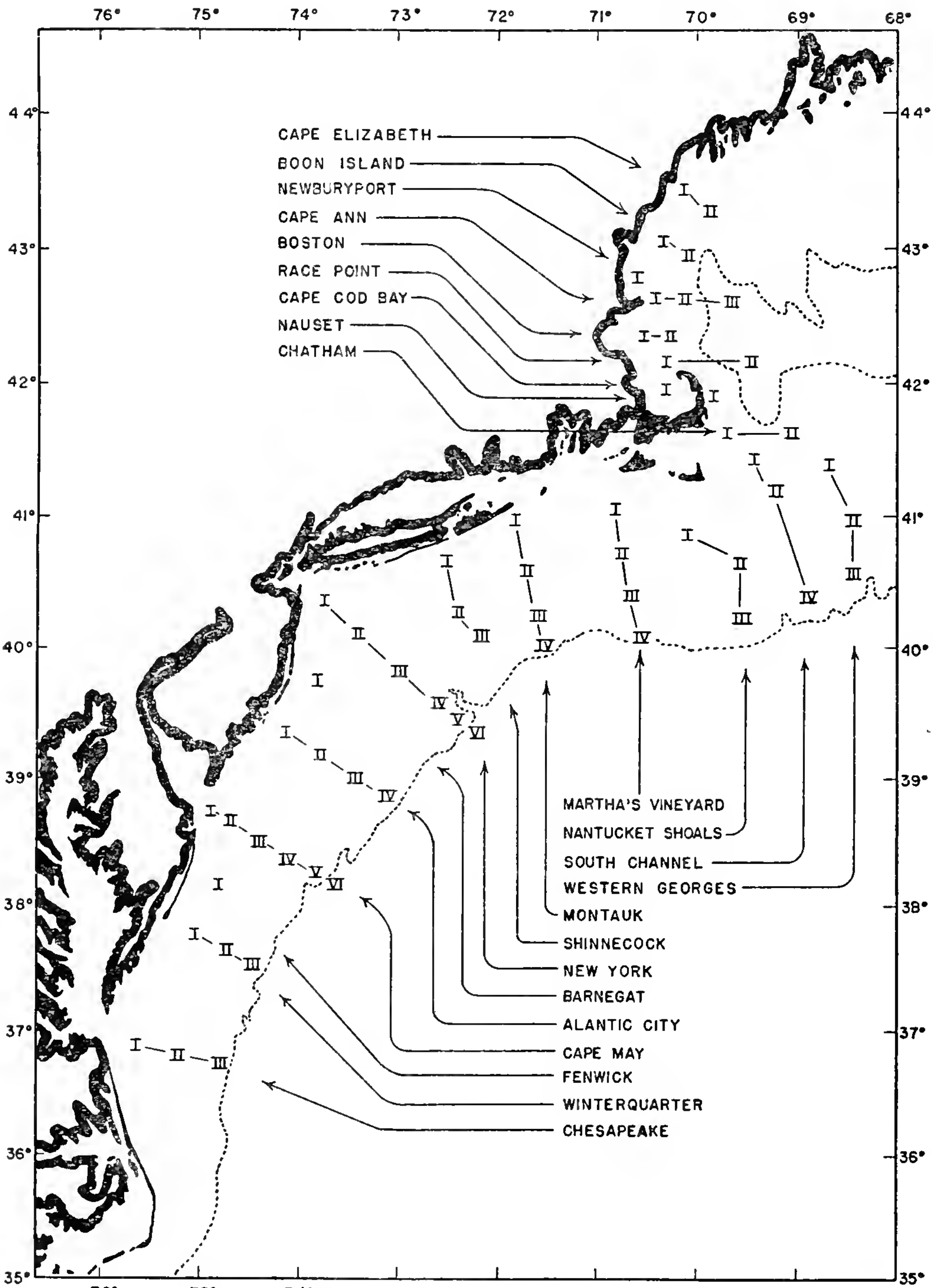

FIGURE 14.—Location of stations occupied during the 9 cruises of 1932.

That it did not do (1) or (2) is proved by the relative scarcity of larvae of appropriate sizes at stations of the Chesapeake section and the outer station of the Winterquarter section; though the few caught at Chesapeake II, III, and Winterquarter III indicate a slight tendency for southward and outward streaming. That (3) was the major result is shown by the "snubbing" of the southern center in its southward travel and by the increase in numbers of larvae in the southern center relative to the number

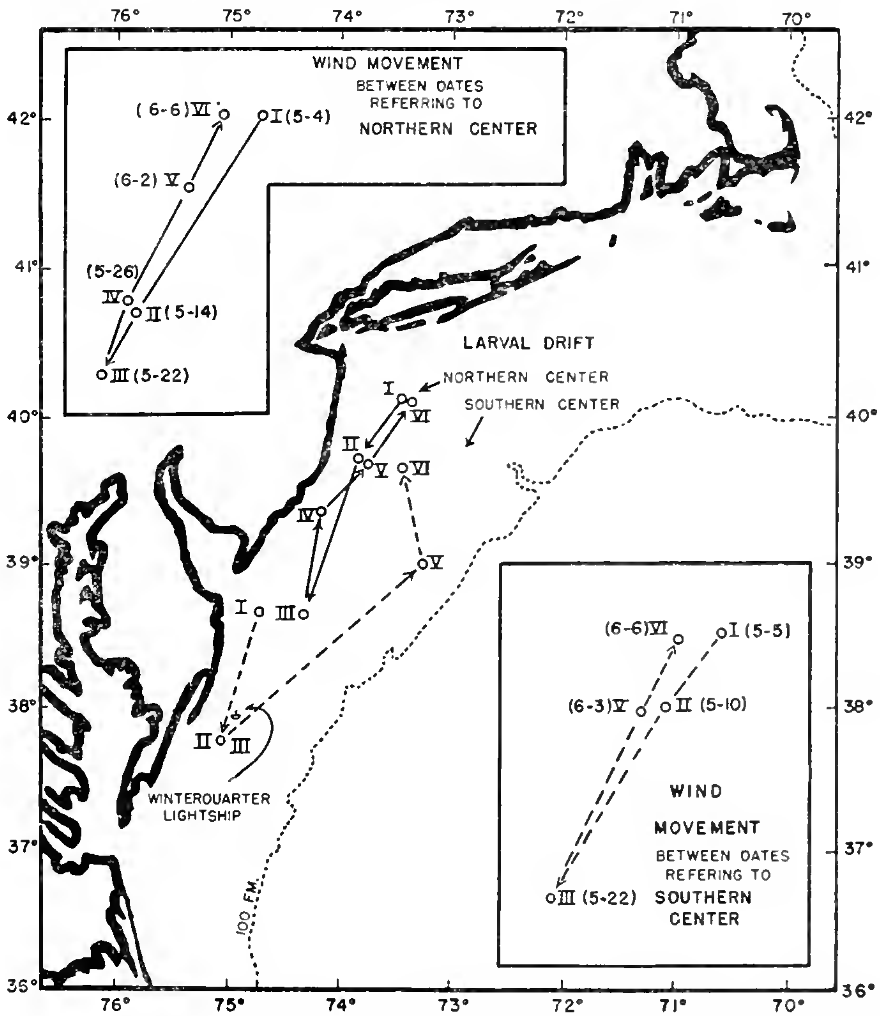

FIGURE 15.—Drift of the 2 centers of distribution of the S group compared with wind movements, as recorded at Winterquarter Lightship.

in the northern center,[17] as if indeed the water and its burden of larvae did pile up in the vicinity of Winterquarter I. This piling up very likely was in the nature of a thickening of the surface stratum of light water offset by a depression of the lower layers of heavier water rather than an outright raising of the water level. Of course, the depressing of the subsurface stratum would set up a subsurface flow to restore equilibrium. This flow would not transport the main body of larvae, since they were

[17] It is not supposed that the entire increase in relative number at the southern center was due to the mechanism being discussed. Part of it could have been due to random fluctuations of sampling.

confined to the upper stratum (p. 172); it could and probably did carry a few that happened to be near the interface as indicated by the light spread of larvae southward and outward to Chesapeake II and III and Winterquarter III.

While this accounts for the halting of southerly drift of the southern center and its increase in relative numbers, there is still to be considered the apparently too rapid drift of this center northward when the wind direction was reversed. Let it be supposed that the aforesaid piling-up of surface waters took place more rapidly than could be counterbalanced by subsurface flow. Then the sea surface would actually have risen and remained at a higher level as long as the wind continued to transport surface water to the area faster than the subsurface water could flow away. Then when the wind reversed its direction, the energy so stored would be released and act in the same direction as the wind. The two forces together would produce a faster drift than could result from the wind force alone, and thus account for the high rate of movement of the southern center between May 22 and June 3.

Whether the interactions of the wind forces and water movements here postulated were theoretically probable from dynamic considerations must be left to the physical oceanographer. He can find here an example of biologically marked water probably of considerable aid in the deciphering of the pattern of circulation in shallow water, where difficulties of dynamic analysis are heightened by topographical features, and where a better understanding would be of greatest practical use in dealing with fishery problems.

Whatever the outcome of any future examination of the dynamics of this situation, the outstanding resemblance of the main features of wind movement to larval drift, together with the fact that deviations from the parallelism between the two have a plausible though not proved explanation, leaves no doubt that the larvae (and the water with which they were surrounded) were drifted from place to place by the wind's action on the water, and that this alone accounted for their movements until they reached the end of the larval stage at a length of about 8 to 10 mm. and entered upon the post-larval stage.

Subsequently the movement of larval concentrations corresponded less perfectly with that of the wind (fig. 16). Between cruises VI and VII, when there was a gentle easterly wind movement, the post-larvae also moved eastward, but proportionately father than might have been anticipated from the moderate wind movement. Between cruises VII and VIII, when there was a northeasterly wind movement, they moved northwesterly. After cruise VIII it is difficult to be sure of the homology of the group under consideration, but the only post-larvae (lengths 37 and 51 mm.) of cruise IX identifiable as belonging to this group were caught at Chatham II and Cape Ann II, off eastern Massachusetts. The indicated movement was in the same general direction as the prevalent strong winds, but again sufficiently divergent to indicate some independence. Since the drift of water under impulse from the wind accounts for only a portion of their movement and since such evidence as is available on residual surface flow in this region [18] indicates water movement westerly, hence in a direction contrary to the movement of the post-larvae, the evidence does not favor the transport of the post-larvae as purely passive organisms, and it must be concluded that they moved to an important extent by their own efforts.

This is in complete harmony with their developmental history. As larvae, without swimming organs other than the rather flaccid finfold, they drifted with the

[18] Drift-bottles set out by Wm. C. Herrington (unpublished data) in connection with his haddock investigations in the spring of 1931 and 1932 drifted westward past Nantucket shoals, fetching up on beaches of southern New England and Long Island.

current; as post-larvae, with capable fins, they were able to swim and exercised this faculty. The change in locomotive ability coincided with change in method of transport.

Thus far, attention has been focused on the main centers of larval concentration. It will have been noted in figure 13 that there were indications of a smaller body of larvae not included in the groups whose centers were followed. This body probably became separated from the southern center about May 23, when the center was at its extreme southerly position, and, as previously pointed out (p. 187), there was a spread to Chesapeake II and III and Winterquarter III, probably consisting of only

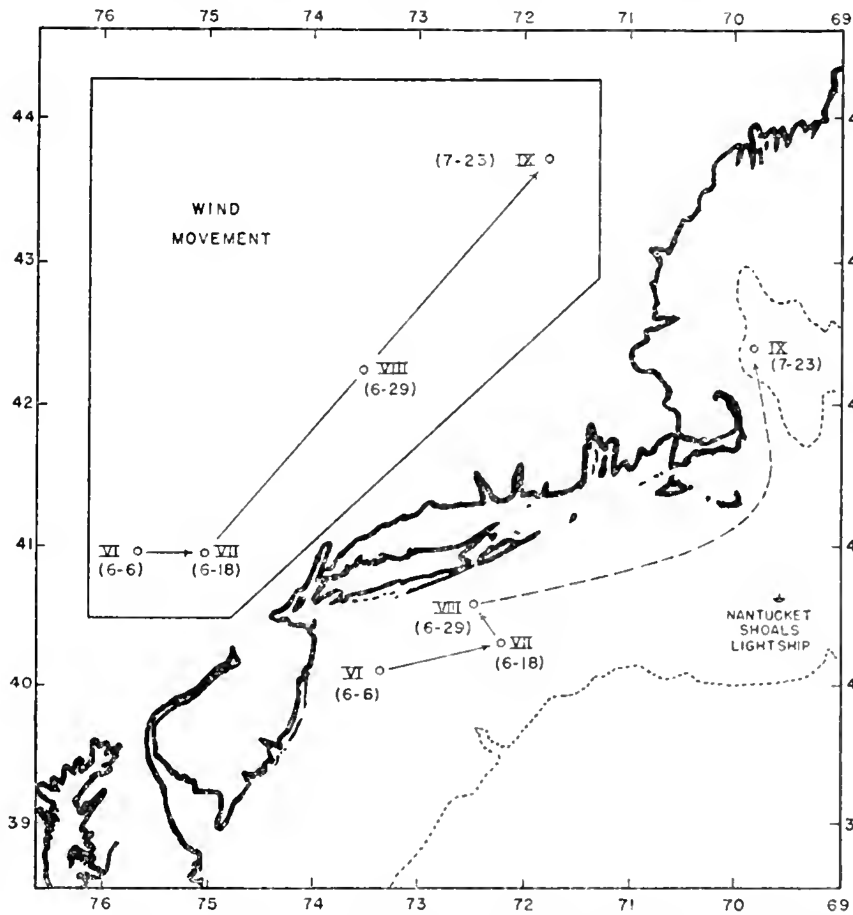

FIGURE 16.—Drift of post-larvae of the S group compared with wind movement, as recorded at Nantucket Shoals Lightship.

those larvae that were at the interface between the accumulating surface water and the outward streaming subsurface layer (p. 187). Having been caught in this outward and perhaps somewhat northerly flow, their northward drift could start sooner and would take place farther offshore than the drift of the southern center itself. With this in mind, it is easy to account for the catches at Atlantic City IV on cruise IV and at Montauk II and No Man's Land II on cruise VI. That they did not appear on other cruises is not surprising, for their numbers were few (1, 1, and 2 were caught at the respective stations above mentioned) and as the result of chance fluctuations in random sampling they could easily fail to appear in our hauls.

The average rate of movement of the S group larvae during the period from May 4 to June 6, while they were dependent for transport on wind-impelled drift, was 6 nautical miles per day. As nearly as may be estimated from data recorded on the Beaufort Scale, the net wind movement in the direction of the resultant (neglecting forces under Beaufort 3), was about 60 nautical miles per day. The movement of the center of post-larval abundance between June 6 and July 1, accomplished in part by swimming, averaged 3½ nautical miles per day. If the movement of post-larvae between June 27 and July 24 may be taken as from off Shinnecock to off Chatham, the average rate during this period was 6 nautical miles per day.

The movements of the R and T groups of larvae can be traced in the same manner as were those of the S group. The R group, beginning with cruise I, as 3 to 5 mm. larvae, moved southward from the Winterquarter section to the Chesapeake section. Like the S group, they remained at this southern extremity of the range through cruise III and also probably through cruise IV, though during the latter cruise there were not sufficient stations occupied in this area to prove this. On cruise V, however, they were found to have moved northward to Cape May, and on cruise VII were discovered off Shinnecock. At the beginning of this northerly movement, they were already 8 to 10 mm. long, and thus capable of swimming. With favoring winds during all but the last portion of this northerly trip, their movement was rapid, averaging 11 nautical miles per day.

The T group could not be so readily followed, but in general its movements were with the wind in the larval stage and indifferent to the wind in post-larval stages. Between cruises III and VI, when the winds were from the southwest, it shifted in an easterly direction from the Shinnecock section to the Martha's Vineyard section. The correspondence between wind direction and this movement was not as perfect as that of the S group, formerly described. From cruise III to cruise IV, there appeared to be a spread in both easterly and westerly directions, and between IV and V, there was a contraction toward the center of the group off Montauk Point. These changes in distribution may be indicative of spurts of spawning rather than movements of the egg population, for they occurred during periods of egg development, and the stages chosen may not have been exactly the continuation of the original stage A eggs of cruise III. It probably suffices to note that when first seen as stage A, they were off Shinnecock, and by attainment of lengths of 4 to 5 mm. at cruise VI, they were off Martha's Vineyard. Then between cruises VI and VII, with only a slight wind movement from the west, the zone of densest larval population remained at Martha's Vineyard, though fair numbers were as far west as Shinnecock. Between cruises VII and VIII, while the winds were from the southwest, the members of this group spread over the waters abreast of Long Island, extending from the New York to the Shinnecock section. During this interval they had grown into the post-larval stage, 10 to 12 mm., when swimming activity made their movements fairly independent of the wind.

It may be concluded therefore, that the movement of eggs and larvae (up to 10 mm. in length) in the southern spawning area between Cape Cod and Cape Hatteras was governed by the drift of surface waters, and this, in turn, by the direction of the stronger winds during the 40 days while the mackerel were passing through these phases of development and growth. These drifts may be as fast as 6 nautical miles per day and may convey the mackerel several hundred miles. After reaching the post-larval stage (10 mm. and upward) the movements are less dependent on drift, and probably are considerably aided by the tiny fishes' own swimming efforts. The average rate of movement is sometimes about 3½ nautical miles per day and may at times, on the part of the largest individuals, attain eleven nautical miles per day. In 1932, the combined drift and swimming movements brought the larvae to the shores of Long Island and southern New England.

MORTALITY

Outstanding in the early life history of marine fishes is the high mortality in early stages. At sea, this is evident from the low numbers of larvae compared to the high number of eggs taken in plankton tows. In marine fish hatcheries, it has been evident from the high loss of larvae in all attempts to keep them beyond absorption of the yolk sac. It is probable that the fish cultural experience led to the generally accepted theory that the time of yolk sac absorption is the most critical period, and that it is so because the fish at that time must find proper food or die as soon as all the yolk is gone. Moreover, Hjort (see p. 207) believed that annual variation in the times and places of plankton increase during spawning might be such that an abundance of the right kind of food might coincide with this critical stage in one year and not in another. The coincidence of the two would produce a successful year class; the non-coincidence, a failure.

However elaborate the theory, it has yet to be proved at sea that the yolk sac stage is critical or that the annual variation of mortality in this stage is responsible for the variation in year-class strength. Thus, a determination of mortality of the young stages of mackerel in 1932 is not only of interest in itself, but has an important bearing on the general theory of fluctuations in fish populations. Inasmuch as the year class of 1932 has subsequently failed to appear in the commercial stock in important numbers (Sette, 1938), the present examination of mackerel mortality in the season of 1932 deals with the record of a failing year class and should bring to light the stages that were critical in its failure.

Determination of mortality.—There is at hand a simple way of determining the mortality rate of that year if it may be assumed that all the various egg and larval stages were sampled in proportion to their abundance in all parts of the spawning grounds, and during the entire period of planktonic existence. Then a frequency distribution of the summed numbers at each stage through the season would express their average relative numbers and constitute a survival curve. Although the sampling in 1932 approached a stage of perfection warranting treatment based on this general plan, there were nevertheless imperfections requiring secondary modifications, as will be explained.

The actual drawing of hauls appears to have been qualitatively and quantitatively adequate. At each station, all levels at which eggs or larvae might be expected to occur were sampled uniformly, and the subsequent adjustment for volume of water strained per meter of depth provided totals at each station which may be taken as the summation of individuals below 17.07 square meters of sea surface, irrespective of their level in the water. Comparison of 1-meter and 2-meter net hauls indicated that there was relatively little selective escapement from the nets (p. 215). Also, the towing stations formed a pattern reasonably well covering all parts of the important spawning grounds off the United States coast.

On the other hand, in some respects the samples did not adequately cover the entire season. At the time of the first cruise, spawning had already begun and larvae were taken for which there were no corresponding eggs. Similarly, force of circumstances prevented cruises from being taken as frequently in July as earlier in the season, and also prevented their continuation into August. Thus, there was less opportunity for taking large larvae corresponding to the eggs and small larvae of the earlier cruises. However, the cruises did thoroughly cover the major portion of the season of maximal spawning and subsequent larval development; so there need be only a treatment which excludes from comparison the large larvae early in the season and the eggs and young larvae late in the season which were not proportionately represented in the other stages of their planktonic existence.

This was done by taking the average numbers of eggs and larvae per cruise for the several cruises that spanned the period of maximal numbers of each stage of egg and larva.[19] The selection of cruises for these averages was as follows: for egg stages A to C, cruises I to IV; 3-mm. larvae, cruises II to V; 4- to 7-mm. larvae, cruises III to VI; 8- to 9-mm. larvae, cruises IV to VII; 10- to 12-mm. larvae, cruises V to VIII; 13- to 15-mm. larvae, cruises VI to IX; 16- to 22-mm. larvae, cruises VII to IX; and 23- to 50-mm. larvae, cruise IX.

TABLE 7.—*Survival of young stages of mackerel in 1932*

Categories[1]	Duration of category[2]	Average age of category[2]	Frequencies: Average per cruise[3]	Frequencies: Average per cruise adjusted for duration of category[4]	Survival per million newly spawned eggs: Logarithmic values: Empirical[5]	Logarithmic values: Computed[6]	Arithmetic values: Empirical	Arithmetic values: Computed[6]
	Days	*Days*	*Number*	*Number*	*Log*	*Log*	*Number*	*Number*
Egg stages:								
A	2.53	1.3	16,900	6,680	5.866	5.915	735,000	822,000
B	2.32	3.7	12,600	5,430	5.776	4.759	597,000	574,000
C	2.38	6.0	12,500	5,250	5.761	5.609	576,000	406,000
Fish lengths (millimeters):								
3.2	5.14	9.9	9,310	1,810	5.299	5.354	200,000	226,000
4	6.86	16.0	4,270	622	4.835	4.957	68,400	90,600
5	5.48	22.1	1,760	321	4.547	4.559	35,200	36,200
6	4.56	27.1	717	157	4.237	4.233	17,300	17,100
7	3.91	31.3	403	103	4.054	3.959	11,300	9,100
8	3.41	34.9	192	56.3	3.791	3.724	6,180	5,300
9	3.04	38.1	73.5	24.2	3.425	3.516	2,660	3,280
10	2.73	41.0	18.4	6.74	2.870	2.950	741	891
11	2.48	43.6	7.70	3.10	2.532	2.483	340	304
12	2.28	46.0	4.95	2.17	2.377	2.372	238	236
13	2.10	48.2	2.98	1.42	2.193	2.271	156	187
14	1.95	50.2	3.38	1.73	2.279	2.179	190	158
15	1.82	52.1	1.72	.945	2.016	2.092	104	124
16	1.71	53.8	1.10	.643	1.849	2.013	71	103
17	1.60	55.5	1.10	.688	1.879	1.935	76	86
18	1.52	57.1	1.70	1.118	2.090	1.861	123	72
19	1.43	58.5	1.10	.769	1.927	1.797	85	63
20	1.37	59.9	.533	.389	1.631	1.733	43	54
21	1.27	61.3	.500	.388	1.630	1.668	43	47
22	1.24	62.5	.467	.377	1.617	1.613	41	41
23	1.19	63.8	1.300	1.092	2.078	1.553	120	36
24	1.14	64.9	.300	.263	1.461	1.502	29	32
25	1.09	66.0	.800	.734	1.907	1.452	81	28
30	8.65	71.0	3.900	.451	1.695	1.222	50	17
40	6.86	78.9	.300	.0437	.681	.858	5	7
50	5.72	85.0	.100	.0175	.284	.577	2	4

[1] The categories of egg stages are defined on p. 178, the categories of larval lengths are the midpoints of the class interval.
[2] See text p. 179.
[3] See text p. 192.
[4] Items in the third column divided by the items in the first column.
[5] Logarithms of the items in the fourth column plus the constant 2.041.
[6] These are the values represented by the heavy lines of fig. 17.

This selection provides a series that approximately follows the eggs of cruises I to IV through their subsequent stages. Since by far the largest numbers of eggs were

[19] Before the averages were drawn an adjustment was made in the numbers of larvae from cruise IV on which a group of stations, Fenwick 1, Winterquarter 1, II, and III, and Chesapeake I and III had been omitted. These stations were located in the area where only 2 days previously there had been found most of the 5- to 11-mm. larvae and the omission of these stations caused a marked, deficiency of these sizes in the totals of cruise IV (note in table 5, column 4, the abrupt drop in numbers from the 3- to the 5-mm. class). Since these particular stations were occupied at the very end of cruise III, growth and mortality in the few intervening days before cruise IV would have only slightly altered the catches at these stations by the time of the latter cruise. Therefore, to restore the deficiency, the catches of cruise III at these stations were added to the cruise IV totals, giving new values of 5381, 1998, 682, 150, 67, 31, 5, and 3 for the 4- to 11-mm. classes in the 4th column of table 5.

taken on the first 4 cruises, the treatment includes the population resulting from the major portion, perhaps 70 percent, of the season's spawning. It of course ignores the fate of the fewer eggs spawned prior to or later than the first four cruises, but the neglected portion is probably so small that it is unlikely that the survival of the whole season's brood of young differs from that of the treated portion. It could do so only if the mortality of the neglected portion differed widely from the included portion. There appears to be no reason for believing that there was any such wide difference. On the contrary, examination of the relative numbers of the various stages and sizes caught on those cruises which included a part of the history of the neglected portions suggests that these had a survival rate similar to that of the included portion.

Having the average relative numbers of each category of egg and larva from this selected series (table 7, column headed "Average per cruise") there remained the necessity of adjusting the numbers to compensate for the differences in the duration of

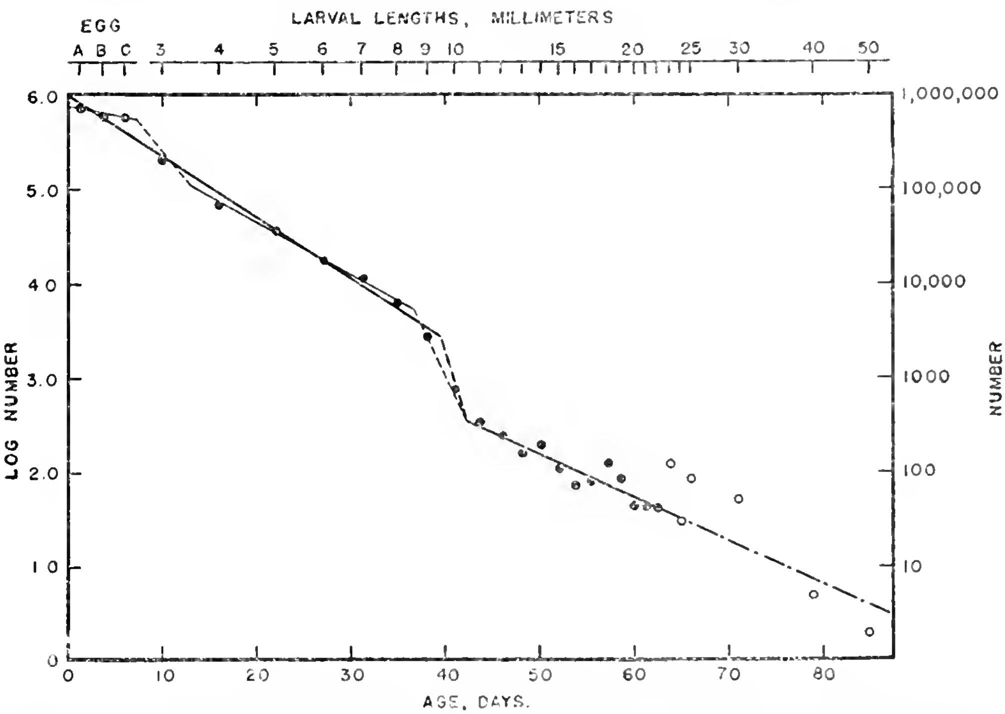

FIGURE 17.—Survival of young stages of mackerel in 1932. Solid dots represent the means of three or four cruises each. Open circles represent the less reliable values based on only one cruise. The heavy lines represent a simple interpretation of survival rates, and the fine lines, a more complex alternative interpretation. Solid lines are fitted to the solid dots by the method of least squares. Lines of dashes connect their ends, and the line of dots and dashes is an extrapolation.

time represented by each egg stage and each larval-length class. The stages or classes representing a long period of development would be passed slowly and the catches of such a category would represent a larger accumulation of individuals than a category representing a shorter period of development. Since the accumulation would be directly proportional to the duration of the category, the true relative values were obtained by dividing the numbers of individuals in each category by the number of days required to pass through that category, according to the schedule, given in the column headed "Duration of category" of table 7. This, in effect, reduces the data to represent what the relative numbers would have been had it been possible to subdivide the material into categories that occupied uniform time intervals—in this instance, one day. The resulting values are given in the fourth column, and the logarithms of these (column 5) of table 7 are plotted in figure 17.

Reliability of the survival curve.—The determination of the survival curve was based on plankton hauls generally considered to be only approximately quantitative, it utilized only selected portions of the original material, and it involved extensive computations. The reliability of the result therefore depends not only on quantitative adequacy of the original material, but also on whether the subsequent procedure introduced any biasing influences. The following discussion will draw attention to the facts which appear to have an obvious bearing on reliability. Unless some pertinent features have escaped notice, the conclusion is inevitable that this survival curve has surprisingly high reliability for all stages up to the length of 22 mm., or, for the first 60 days of life.

Considering first the collection of material, attention may be confined to those influences that might possibly cause large larvae to be caught in relatively greater or lesser proportion than small larvae, for it is only by such "size selection" that the slope of the survival curve, and hence the conclusions as to mortality rates, could be affected. On this score there are two possibilities: the nets' catching ability might differ for different sizes of larvae; or the distribution of the larvae might vary in such a way as to cause a less complete sampling of one size than of another.

In the appendix (p. 215) there is given evidence which appears to be indicative, if not conclusive proof, that the nets caught practically all the larvae in the paths of their travel, at least up to the 22 mm. size; hence net selection was probably not a biasing influence in this size range.

Since the nets were fished from surface to below the thermocline, and since the larvae probably do not descend below that point (p. 173), and since straining was substantially uniform for all levels fished, there is little likelihood that differential vertical distribution was a biasing factor. There remains, then, the possibility that larvae of different sizes had different horizontal distributions, and that these distributions differed in a manner which would have affected the relative adequacy of the sampling of the various sizes.

For small larvae up to 10 or 12 mm. in length, the drift was determined (pp. 183 to 191) with sufficient precision to establish the fact that the population of these sizes did not drift out of the area sampled. The majority of large larvae 22 to 53 mm. long, however, taken off eastern Massachusetts on the final (ninth) cruise, were outside the area covered on earlier cruises. Could, then, a portion of the population of medium sizes (12 to 22 mm.) have left the waters south and west of Nantucket Shoals, that is, the area of survey, prior to the ninth cruise, and thus have been undersampled? If so, they should have been found in the intervening area during the eighth cruise, which, fortunately, included that area. This cruise took place shortly after the main portion of the larval population was in the 12- to 22-mm. size range. It included stations around Nantucket Shoals and on the portion of Georges Bank just east of the Shoals; [20] hence, in the area through which larvae would have been drifting or swimming if they had, by this time, begun their movement north and east past the Shoals. Since no larvae of these sizes were taken there, it seems unlikely that these sizes were undersampled as a consequence of emigration from the area south and west of the Shoals. In other words, the intermediate, as well as small sizes of larvae, were sampled in approximately their true proportions.

[20] These stations of cruise VIII have not been included in any of the tables because the hauls there lacked pertinent material.

For the larvae over 22 mm. long there is no evidence to determine whether or not they were caught by the nets in their true proportions. On general grounds, one would expect that they could elude the nets, though the taking of a specimen as long as 51 mm. shows that the gear could catch at least some large-sized larvae. Offsetting the probability of undersampling the larger sizes, there is the opposite probability of oversampling them, because the stations were somewhat more closely spaced (see fig. 14) in the area north and east of Nantucket Shoals, where they were found, than south and west of the Shoals, where the smaller sizes were most abundant. Whether or not the loss of large larvae by eluding the nets and the gain by possible oversampling as the result of closer station spacing offset each other perfectly is indeterminable from the available data. Hence, the mortality determination is of uncertain reliability for sizes over 22 mm. For those smaller than 22 mm., the determination is reliable as far as collecting methods are concerned.

Having found little reason to suspect size-connected biases in collecting, excepting possibly for sizes over 22 mm. long, two questions remain: were the hauls themselves sufficiently quantitative to give reliable indices of abundance for each station; and were the stations spaced properly to give a reliable summation of abundance for the entire area? To answer the first question separately would require a study of the variation in series of duplicate hauls, and is precluded for lack of material, but both questions may be answered simultaneously by a study of the relative numbers caught at the various stations in relation to the probable nature of distribution of numbers of individuals in the sea.

Inspection of charts of egg or larval distribution (fig. 13) suggests that the pattern of concentration has a form closely related to a normal frequency surface. Near the middle of the area in which eggs or larvae occur are one or several stations with very high concentrations corresponding to the mode; surrounding these are more stations with decidedly lower concentrations corresponding to the slopes; and at the periphery are many stations with very low concentrations corresponding to the "tails" of the normal frequency surface. Let us assume, for the moment, that the concentrations of eggs really do form a normal frequency surface. Then the number of a particular stage caught during a particular cruise is a reliable index of the abundance of that stage at that time, provided that: the stations where the catches were made were so located as to give proper relative representation of the various parts of this normal frequency surface, such as the mode, slopes, and tails; and that the catches also were sufficiently reliable to provide the true relative numbers to be found at the various parts of this surface. Therefore, a test as to the conformity of catches to the normal frequency surface would at once indicate whether the above assumption is correct; whether the catch stations were arranged so as to sample adequately the various parts of the distribution; and whether the hauls themselves were quantitatively reliable.

To translate the normal frequency distribution into a convenient form for making the tests, table 8 has been prepared.[21] It was derived from the curve of the normal frequency distribution where, for unit standard deviation and unit N

$$y = 0.3989 e^{-\frac{x^2}{2}}$$

[21] Buchanon-Wollaston (1935, p. 85) has given a table purporting to give the same statistics, but it appears to represent the results of sampling only along a line passing through the mode of a normal frequency surface, not the results of sampling over the entire surface. For the latter, account must be taken of the fact that in such a surface, so sampled, the areas of classes of equal range in ordinate height increase as the square of the distance from the mode.

by calculating for values of y (catch magnitudes) the corresponding values of x^2 (relative number of catches) over a range of y from 10,000 to 5 and at intervals of 500 for the first 19 classes, of 25 for the next 19 classes, and of 5 for the next 4 classes. For convenience the x^2 series was converted to values giving a cumulative total of approximately 1,000 (actually 999.96). This table can be used for any range of catch sizes in which the maximum is not more than 2,000 times as large as the minimum, by first multiplying the empirical values by 10,000 times the reciprocal of the maximum catch. Linear interpolation is fairly accurate in the table ranges of 10,000 to 5,000 and of 500 to 250; but the work is facilitated and is more accurate for all parts of the range when the tabular values are graphed.

TABLE 8.—*Relative number of catches of given magnitudes to be expected from a population of organisms distributed in the form of a normal frequency surface*

Magnitude of catch	Number of catches, cumulative	Number of catches, by classes
10,000		
		6.71
9,500	6.71	
		7.11
9,000	13.82	
		7.50
8,500	21.32	
		7.96
8,000	29.28	
		8.49
7,500	37.77	
		9.08
7,000	46.85	
		9.74
6,500	66.59	
		10.53
6,000	67.12	
		11.45
5,500	78.57	
		12.57
6,000	91.14	
		13.88
4,500	105.02	
		15.53
4,000	120.55	
		17.57
3,500	138.12	
		20.26
3,000	158.38	
		24.02
2,500	182.40	
		29.34
2,000	211.74	
		37.83
1,500	249.57	
		53.36
1,000	302.93	
		91.19
500	394.12	
		6.71
475	400.83	
		7.11
450	407.94	
		7.50
425	415.44	
		7.96
400	423.40	
		8.49
375	431.89	
		9.08
350	440.97	
		9.74
325	450.71	
		10.53
300	461.24	
		11.45
275	472.69	
		12.57
250	485.26	
		13.88
225	499.14	
		15.53
200	514.67	
		17.57
175	532.24	
		20.26
150	552.50	
		24.02
125	576.52	
		29.34
100	605.86	
		37.83
75	643.69	
		53.36
50	697.05	
		91.19
25	788.24	
		29.34
20	817.58	
		37.83
15	855.41	
		53.36
10	908.77	
		91.19
5	999.96	

In table 9 there are given, as an example, the computations involved in determining the class limits for dividing the catch magnitudes into 5 categories, using the data for stage A eggs from cruise I. Since the sampling of the plankton usually was of a portion that permitted detection of eggs down to 20 per station, 20 was taken as the minimum, giving a range of 5806 to 20 for catch magnitudes (first and last items in column 4 of the example). Multiplying these by $\frac{10,000}{5,806}$ gives 10,000 to 34 as the corresponding tabular range (first and last items of column 3 of the example). Entering table 8 with catch magnitude 34, by interpolation, it is found equivalent to a cumulative catch number of 755, and this figure is entered as the last item in column

TABLE 9.—*Example of the computation of limits for 5 classes within each of which an equal number of catches would be expected if the distribution of stage A eggs during cruise I conformed to a normal frequency surface; and the actual and theoretical number of catches for these class limits*

1	2	3	4	5	6
Equal fifths, cumulative	Tabular number of catches expected, cumulative	Tabular class limits for catch magnitudes	Actual class limits for catch magnitudes	Actual number of catches	Theoretical number of catches
0.0		10,000	5,806		
				2	1.8
0.2	151	3,190	1,853		
				1	1.8
0.4	302	1,010	586		
				4	1.8
0.6	453	321	186		
				2	1.8
0.8	604	102	59		
				0	1.8
1.0	755	34	20		
Total				9	9.0

2 of the example. It indicates that 755/1000 of the frequency surface is to be taken into account. Then 755 is multiplied by the items in column 1 of the example, giving the series of items in column 2. Successive differences in this series would represent equal fifths of the frequency surface out to 755, but it is, of course, not necessary to compute these differences. The corresponding catch magnitudes are secured by entering table 8 in the column of "Number of catches, cumulative," and reading, by graphical interpolation, from the column of "Magnitude of catch." This gives the series of column 3 in the example. These represent the class limits within each of which one-fifth of the catches would fall if the maximum and minimum had been 10,000 and 34, respectively, and the distribution of catch magnitudes conformed perfectly to the distribution expected from a normal frequency surface. Since they were, instead, 5,806 and 20, respectively, the factor 5,806/10,000 is used to convert them from the tabular to the actual basis, giving the values in column 4 in the example. Between each pair of successive figures there should be found, theoretically, an equal number of catches of stage A eggs from cruise I. In the first column of table 19, cruise I, the adjusted totals of individuals of stage A are given, and a count of those lying between each pair of specified class limits gives the numbers in column 5 of the example. Since the total number of catches was 9, neglecting those below 20, the theoretical number for each class is 9/5, or 1.8, as given in column 6 of the example.

When the same computations are performed for the stage A eggs of cruises II, III, and IV, and the actual number of catches are added together, by classes, there results the series of values given under the appropriate heading in the first line of table 10. There are now enough items in each class to apply the χ^2 test; and the probability P, that random variation would exceed the actual variation, is found to be 0.85. This value would appear to be rather high; but when the work is done for the remaining stages up to 22 mm. with due regard to the necessity of having fewer classes for the later stages in order to keep the numbers per class high enough to use the χ^2 test, it is found that the values of P are distributed almost exactly as would be expected, for there are 7 of them below and 8 above 0.5, and the mean is 0.53. Hence it must be concluded that the catch magnitudes of stages up to 22 mm. larvae are related to each other quite as would be expected had these stages been distributed in the sea in conformity with the normal frequency surface.

TABLE 10.—*Summary of test to determine whether the magnitudes of catches of eggs and larvae conformed to the distribution expected from sampling a normal frequency surface*

Stage	Cruises included	Lower limit of catch magnitude	Actual number of catches by classes					Expected number of catches in each class	χ^2	*P*
Eggs:										
A	I-IV	20	8	8	10	6	6	7.6	1.4	0.85
B	I-IV	20	8	13	9	9	9	9.6	1.6	.80
C	I-IV	20	13	9	6	9	12	9.8	2.1	.70
Larvae (millimeters):										
3	II-V	20	7	8	13	6	7	8.2	3.7	.44
4	III-VI	20	9	7	9	4	5	6.8	3.0	.55
5	III-VI	10	6	6	8	9	4	6.6	2.4	.67
6	III-VI	5	10	4	8	3	4	5.8	6.3	.18
7	III-VI	1	7	8	6	9	5	7.0	1.4	.85
8	IV-VII	1	6	5	4	4	10	5.8	4.3	.36
9	IV-VII	1	(1)	4	4	3	9	5.0	4.4	.22
10	V-VIII	1–[2] 0.10	(3)	(3)	8	6	7	7.0	.3	.82
11	V-VIII	1– [2].10	(3)	(3)	7	2	10	6.3	5.2	.07
12	V-VIII	1– [2].10	(3)	(3)	7	5	2	4.7	2.7	.27
13–15	VI-IX	1– [2].10	(3)	(3)	6	5	7	6.0	.3	.82
16–22	VII-IX	1– [2].10	(4)	(4)	(4)	7	4	5.5	.8	.35

[1] The catches were divided into four classes, leaving this class vacant.
[2] Lower limit for cruises VIII and IX where 2-meter nets were used.
[3] The catches were divided into 3 classes, leaving this class vacant.
[4] The catches were divided into 2 classes, leaving this class vacant.

This result may seem one in which the empirical data are closer to theoretical expectation than they should be, for it will be recalled that the frequency surfaces, as exemplified by the charts of figure 13, were not normal, but were skewed in one direction or another, and were elongated rather than circular in form. The skewing might not necessarily be detectable in the test, for the loss on one side may be approximately offset by the gain on the other, but the elongation should have its effect, as is readily apparent if one imagines such elongation carried to its logical extreme. Then the distribution would be in a band so that constant values would be found when sampling longitudinally to the band, and values distributed in accordance with the normal frequency curve, rather than the normal frequency surface, when sampling across the band. At this extreme the catch magnitudes should be related to each other as if drawn from the normal frequency curve instead of the normal frequency surface. With intermediate elongation, such as indicated by the isometric lines of figure 13, it is uncertain whether the distribution of catch magnitudes might be intermediate between the type expected from the frequency curve and that from the frequency surface, and hence fit neither; or whether it might still closely conform to the type expected from the frequency surface as would easily be true if, in the elongated surface, the form of the normal frequency curve were retained in the section along its major axis.

In any event, it is probably significant that the elongation of isometric shapes of figure 13 is generally parallel to the coast, and also that the station grid is rectangular rather than square, so that the mean spacing between stations in a direction longitudinal to the coast is greater than that in a direction perpendicular to the coast, the ratio of the latter to the former averaging 0.44. Furthermore, by measurement it may be found that the mean ratio of the minor to the major axis in the isometric shapes of figure 13 is 0.47. Thus the sampling pattern was warped about the same amount and in about the same direction as the egg and larval distribution patterns. One compensates almost exactly for the other, and it is therefore less surprising that the empirical data should fit the theoretical distribution, even though the latter did not specifically take into account the elongation of the egg and larval distributions.

Since it is impossible that hauls of indifferent quantitative accuracy, or that sampling at a pattern of stations that did not adequately explore the area could, by chance, produce a series of catch magnitudes conforming so well to hypothesis, it has been proved not only that the hauls were quantitative, but also that the sampling provided adequate representation of all parts of the distribution of each of the various stages of eggs and larvae up to 22 mm. long. Nothing is yet proved as to the extent of random variability, either of the quantities caught per haul or per cruise. This would control the scatter of points in figure 17 and will receive consideration in the final paragraphs of this section.

The foregoing has dealt with the collection of material. Turning now to the mathematical treatment, the initial step was to total the catches of a given stage for each cruise and then average these totals for certain groups of cruises. This use of total per cruise is equivalent to a direct arithmetic integration of the frequency surface and could introduce no errors if the same stations were occupied on each cruise, and if all stations represented equal unit areas. These requirements were approximately met because the same station plan (fig. 14) was used for each cruise, and the stations were distributed uniformly enough to represent approximately equal unit areas. The principal change from cruise to cruise was the omission of some stations. As earlier mentioned, stations north and east of Nantucket Shoals were omitted from the first seven cruises, and it already has been pointed out that this probably had no effect on the computation because these northeasterly stations could have contributed nothing to the totals of the group of mackerel that is followed in the survival curve. Besides this the stations at Martha's Vineyard IV, Montauk IV, New York V and VI, and Cape May I were usually omitted. Since they proved always to be at the periphery of the egg and larval concentrations, their exclusion or inclusion could make little difference. However, on four of the first seven cruises, there were additional omissions which could possibly have had important effects.

On cruise I the station at New York I and all of those on the Montauk and Shinnecock sections were omitted. Judging from the catches at adjacent stations, and also from the distribution of appropriate stages on the following cruise, three of these omitted stations might have added low to medium catches to the totals for stage A and B eggs, but this could not have increased their totals for that cruise by more than 5 percent, and could have modified the average per cruise of the four cruises used for these stages by less than 2 percent, so the effect of this omission is inappreciable.

On cruise IV all stations on the Winterquarter section, and those at Chesapeake I and III were omitted. This omission would have a serious effect on the total for that cruise, for these stations could have been expected to yield nearly maximal numbers of 4- to 8-mm. larvae, but the effect of this omission was rectified by substituting the cruise III values for these stations in calculating the average per cruise. (See footnote p. 192.) This substitution could have introduced error only to the extent of 2 days' growth and mortality—an effect that would not be perceptible after inclusion of the data for the three other cruises in the group average.

On cruise V the stations on the Martha's Vineyard section, at Montauk III, and at Shinnecock I and II were omitted. This probably reduced the totals of 3-mm. larvae appreciably, and 4-mm. larvae slightly. If the effect on the 3-mm. larvae is estimated by examining the result of substituting numbers interpolated from the previous and subsequent sampling at these stations, the total for this size of larvae is increased from 5,215 to 12,549 for cruise V and the average per cruise for cruises II to V is increased from 9,310 to 11,144. Substituting the latter in table 7 and carrying the work through to the logarithm of the empirical number surviving per million, it is found that the value increases from 5.299 to 5.378, indicating that the point for 3-mm. in figure 17 should probably be raised by an amount nearly equal to the diameter of the dot representing it. Similar examination of catches of 4-mm. larvae indicates that the total for cruise V might be raised from 8,236 to 9,945, a change that becomes imperceptible when worked through to the values on the graph of survival.

On cruise VIII the stations at Fenwick, Winterquarter, and Chesapeake were omitted. At the very most these could have contributed nothing to any of the averages involving this cruise, excepting possibly a very few individuals in the 7-, 8-, and 9-mm. classes. These would not cause a perceptible change in the survival curve.

By the time of cruise IX, only one larva was found along the New York section, and it was so probable that none at all remained south of that locality that the omisson of all stations from there southward could not have had any effect on the survival curve.

Hence it may be concluded that the use of cruise totals introduced no errors other than a slight lowering of the 3-mm. point on the survival curve.

Turning now to the possibility that errors were introduced by the selection of certain cruises, it will be recalled that the successive points on the survival curve consist of averages of the catches in groups of cruises, using successively later cruises for the successively older larvae so as to follow the main population through the season from egg stages to late post-larvae. Owing, however, to exigencies of boat operation, the cruises toward the end of the season were separated by wider intervals of time, so that the average numbers of older larvae were calculated from samples more widely spaced in time. This would tend to include relatively more submaximal values for the older larvae than were included for the eggs and younger larvae. Although the effect of this cannot be directly measured, it is possible to deduce the extreme amount of distortion to be expected from the inclusion of submaximal values.

This can be done by restoring submaximal values to the computation of the average number of young larvae. For instance, for 5-mm. larvae, the average of the catches for cruises III to VII, which were the ones used in the mortality determination, was 1,760. Inclusion of cruises I, II, and VII would restore submaximal values and produce an average of 1,220. Substituting the latter figure in column 3 of table 7 and carrying the computation over to column 5 gives a figure of 4.387 instead of 4.547 for the 5-mm. class. This would lower the point for 5 mm. in figure 17 by about 1½ times the diameter of the dot representing that point in the graph. This is a very small alteration brought about by a relatively large increase in submaximal values. Therefore the inclusion of what was probably a relatively small number of submaximal values for the older larvae by the method used in averaging cruises to obtain the mortality curve could have lowered the points representing the older larvae very little indeed, and therefore have altered the curve by only the slightest amount.

Next may be examined the distortion that could be connected with the growth-rate data employed in computing the mortality curve. Evidences of the reliability of the growth-rate determination were given in the section on that subject, and it was concluded that the general course of the growth curves must be essentially correct. It remains to be considered here whether there might nonetheless actually have been irregularities in growth, and because they were not reflected in the growth statistics used in computing mortality rates, they could have produced the observed peculiarities in the survival curve.

The outstanding peculiarity in the survival curve is, of course, the abrupt change of level and slope at the age of 40 days, or length of 10 mm. To investigate the possibility that this might have been due to the mathematical effect of a fluctuation in growth rate, rather than a fluctuation in mortality rate, let it be assumed that the mortality rate through and beyond this period was constant, and compute the changes in growth rate required to fit this hypothesis. The resulting new values for growth rate, in terms of days required to grow one mm. in length, are as follows:

Millimeters:	Days
9	3.04
10	.80
11	.38
12	.24
13	.15
14	.18
15	.09

Thus, this hypothesis would require growth at an ever-accelerating rate from 10 mm. on, such that less than a day would be occupied in growing from a length of 10 to a length of 15 mm., and by that time growth would be at the rate of 10 mm. per day. Clearly this hypothesis is untenable, for such high growth rates are not only absurd *per se*, but also inconsistent with the distributions of lengths of larvae taken on successive cruises; and it may be concluded that the outstanding peculiarity in the mortality curve cannot have resulted from a fluctuation in growth rate. This demonstration, having proved that it requires striking changes in growth rate to produce material effects on the survival curve, indicates also that errors of the order of magnitude which likely exist in the determination of growth would not materially affect the determination of mortality rates.

Thus far attention has been centered on the possible elements of selective error or bias connected either with collection of the material or the subsequent mathematical treatment. There remains the question of the effect of random variability. This could not alter the level or the trend of the survival curve, for random variability would produce empirical values that tend to deviate equally above and below the true values, so that the sole effect would be on the scatter of points, or, in other words, the relative reliability of fit by any lines expressing their trends. This is readily investigated by conventional statistical methods.

Because the points in the curve obviously lie along straight lines over considerable segments, such lines have been fitted, by the method of least squares, to various combinations of segments. Since our interest lies principally in the mortality rates expressed by the slopes of the lines, attention may be focussed on the b value, or regression coefficient, in the equation: [22]

$$y=a+bx$$

which describes these lines. The standard deviation s of the regression coefficient b may be estimated by the formula

$$s=\frac{S(y-Y)^2}{n^1-2}$$

To investigate the reliability of the slopes of the lines for various segments of the diagram, one may calculate

$$t=\frac{b-\beta\sqrt{S(x-\bar{x})^2}}{s}$$

and find, from published tables, the probability, P, that any other slope β might result from sampling the same universe. Being interested in knowing the limits of

[22] The symbols given in this and following equations are those used by Fisher (1932).

accuracy of the slopes, values of t may be selected for P=0.05, and by substituting these in the equation,

$$b-\beta=\frac{st}{\sqrt{S(x-\bar{x})^2}}.$$

values of $b-\beta$ may be calculated which, when added to b, or subtracted from it, will give the limits of a range of slope values. The chances will then be 19 out of 20 that the true slope lies within this range.

From these calculated ranges (table 11), it is clear that there was so little random variability of the points about the lines of best fit, that mortality values are accurate to within one or 2 percent per day for all segments other than A to C.

There still remains the question: which of these combinations of straight lines gives the most probably true series of survival rates? This may be investigated by the formula for the significance of the difference of two slopes, again going through the t test, using the formula

$$t=\frac{b_1-b_2}{\sqrt{s^2\left[\frac{1}{S(x_1-\bar{x}_1)^2}+\frac{1}{S(x_2-\bar{x}_2)^2}\right]}}$$

where

$$s^2=\frac{S(y_1-Y_1)^2+S(y_2-Y_2)^2}{n'-4}$$

From the results given in table 11, where the subscripts of b represent the initial and terminal points of the segments, it is apparent: (1) That b_{A-C} differs from b_{4-8} just enough to indicate that the survival rate probably is significantly higher in the larval stages than in the egg, and therefore the two lines A-C and 4-8 better describe this segment than the one line A-9. However, the latter does not differ significantly enough from each of the former to preclude the possibility that it fairly well represents the general course of survival from the early egg stage to the 9-mm. larva. (2) That b_{11-22} is certainly significantly different from b_{A-9}, though not from b_{4-8}. The interpretation of these findings will be discussed in the following section.

TABLE 11.—*Estimates of accuracy of slopes of lines in figure 17*

Segment	b	s	$b-\beta$	Equivalent mortality rates in percent per day		
				Indicated (b)	Lower limit $b-(b-\beta)$	Upper limit $b+(b-\beta)$
A-C	−0.02246	0.0307	0.1170	5.0	−21.0	27.5
4-8	−.05465	.0337	.00716	11.8	10.4	13.3
A-9	−.06521	.0905	.00515	13.9	13.0	15.0
11-22	−.07467	.1165	.0128	10.1	7.4	12.7

TABLE 12.—*Significance of the differences of the slopes of the lines fitted to various segments of the survival curve*

Slopes compared	Difference	s	S. E.b_1-b_2	t	P
b_{A-C} and b_{4-8}	0.03219	0.03294	0.0102	3.169	0.05-0.02
b_{A-9} and b_{11-22}	.01901	.10562	.0058	3.276	<.01
b_{A-C} and b_{A-8}	.04275	.08574	.0259	1.651	.2-.1
b_{4-8} and b_{A-9}	.01056	.07898	.0056	1.875	.1-.05
b_{4-8} and b_{11-22}	.00845	.01030	.0086	.988	.4-.3

Mortality rates.—When the logarithms of the fully adjusted survival numbers are plotted, as in figure 17, the series describes nearly straight lines over certain portions of its extent, indicating that in each of these straight-line segments, mortality must have proceeded at a uniform percental rate. The major feature to be noted is the break at about 35 days when the larvae are 10 mm. long. At this point there is a change of level and of slope which may be considered as dividing the curve into three portions: (1) egg, yolk-sac, and larval stages, (2) transition between larval and post-larval stages, and (3) post-larval stage. Each will be discussed separately.

The first portion representing stages up to 10 mm. in length is subject to alternative interpretations due to the nearly, but not wholly, linear arrangement of points. The simplest interpretation is that the mortality rate was uniform and that the deviations from linearity were due to defective sampling. If so, the single heavy straight line drawn from A to 9 mm. in figure 17 expresses the mortality. Accordingly, this mortality was at a constant rate, and amounted to 14 percent per day. On the other hand, it has been shown in the previous section that there is little ground for suspecting serious defects in sampling, and also that the slope of the line A to C differs significantly from that of the line 4 to 8 mm. This being true, the mortality rate would be better described by the three fine lines of figure 17, the one extending from A- to C-stage eggs; another from 4- to 8-mm. larvae; and still another joining their ends across the 3-mm. (yolk-sac) stage. According to this interpretation, the initial rate, i. e., the rate during the egg stage, was 5 percent per day. The next rate, i. e., during the yolk-sac stage, was 23 percent per day, and the third rate, i. e., during the larval stage, was 12 percent per day.[23] However, according to both interpretations, mortality has reduced the population to about one-tenth of its original numbers by the time the larvae reach 4 mm. long, and when they attain 9 mm. in length at 35 days of age, to one-thirtieth of the original number.

If any one period is to be singled out as the most critical, it must be the ensuing period during the transition from larval to post-larval stages, when in passing from 9 to 11 mm., the numbers are reduced by 90 percent in the short space of about 3 days. The rate of mortality may be variously computed, depending on the choice of straight lines in figure 17. The lowest is 30 percent, and the highest, 44 percent per day. Either of these rates is distinctly higher than the highest alternative estimate (23 percent per day) in the yolk-sac stage. The high mortality during this short period, coupled with the losses previous to this stage, reduced the survivors to only one three-hundredth of their original numbers; thus the population was already severely decimated on entering the post-larval stage.

During the post-larval stage, the rate of mortality apparently was more moderate than in earlier stages. The data on which the rates are based appear fairly reliable up to the 22-mm. stage, or 62 days of age, and the fitted line for the segment 11 to 22 mm. in figure 17 represents a mortality of slightly over 10 percent per day. Beyond 22 mm. the catches of larvae were few and were confined to only one cruise, so that the reliability of their relative numbers is in doubt; but the evidence, such as it is, points towards the continuation of the same rate of mortality to the size of 50 mm., or age of 85 days.

Restating the history of mortality, it appears that there was a general basic rate of 10 to 14 percent mortality per day throughout the period studied. The most important deviation from this general rate was during the 9- to 11-mm. stage, when the population suffered about 30 to 45 percent mortality per day. Other deviations

[23] Also, according to this interpretation, the data in the last column of table 7 should be taken as representing the number of survivors per 840,000 newly spawned eggs instead of per million, as given in the column heading.

of somewhat doubtful significance occurred during the egg stages, when a lower rate of 5 percent per day was indicated, and during the yolk-sac stage, when a higher rate of about 23 percent may have intervened. The net survival to the 22-mm. stage, or 62-day age, was 40 per million newly spawned eggs, and, assuming a continuation of the 11 to 22-mm. rate of mortality to the 50-mm. stage, or 85-day age, it was 4 per million newly spawned eggs.

Discussion.—Since it is probable that the success or failure of year classes is determined during early life, and since it is known that the year class of 1932 was a failure, it is natural to assume that the mortality curve just given represents the record of that failure. That this is true appears from the following considerations. From fecundity data (p. 156) it is estimated that a female spawns about 500,000 eggs per year, and from the size composition of the adult stock (unpublished notes) it may be estimated that each female spawns over an average period of about four years, producing a total of 2,000,000 eggs. Therefore, to keep the population constant, from 2,000,000 eggs, one female on the average should reach average spawning age; i.e., a survival of one fish per million. But in 1932 only four fish per million were left at the early age of three months. At this age, the rate of mortality was about 10 percent per day. Were this rate to continue only 35 days longer, the survivors would number only 0.1 per million; i.e., only 0.1 the number required to reach average spawning age. Of course, it should not be assumed that the 10 percent mortality would continue indefinitely. But even should it be as low as 2 percent per day, the year class would be reduced to the 0.1 per million level before the end of the first year of life; and even then they are at least 2 years removed from average spawning age. To reach that age with survival of one per million, mortality could not average more than 0.12 percent per day during the time intervening between 50 mm. and average spawning age. It is unreasonable to suppose that the mortality, last observed at 10 percent per day, could immediately drop to such a low rate and remain there. Hence it is likely that a year class, to be successful, must have a survival well above four per million at the 50-mm. size, and that the 1932 class was a failure because of the high mortality during stages preceding the 50-mm. length.

The causes of this failure may be sought in the record of mortality during the various stages. The outstanding feature in this record is that no single period could be considered crucial in the survival of the year class with which we are concerned. Mortality in all phases of development contributed substantially to the decimation of the population. This fact is most readily appreciated when the contribution to total mortality by the periods of relatively high rate is compared with the contributions by the periods of low rate. The mortalities in the yolk-sac stage and in the transition between larval and post-larval stages (taking the highest alternatives in each case) together represent the passage through 1.9 logarithmic phases. All the other stages together represent 3.6 logarithmic phases. Hence, one may say that about one-third of the mortality was suffered during the so-called "critical" stages, and the other two-thirds during what might be called "non-critical" stages.

The question naturally arises, which of these was in 1932 the determining factor in the failure of the year class? To answer the question calls for comparable data on mortality during the early life history of a successful year class. Lacking this, one can only speculate. If in 1932 the so-called critical stages were to have been eliminated, the survival to the 50-mm. point would have been 250 per million eggs spawned. If the so-called noncritical stages were to have been eliminated, it would have been 12,500 per million eggs spawned. Of course, it is difficult to conceive of complete elimination of mortality from any of these stages, but if a year class is to be successful there is obviously greatest opportunity for improved survival in the noncritical stages, for they contributed most heavily to the failure of the year class. For this reason, one must look with at least as much suspicion on the mortality during non-critical stages as on the mortality during critical stages when in search for casual agencies that may have been operative during 1932.

In looking for such agencies, there are two features of the 1932 season that appeared to be unusual and of the sort likely to have affected survival. One of these was the relative paucity of zooplankton in the area of survey during the spring and early summer (i.e., May and June). The zooplankton catches averaged only 280 cc. per haul, as compared with 556 cc. in 1931 and 547 cc. in 1930 (Bigelow and Sears, 1939, p. 200). Both of the last named seasons produced good year classes, and there is, therefore, an indication of correlation between zooplankton abundance and the survival of a mackerel year class. If failure to survive in good numbers in 1932 was in fact due to dearth of food, and the dearth was continuous throughout the season

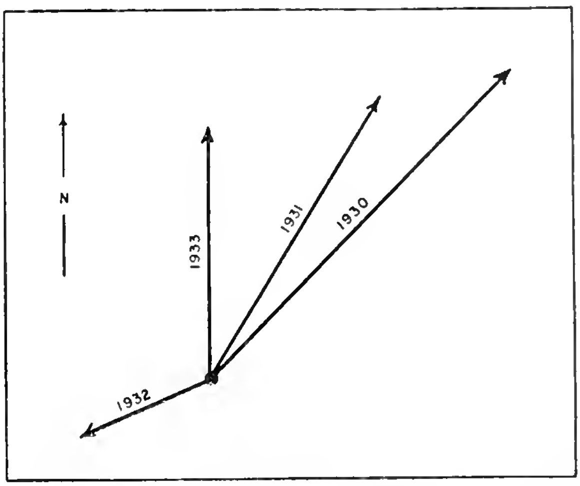

FIGURE 18.—Resultants of wind movement, as recorded at Winterquarter Lightship during May of each year 1930–1933.

of larval development, as the data indicate, it could easily affect the mortality through virtually all stages, for the smaller fish larvae probably feed on the young stages, and larger larvae on the adult stages of zooplankton forms.

The other distinctive feature was the prevalence of northeasterly winds during the period of larval development in 1932. Figure 18, in which are plotted the resultants of wind movement of force 3 Beaufort scale or higher, during May of each year, 1930–33, demonstrates how 1932 differed from the other years in having an excess of northeasterly over southwesterly winds. That this may well be related to the production of successful year classes is indicated by the fact that 3 years, 1930, 1931, and 1933, all with an excess of winds from the southwest, gave rise to successful year classes, while 1932, the only one with an excess from the northeast, failed to produce a successful year class [24] (Sette, 1938, p. 19).

Since the discovery of this relation between successful mackerel year classes and wind movement, similar phenomena have been reported for other fishes. Carruthers

[24] The wind directions in 1928 and 1929 were not consistent with this rule of correspondence of southwesterlies and successful year classes, but there were other unusual features of the year classes from these seasons and therefore consideration of them will be left to a subsequent paper of this series.

and Hodgson (1937) reported correspondence of relative success of six herring year classes and the strength of winds from certain quarters as inferred from pressure gradients; and Carruthers (1938) amplified these findings, presenting the relation for 11-year classes in the East Anglian herring fishery. He concluded: "It is reasonable to argue along these lines:—as from year to year, increased 'from-Channel' air flow means increased 'from-Channel' water flow, and this in turn means:—(1) That the passively drifting spawning products will be drifted farther afield—apparently a good survival augury for the herring * * *." In the same paper, Carruthers demonstrated the parallelism between changes in both certain pressure gradients and east wind component, on the one hand, and relative strength in a series of 15 haddock year classes on the other hand. These illustrations support the theory that local winds affect year-class survival. Though they demonstrate the importance of transport, the remainder of the survival (or mortality) mechanism, particularly its biological aspects, has yet to be elucidated.

For the mackerel of the American Atlantic seaboard, however, it is possible to advance a reasonable explanation for the connection between wind direction and survival. The center of spawning, it will be remembered, is southwest of Fire Island. The juvenile nursery grounds, judging from relative quantities of young mackerel usually found along various parts of the Atlantic seaboard, is along the coast of southern New England from Cape Ann to about the eastern end of Long Island. Therefore the prevalent southwest winds during May of 1930, 1931, and 1933 conveyed the larvae toward the nursery grounds. Conversely, the prevalently northeasterly winds of May 1932, on the average, were of hindrance rather than help to the larvae in reaching their nursery ground.

If this be true, there is the further probability that the significantly higher mortality in 1932 at the transition phase when fins were developing was a consequence of the pattern of drift in that year. The formation of fins and their subsequent use undoubtedly enlarged the expenditure of energy and hence increased the food requirement at the transition phase. At this time, on the average, the larvae were still distant from their nursery ground and if feeding was poorer where they were than on the nursery ground, the observed heightened mortality at this phase would thus be explained. Shortly after, by directional swimming, and with some assistance from favorable winds, some of the larvae did reach the presumedly more favorable location and thereafter were subject to a distinctly lower mortality rate.

Thus, there are evident two influences that contributed to the failure of the 1932 class. One was the general paucity of plankton, which probably increased mortality throughout the entire early life history; the other was the apparently unusual direction of their drift, which probably heightened mortality mainly during the transition from larval to post-larval stages. Though either one of these influences might conceivably have been the sole cause of the failure of the 1932 class, the shape of the survival curve suggests that both contributed substantially. Indeed, the two might be related to each other as well as to the mortality of the mackerel. To be sure, these are speculative conclusions. However, they furnish hypotheses that should be useful in planning further observations, especially in seasons of successful survival.

Significance of observed mortality in 1932.—Although one season's observations on one species of fish form a slender basis for generalizations, the fact that it is perhaps the only determination of mortality of a marine species under natural conditions gives special significance to the results, for it affords opportunity, for the first time, of comparing actual observations with theory.

In stating existing theory, one can do no better than to quote Johan Hjort, who, perhaps more than anyone else, was responsible for bringing attention to the importance of year-class success or failure as the explanation of fluctuations in the sea fisheries. In 1914 he advanced, and in 1926 (p. 32) reiterated, the theory that:

> The rich year-classes appear to make their influence felt when still quite young; in other words, the numerical value of a year-class is apparently determined at a very early stage, and continues in approximately the same relation to that of other year-classes throughout the life of the individuals.

It has already been shown that the observations on mackerel in 1932 are in harmony with this theory (p. 204).

Hjort (1926, p. 33) in discussing the great Norwegian cod and herring fisheries, suggested further:

> As factors, or rather events which might be expected to determine the numerical value of a new year-class, I drew attention to the following two possibilities:
>
> (1) That those individuals which at the very moment of their being hatched did not succeed in finding the very special food they wanted would die from hunger. That in other words the origin of a rich year-class would require the contemporary hatching of the eggs and the development of the special sort of plants or nauplii which the newly hatched larva needed for its nourishment.
>
> (2) That the young larvae might be carried far away out over the great depths of the Norwegian Sea, where they would not be able to return and reach the bottom on the continental shelf before the plankton in the waters died out during the autumn months of their first year of life.

Observations on mackerel do not support the first possibility. Mortality immediately after hatching was little, if any, greater than at other times, and hence failure of the 1932 class could not have been due to acute dearth of food at the hatching time. If shortage of food was responsible, it had its effect either throughout the period of planktonic existence or at the transition phase (9- to 10-mm.), well after the hatching time.

On the other hand, the second possibility has strong indications of support in the mackerel data. Not only did the heightened mortality at the 9- to 10-mm. lengths appear to be connected with drift of the larvae, but there also was a marked correspondence between success of the year-classes 1930 to 1933, and the drift that they must have experienced as the result of dominant winds in May of these four years.

That drift may in general be an important influence on success of year classes is further suggested by a similar finding for the American haddock (Walford, 1938, p. 55), wherein the relative failure of the 1932 class corresponded with drift of larvae away from Georges Bank, and relative success of the 1931 class corresponded with a pattern of circulation that kept the larval population on Georges Bank.

Thus, in the two instances where the events at sea have been traced, it was the oceanic circulation that influenced the success of year-classes; and in the one case where the course of mortality (in a failing year class) at sea was traced, it was not any, if at all, higher at the hatching time, and hence failure could not be attributed to acute shortage of food at this period.

In addition to the actual facts observed and their contribution to the understanding of year-class success or failure, the development of technique for determining mortality rates can have significant influence on future development of fishery science. If applied over a series of years, it would provide the data needed for separately evaluating the correlation of the size of the spawning stock with numbers of resulting offspring, and the correlation of the survival of offspring with the contribution of the year-class to the commercial stock. The predictive uses of such knowledge would be of obvious value to the conduct of fishing operations and to the trade in fishery products. But the value of such knowledge in formulating conservation policies would be even greater than its value for predictions. These separate correlations would provide a basis for determining the size of spawning stock necessary to maintain an undepleted fishery. Efficient utilization will be possible when a reliable estimate can be made of the proper size of spawning reserve. Until then, there will always be danger of reducing the annual take, on the one hand, by attempting to preserve more spawners than needed, or, on the other hand, by catching more spawners than can be spared from the stock needed for adequate reproduction.

APPENDIX

METHODS OF DETERMINING SIZE AT MATURITY

Samples of fish were taken at various times at Woods Hole, Provincetown, and Sagamore, Mass., during the period June 24 to July 21, 1925. The fish were measured to the nearest half centimeter on a straight line from tip of snout to the extremity of the midcaudal rays. Gonads of the males were graded by eye as small translucent, small opaque gray, enlarged white, running milt, and spent. The last three grades were classified as mature. Gonads of females were graded by eye as small translucent, small granular, enlarged granular, translucent spots, running ripe, and spent. The last three grades were classified as mature. The results are summarized in table 13.

TABLE 13.—*Size of mackerel at maturity as indicated by 1,116 individuals taken by traps in the vicinity of Woods Hole, Mass., and in Massachusetts Bay during the period, June 24 to July 21, 1925*

Length, centimeters	Males			Females		
	Immature	Mature	Mature	Immature	Mature	Mature
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
22.0	1			1		
22.5	1					
23.0	1			3		
23.5	10			6		
Total	13			10		
24.0	16			8		
24.5	22			16		
25.0	27			32		
25.5	25			33		
26.0	37	2		45		
Total	127	2	2	134		
26.5	35	1		47		
27.0	17	1		22		
27.5	18	1		27		
28.0	7	2		20		
28.5	10	2		14		
Total	87	7	9	130		
29.0	14	5		21		
29.5	12	7		16	1	
30.0	16	4		21	1	
30.5	9	3		17		
31.0	9	2		14		
Total	60	21	26	89	2	2
31.5	7	5		13		
32.0	11	7		12	5	
32.5	5	8		14		
33.0	5	11		9	6	
33.5	5	5		7	6	
Total	33	36	52	55	17	24
34.0	6	15		5	5	
34.5	6	29		8	7	
35.0	7	25		1	14	
35.5	3	28		4	8	
36.0	2	20		2	11	
Total	24	117	83	20	45	69

Table 13.—*Size of mackerel at maturity as indicated by 1,116 individuals taken by traps in the vicinity of Woods Hole, Mass., and in Massachusetts Bay during the period, June 24 to July 21, 1925.*—Continued.

Length, centimeters	Males			Females		
	Immature	Mature	Mature	Immature	Mature	Mature
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
36.5	3	7			7	
37.0		6		1	3	
37.5		2		1	4	
38.0		2			2	
38.5		2			2	
Total	3	19	86	2	18	90
39.0		2				
39.5		2			2	
40.0		1				
Total		5	100		2	100
More than 40	1	23	96		14	100
Grand total	348	230		440	98	

METHODS OF COLLECTING EGGS AND LARVAE

Mackerel eggs and larvae were collected during the spawning season in the spring of each year from 1926 to 1932, inclusive. The initial work was exploratory and qualitative in nature. Tows during the period 1926 to 1929 were drawn horizontally at the surface, mid-depth, and just above bottom. In 1930 and 1931 oblique hauls were employed. In 1932, oblique hauls were continued, and a device employed to measure the quantity of water strained through the nets. The following description refers to the collections made during 1932.

Nets used.—The plankton net used during the first 7 cruises was 1 meter in diameter at the mouth, and 4 meters long. The first meter of length was cylindrical and composed of No. 0 millers' gauze with 15 meshes per lineal centimeter, and for the last 3 meters the shape was conical and the material of No. 2 gauze, with 21 meshes per lineal centimeter. At the end of the cone, attached by a coupling device, was a "cod-end" 5 inches in diameter and 10 inches long, of No. 12 gauze, in which the catch collected. During the ninth and tenth cruises, a stramin net was used, which was 2 meters in diameter (at mouth), and of the same proportions as the meter net.

Method of towing.—To sample uniformly throughout the range of vertical distribution of eggs and larvae, the method of oblique towing was used. This consisted of paying out an amount of line appropriate for the maximum depth to be reached by the particular tow, then hauling back a certain amount of line at fixed intervals of time, usually 5 meters every 2 minutes or 2 meters every 1 minute, until completion of the haul. During the period of hauling, the speed of the ship was kept as nearly uniform as possible.

During the first seven cruises, when 1-meter nets were used, one net was towed at the shoal stations where the water was nearly uniform from surface to bottom, and two nets at the deeper stations where thermal stratification of water was prevalent. At the stations where two nets were used they were attached to the towing cable at intervals estimated to be appropriate for the upper net to sample down to the thermocline and the lower net a nearly equal distance below the thermocline. In a typical instance, with a sounding of 50 meters, the lower net would be attached at the end of the line, the upper net 25 meters from the end, and another 25 meters payed out, making 50 meters of line all told. Towing at the usual speed, the line would stray

45° above the first net and 28° below it. The depth ranges of fishing would then be 0–18 meters and 22–44 meters, respectively, for the upper and lower nets. Since the course of plankton nets through the water usually is undulating (Russell, 1925, pp. 603–604), the theoretically unfished gap between the nets and the theoretically stepwise character of hauls would both be practically obliterated and the sampling virtually uniform, except for the greater depth range covered in unit time by the lower net. The latter was taken into account in the subsequent treatment of data.

During the eighth and ninth cruises when the hauls were made with a 2-meter net, only one such net was used, and at the deeper stations it was sent down to a depth roughly equivalent to that reached by the deeper of the two nets employed on earlier cruises, so that the single, oblique haul of the 2-meter net sampled through approximately the same strata as the two nets of the preceding cruises.

Measurement of quantity of water strained by the nets.—It is obvious that two variables, speed of towing and degree of clogging, seriously modify the flow of water through plankton nets, causing variations in the catching capacity. To eliminate these sources of variability, a current meter was installed in the mouth of the net to measure the flow. The utility of current meters in measuring the volume of water passing through a plankton net depends on whether or not the flow past the meter is equal to or proportional to the average flow of water into the net. By towing, at usual speeds, a standard net with a current meter in the center of the mouth and another meter at the periphery, it was found (William C. Herrington, unpublished notes) that the flow past these two positions differed less than 10 percent. Since these positions were such as to register the maximum difference in rate of flow, if any existed, this evidence was taken as indicating uniform flow into all parts of the mouth of the net. Hence we regarded the registration of flow past the meter as directly measuring the flow through the entire opening.

The instrument used for measuring the flow consisted of the propeller mechanism and revolution counter from a dismembered Ekmann current meter, turning five to six revolutions per meter of flow at usual towing speeds. For precise determination the meter was calibrated over the range of towing speeds. The total revolutions turned during a tow were converted to speed by dividing by the duration of the haul, in seconds; and the equivalent rates of flow were found from the calibration graph. These are the rates used in the specimen computation of table 15.

While the current meter was used as a standard procedure, there were times when mechanical difficulties prevented proper registration. To provide basic data for comparable treatment of hauls made on such occasions, records were taken periodically, during each haul, of the towing wire's angle of stray and of the ship's speed as measured by timing the progress of the ship past a chip cast alongside. An estimate of the extent to which the net was clogged was made at the end of each haul. Relations between these observations and flow past the current meter gave average factors by which angles of stray or ship's speed could be translated to terms of equivalent current meter measurements. This afforded means of estimating the flow on those hauls which were not accompanied by reliable current-meter records. All the hauls of cruise I, and 5 percent of the hauls on subsequent cruises were of this class. For these hauls there was some error of estimate which may have been considerable for individual instances, but were, we believe, of random nature tending to balance each other, and so could have introduced very little inaccuracy into the general results, based on averages of a number of stations.

Only one current meter was available, and this was used in the upper of the two nets. When more than one net was on the line, the flow through the lower net was assumed to be the same as that through the upper net except as modified by clogging.

Four degrees of clogging were recognized according to the following definitions: 0—When net is hauled to deck, water runs freely out of net and cod-end so that no water is left by the time the net reaches deck. 1—Water runs out of net freely but out of cod-end slowly so that some water is left in cod-end when net reaches deck. 2—Water runs out of net so slowly that it remains above level of cod-end coupling when net reaches deck, but falls to level of coupling after a short interval of time. 3—Entire net visibly covered with clogging organisms and water stays above coupling so that special means must be taken for washing down net.

By the graphical partial correlation method (Ezekiel, 1930, pp. 143–145), it was found how much the relation between the angle of stray and the quantity of water strained was modified by the various degrees of clogging. The amounts by which clogging changed the average rate of flow for given angles of stray was +0.032, −0.03, −0.073, and −0.108 meters per second for cloggings of 0, 1, 2, and 3, respectively, on the clogging scale as above defined. For the hauls made without current meters in the nets, these values were added to the theoretical flow as estimated from the angle of stray. The magnitude of these corrections is given by their percentage relations to the average rate of flow, which were +8, −1, −18, and −26 for the respective degrees of clogging. These, of course, are averages for each of the 4 degrees of clogging. The extreme individual values were plus 37 percent and minus 29 percent, which indicates that the total flow through an extremely clogged net at times was only half as much as through a very clean net. Since the clogging is progressive during a haul, it is obvious that practically no water is strained toward the end of any haul in which the net becomes badly clogged. The hauling method employed in this work, therefore, would undersample the upper layers relative to the lower layers. This would be a serious difficulty if clogging were often severe, but during 1932 only 4 percent of the hauls were of third degree and 15 percent of second degree clogging; hence uneven vertical distribution of sampling did not often occur. No adjustment was made for this effect.

ENUMERATION OF EGGS AND LARVAE

Eggs and small larvae were so abundant in many of the meter-net catches that a sampling method was necessary to estimate the total numbers caught. The formalin preserved plankton catch was transferred to a wide-mouthed graduated receptacle, enough liquid added to bring the level to a certain mark (often 2,000 cc.), the contents stirred vigorously to mix uniformly, and a dipper then plunged into the mixture and withdrawn level full. The dippers were of the type made for dipping cream, each comprised of a small straight-sided cup with a long handle. Several sizes of dipper, each of known capacity, were used and one or several dipperfuls taken, depending on the size of sample desired. All fish eggs and larvae were removed from the sample. From the remainder of the catch, all larvae larger than about 5 mm. in length were removed. From the 2-meter net catches all the larvae were removed.

Mackerel eggs and larvae were separated from those of other species and further examined, counting the number of eggs at each of three stages of development and the number of larvae at each millimeter of length. Measurements were made with the aid of microscope and eye-piece micrometer for larvae under 7 mm. and with millimeter rule and unaided eye for larger ones. The measurement was from tip of snout to end of notochord in larvae, and to base of caudal rays in post-larvae. Distorted specimens were classed by matching them with straight specimens of known length.

The method of converting the counts to total catch was simple in the majority of instances because usually the mackerel material consisted either entirely of eggs and small larvae, so that the total catch could be computed directly from the known volume of sample sorted and the known volume of the plankton from which the sample was drawn; or entirely of large larvae sorted from the entire catch, so that a simple count represented the total. In a minority of instances, when both small and large larvae occurred in the same haul the total had to be computed from a combination of the sampled numbers of small larvae and the total numbers of large larvae.

The specimen tabulation (table 14) illustrating the computation is self-explanatory except for the treatment of those sizes of larvae which were too scarce to be adequately represented in the small sample. Referring to columns 2 and 3 of table 14, it is obvious that the numbers of 8-mm. larvae were too few to have been taken in the small sample and also that in sorting the remainder, larvae as small as 6 mm. and perhaps also 7 mm. were not fully removed. Therefore, the 3- to 6-mm. larvae, inclusive, in the small sample were taken as representing the catch of these sizes and the items of column 2 were multiplied by $\frac{2{,}000}{112}$ and entered in column 4. The numbers (2) in the 7-mm. category in the small sample (column 2) were taken as representing the numbers of larvae 7 mm. *and over*, which should then total $2\times\frac{2{,}000}{112}=36$ in the entire sample. Since there were known to be 6 larvae of 8-mm. length (column 3) in the catch, the entry of 6 was made opposite the 8-mm. class in column 4 and the entry of $36-6=30$ opposite the 7-mm. class. The count of larvae in the lower haul (table 14) included no larvae larger than those found in the small sample, and the total numbers of each size (column 8) were computed simply by multiplying the counts in the sample (column 6) by $\frac{1{,}500}{112}$.

TABLE 14.—*Specimen computation for converting counts of eggs and larvae to total catch on the standard basis of 17.07 cubic meters of water strained per meter of depth fished*

[Data relate to station 21491]

Classes	Upper haul					Lower haul						Total catch
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
	Count in sample of 28/2000 sorted for eggs	Count in sample of 112/2000 sorted for larvae	Count in remainder sorted for large larvae	Computed total catch	Standardized catch (Column 4 × 0.70)	Count in sample of 112/1500	Count in remainder sorted for larger larvae	Computed total catch	Contamination (Column 5 × 0.21)	Net catch (Column 8) − (Column 9)	Standard ized catch (Column 10 × 0.63)	(Column 5) + (Column 11)
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Eggs: Stage C	2			143	100							100
Larvae (mm.):												
3		27		483	338	8		107	71	36	23	361
4		12		214	150	4		54	32	22	14	164
5		15		268	188	6	1	80	39	41	26	214
6		11	10	197	138	1	2	13	29	−16	−16	122
7		2	20	30	21	1	3	13	4	9	6	27
8			6	6	4				1	−1	−1	3

In this particular sample the special treatment concerned the larvae of 7-mm. and upward. This was not uniformly true. The completeness of removal of large larvae from the remainder varied with the character of the plankton with which they were mixed and also, no doubt, with the fatigue of the person sorting the material. Due to this variation each haul was treated according to the internal evidence provided by the counts therefrom. More often than not the relative counts of the small sample and of the remainder indicated completeness of removal of smaller than 7-mm. sizes from the latter so that the length of larvae concerned in the special treatment was usually 5 or 6 mm. rather than 7 mm. as in the sample given.

COMPUTATIONS OF CATCH PER STATION

Standard haul.—Since it was desired to have a number representing the total population of eggs and larvae at each station, regardless of depth, the catches were converted to the basis of a standard amount of straining per meter of depth fished. The standard amount selected was the average of actual performance, as measured by the current meter during the first seven cruises of 1932, which was 17.07 cubic meters of water strained per meter of depth fished. The average performance was taken rather than any arbitrary amount because it involved a minimum alteration of original data, and the resulting figures represent nearly the actual numbers caught, except for the last two cruises, when the adjusted two-meter net catches represent approximately one-sixth of the actual numbers taken. Where an upper and a lower net were employed, the standardized catch of the lower net was added to the standardized catch of the upper net after a correction for contamination was applied to the numbers found in the catch of the lower net. The computations are illustrated in table 15.

The procedure for 2-meter-net hauls was exactly the same as for 1-net hauls by 1-meter nets except that an additional factor of one-fourth was applied to offset the quadrupled cross-sectional area of the net's mouth. Other things being equal, this would have resulted in standardization factors about one-fourth as large as those for the 1-meter nets, but actually the 2-meter net was towed somewhat faster and its oblique path was somewhat more gradual due to a higher towing angle in relation to the amount of line hauled in at each time interval. Hence the average amount of water strained per meter of depth fished was about 6 times, instead of 4 times, as great as in the 1-meter nets, and the factors for standardizing accordingly averaged about one-sixth.

For both sizes of net, therefore, the resulting factors for standardizing given in the columns headed "S factor" in tables 17 and 18 are such as to convert the catches at each station to the equivalent of the numbers that would be found in a column of water with a cross-sectional area 17.07 square meters, and extending from the surface to the deepest level reached by the nets at each station. This may also be stated as being equivalent to 21.7 times a vertical haul of a 1-meter net of perfect straining capacity.

TABLE 15.—*Specimen computation of factors for adjustment of haul to standard basis of straining 17.07 cubic meters of water per meter of depth fished and for ascertaining contamination of catch of the lower net in passing through the upper stratum*

[The data relate to station 21491]

Item	Unit	Upper net	Lower net
1. Length of line payed out	Meters	0–25	25–55
2. Average stray	Degrees from vertical	51.3	35.0
3. Stratum fished	Meters	0–16	20–45
4. Thickness of stratum fished	Meters	16	16
5. Time fished (exclusive of time spent by the lower net in passing through the upper stratum).	Seconds	865	980
6. Rate of flow through net (from current meter)	Meters per second	0.574	
7. Clogging (on arbitrary scale, see text)		1	1
8. Adjustment for clogging	Meters per second		−0.007
9. Adjusted flow (item 6 plus item 8)	Meters per second	0.574	0.567
10. Total flow (item 5 times item 9)	Meters	496	556
11. Standard flow $\left(\text{item 4 times } 17.07\frac{4}{\pi}\right)$	Meters	348	348
12. Factor for adjusting to standard haul $\left(\frac{\text{item 11}}{\text{item 10}}\right)$		0.70	0.63
13. Time spent by lower net in passing through the upper stratum	Seconds		127
14. Flow through net while passing through the upper stratum (item 9 times item 13).	Meters		72
15. Factor to be applied to catch of upper net to find the number of organisms caught by lower net while passing through the upper stratum.			0.21

Correction for contamination.—The nets were lowered and raised without closing. Consequently when two nets were used, the portion of the catch of the lower net taken during its passage through the stratum fished by the upper net may be considered as a contamination. The amount of this contamination was computed from the known average concentration of mackerel eggs and larvae in the upper stratum, the known time spent by the lower net in passing through this stratum and the assumed flow through the net (the same as that registered by the current meter installed in the upper net after correction for clogging). The computations were made for each stage of egg and length of larva, and the resulting numbers subtracted from the catch of the lower net (table 14). In all instances, the corrections were substantial, and at many stations approximated the entire catch of the lower net. Important numbers usually remained after the correction at those stations where the upper net did not fish down to the thermocline and the lower net fished in the stratum above the thermocline for a time in addition to the time spent while it was being payed out and hauled back through this stratum. As might be expected from consideration of the laws of random sampling, the amounts to be subtracted were sometimes in excess of the amounts caught in the lower net. When this occurred, differences were negatively added to the catch of the upper net, these instances of over-correction offsetting other instances of under-correction, leaving the average undisturbed.

Relative catch of 1-meter and 2-meter nets.—A comparison of the catching efficiency of 1- and 2-meter nets is afforded by 19 instances during cruises VI and VII where both nets were hauled at the same station. The hauls were made, and the results were converted to the standard basis by the methods already described for both nets, excepting that no current meter was employed to measure the flow of water through the 2-meter net. In lieu of this measure, the speed of towing was measured by timing the travel of the ship past a chip cast alongside. It was later found from a statistical analysis of the relation between chip speed and flow through meter nets as measured by the current meter, that the force of the wind modified the chip speed materially. From the relationship established, a schedule of adjustments was applied to the apparent chip speed, to convert it to an approximation of true towing speed. This apparent flow was used instead of a current meter reading. Because of the substitution of a deduced value based in part on average performance instead of on actually measured value, the two members of individual pairs of hauls are not strictly comparable, but the average, or sum, of the 19 hauls with each type of net is not subject to this fault.

From the distribution of sizes of larvae caught by the respective nets (table 16), it is obvious that the smallest sizes of mackerel larvae were almost entirely lost through the coarse meshes of the 2-meter net; that the 6- to 9-mm. sizes were incompletely retained; and that sizes from 10 mm. upward were fully retained by the larger net.

Two conclusions may be drawn from the comparison: (1) the catches of the two nets, per unit volume of water strained, are virtually identical for larvae 10 mm. and upward, and nearly so for the 7- to 9-mm. sizes, hence no material distortion can have resulted from the pooling of data from the two types of nets, according to the methods employed in this report. (2) Both types of net must have taken essentially all the larvae of sizes 10 to 22 cm. in length that chanced to be in their path, for if any larvae tended to dodge the nets they would surely have been relatively more successful in eluding the 1-meter net, and thus lowered its catch of the elusive sizes in relation to that of the 2-meter net. The closeness of the paired values for the size range specified is eloquent evidence this did not take place. It is to be regretted that no such paired hauls are available for the later cruises, when catches of still larger larvae might have indicated the upper size limit for effective catching of larvae by plankton nets.

TABLE 16.—*Comparison of numbers of larvae caught by 1-meter nets and by 2-meter nets at identical stations of cruises VI and VII*

[Catches of both nets were converted to the basis of straining 17.07 cubic meters per meter of depth fished]

Length of larvae (millimeters)	2-meter net	1-meter net	Length of larvae (millimeters)	2-meter net	1-meter net
	Number	*Number*		*Number*	*Number*
3	0.39	6,214	12	12.84	13
4	.61	230	13	9.50	10
5	1.76	143	14	5.86	5
6	7.40	56	15	3.14	4
7	17.33	33	16	.48	
8	28.10	25	17	.48	1
9	20.28	37	18		1
10	13.75	24	20	.09	
11	13.17	14	22	.09	

TABLE 17.—*Record of oblique hauls made by 1-meter nets during cruises I to VII, inclusive, in 1932*

[For explanation, see items of table 15 designated by the figures enclosed in parentheses in the column headings of this table]

Cruise, locality, and haul	Station	Date	Hour	Upper net					Lower net						
				Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Time (13)	C factor (15)
CRUISE I															
Martha's Vineyard:															
I	21327	May 2	20	39	1,200	[1] 392	2.16	2	----	----	----	----	----	----	----
II	21328	do	23	25	960	[1] 406	1.34	0	30	----	----	----	0	----	----
III	21329	May 3	2	44	780	[1] 203	4.71	2	48	----	----	----	2	----	----
IV	21330	do	7	54	1,380	[1] 538	2.18	2	72	----	----	----	2	----	----
New York:															
II	21335	May 4	3	14	1,140	[1] 492	.62	0	17	1,324	392	0.94	3	[2] 116	0.06
III	21334	May 3	24	13	1,320	[1] 470	.60	2	17	1,444	507	.73	2	[2] 116	.09
IV	21333	do	21	15	1,260	[1] 521	.62	0	18	1,444	601	.65	0	[2] 116	.12
V	21332	do	18	15	1,320	[1] 465	.70	1	18	1,444	578	.68	0	[2] 116	.12
VI	21331	do	17	17	1,200	[1] 442	.84	0	15	----	----	----	0	----	----
Barnegat: I	21336	May 4	7	19	900	[1] 292	1.41	2	----	----	----	----	----	----	----
Atlantic City:															
I	21337	do	10	21	900	[1] 391	1.17	0	----	----	----	----	----	----	----
II	21338	do	13	15	660	[1] 266	1.22	0	18	664	243	1.61	1	[2] 116	.11
III	21339	do	15	19	960	[1] 377	1.10	0	22	1,059	419	1.14	0	[2] 141	.12
IV	21340	do	18	19	900	[1] 367	1.12	0	22	999	410	1.17	0	[2] 141	.12
Cape May:															
II	21345	May 5	9	19	950	[1] 416	.99	1	----	----	----	----	----	----	----
III	21344	do	7	14	805	[1] 309	.98	1	17	920	360	1.03	1	100	.10
IV	21343	do	5	18	880	[1] 368	1.06	0	22	900	292	1.64	2	139	.07
V	21342	do	2	18	820	[1] 306	1.28	1	22	900	380	1.26	0	154	.13
VI	21341	do	1	18	860	[1] 350	1.12	0	22	940	385	1.24	0	----	----
Fenwick: I	21346	do	13	19	860	[1] 330	1.25	2	----	----	----	----	----	----	----
Winterquarter:															
I	21347	do	16	21	900	[1] 394	1.16	0	----	----	----	----	----	----	----
II	21348	do	18	16	845	[1] 386	.90	2	20	920	385	1.13	1	150	.17
III	21349	do	21	16	820	[1] 295	1.18	0	20	900	407	1.07	0	145	.12
Chesapeake:															
I	21352	May 6	8	22	765	[1] 322	1.48	0	----	----	----	----	----	----	----
II	21351	do	5	20	900	[1] 394	1.10	0	----	----	----	----	----	----	----
III	21350	do	2	16	805	[1] 363	.96	0	20	860	390	1.11	0	----	----
CRUISE II															
Martha's Vineyard:															
I	21381	May 16	9	15	710	283	1.15	0	22	765	331	1.44	0	----	----
II	21380	do	6	19	870	235	1.76	2	22	965	254	1.88	1	----	----
III	21379	do	3	17	940	256	1.44	3	21	1,020	213	2.14	2	----	----
Montauk:															
I	21375	May 15	15	22	910	364	1.31	0	----	----	----	----	----	----	----
II	21376	do	18	18	915	389	1.01	0	22	960	441	1.08	0	----	----
III	21377	do	21	15	895	283	1.15	2	20	965	298	1.46	1	----	----
Shinnecock:															
I	21374	May 15	11	13	635	[1] 250	1.13	1	17	695	297	1.24	0	----	----
II	21373	do	8	14	875	481	.63	0	19	925	503	.82	1	----	----
New York:															
I	21369	May 14	18	19	895	421	.98	0	----	----	----	----	----	----	----
II	21370	do	21	12	725	276	.95	0	16	795	329	1.06	0	140	.15
III	21371	do	24	16	840	[1] 298	1.17	1	20	900	344	1.25	0	----	----
IV	21372	May 15	3	17	920	389	.95	0	22	965	442	1.08	0	----	----
Barnegat: I	21368	May 14	14	17	700	267	1.38	0	----	----	----	----	----	----	----
Atlantic City:															
I	21367	May 14	10	19	925	343	1.20	1	----	----	----	----	----	----	----
II	21366	do	8	20	840	311	1.40	1	----	----	----	----	----	----	----
III	21365	do	5	16	910	369	.94	0	20	945	376	1.16	1	150	.12
IV	21364	do	3	18	920	488	.80	0	22	975	550	.87	0	----	----
Cape May:															
I	21359	May 13	11	17	780	294	1.26	0	----	----	----	----	----	----	----
II	21360	do	12	13	595	281	1.01	0	----	----	----	----	----	----	----
III	21361	do	15	22	760	284	1.68	0	----	----	----	----	----	----	----
IV	21362	do	18	19	960	332	1.24	0	22	1,030	392	1.22	0	130	.09
V	21363	do	20	16	860	423	.82	0	21	910	479	.95	0	140	.15
Winterquarter:															
I	21358	May 10	11	22	845	212	2.26	2	----	----	----	----	----	----	----
II	21357	do	9	13	720	292	.87	1	21	785	269	1.70	2	130	.08
III	21356	do	6	19	895	318	1.30	1	22	960	280	1.71	2	145	.07
Chesapeake:															
I	21353	May 9	16	9	480	190	1.03	0	----	----	----	----	----	----	----
II	21354	do	20	21	860	406	1.12	1	----	----	----	----	----	----	----
III	21355	do	24	19	865	326	1.27	0	22	1,010	415	1.15	0	155	.12

[1] The flow was deduced from angle of stray of towing wire and degree of clogging by means of correlation diagrams based on the relation between these and flow through the net as measured by current meter at all other stations of this series.

[2] Deduced from average data on subsequent hauls.

TABLE 17.—*Record of oblique hauls made by 1-meter nets during cruises I to VII, inclusive, in 1932*—Continued

Cruise, locality, and haul	Station	Date	Hour	Upper net					Lower net						
				Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Time (13)	C factor (15)
CRUISE III															
Martha's Vineyard															
I	21382	May 19	17	13	770	396	0.71	0	16	845	463	0.75	0		
II	21383	do	20	16	840	264	1.32	1	20	905	315	1.38	0		
III	21384	do	23	18	870	193	2.02	3	22	955	113	4.23	3		
Montauk:															
I	21387	May 20	10	12	815	327	.80	2	16	885	299	1.16	2		
II	21386	do	7	18	875	284	1.38	1	22	960	252	1.90	2		
III	21385	do	4	16	1,000	243	1.43	2	21	1,110	154	2.96	3		
Shinnecock:															
I	21388	May 20	14	16	965	328	1.06	1							
II	21389	do	18	18	925	353	1.11	1	22	1,060	398	1.20	1		
New York:															
I	21393	May 21	8	15	725	297	1.10	1	18	830	359	1.09	1	108	0.11
II	21392	do	5	12	755	374	.70	1	16	1,000	488	.71	1	129	.18
III	21391	do	1	15	995	438	.74	1	19	1,140	493	.84	1	154	.16
IV	21390	May 20	22	18	875	412	.95	1	22	1,030	478	1.00	1	146	.14
Barnegat: I	21394	May 21	13	18	760	170	2.30	2							
Atlantic City:															
I	21395	do	17	16	690	271	1.28	1							
II	21396	do	19	14	775	205	1.48	2	17	890	230	1.60	1	94	.08
III	21397	do	22	20	840	323	1.35	0	23	1,020	385	1.30	1	121	.08
IV	21398	May 22	1	19	955	465	.89	0	22	1,090	568	.84	0		
Cape May:															
II	21402	do	14	13	555	233	1.21	0							
III	21401	do	11	13	765	260	1.08	1	17	845	316	1.17	0	85	.09
IV	21400	do	9	18	895	337	1.16	2	22	955	300	1.59	2	113	.07
V	21399	do	7	16	850	508	.68	0	20	955	604	.72	0	128	.18
Fenwick: I	21403	do	17	16	765	264	1.32	0							
Winterquarter:															
I	21404	do	20	17	860	469	.79	0							
II	21405	do	22	20	925	324	1.34	1							
III	21406	do	24	16	975	400	.87	0	20	1,105	490	.89	0	122	.12
Chesapeake:															
I	21409	May 23	12	14	700	358	.85	0							
II	21408	do	9	21	825	334	1.37	1							
III	21407	do	7	11	725	399	.60	2	16	810	440	.79	1	115	.20
CRUISE IV															
Martha's Vineyard:															
I	21431	May 28	3	17	980	340	1.09	3	20	1,150	326	1.33	2	110	.08
II	21430	May 27	24	22	990	205	2.33	3	24	1,140	228	2.28	1	128	.07
III	21129	do	21	19	935	365	1.13	0	23	1,030	437	1.14	0	110	.09
Montauk:															
I	21426	do	10	20	860	363	1.20	1							
II	21427	do	13	15	960	401	.81	1	18	1,050	432	.90	1	120	.13
III	21428	do	17	15	885	363	.90	0	20	1,015	450	.97	0	105	.10
Shinnecock:															
I	21425	do	6	22	960	356	1.34	2							
II	21424	do	2	16	1,000	435	.80	1	21	1,145	537	.85	0	131	.14
New York:															
I	21420	May 26	11	20	950	284	1.53	1							
II	21421	do	14	14	735	251	1.20	0	17	850	322	1.15	0	100	.09
III	21422	do	18	17	880	367	1.01	0	21	980	442	1.03	0	130	.12
IV	21423	do	21	20	915	327	1.33	0	23	1,040	406	1.23	0	102	.07
Barnegat: I	21419	do	7	20	940	325	1.34	1							
Atlantic City:															
I	21418	do	4	21	910	257	1.78	1							
II	21417	do	1	11	550	161	1.48	2	18	840	159	2.46	3	116	.04
III	21416	May 25	22	20	965	355	1.22	0	23	1,075	433	1.15	0	123	.09
IV	21415	do	20	20	860	404	1.08	0	23	960	484	1.03	0	115	.11
Cape May:															
II	21411	do	7	22	970	301	1.59	0							
III	21412	do	9	16	800	274	1.27	0	18	890	334	1.17	0	109	.10
IV	21413	do	12	18	955	285	1.37	2	22	1,080	210	2.28	3	120	.04
V	21414	do	14	15	940	369	.88	0	20	1,035	443	.98	0	121	.11
Chesapeake: II	21410	May 24	19	19	750	248	1.66	0							
CRUISE V															
Montauk:															
I	21432	June 1	20	12	770	383	.68	0	16	925	454	.77	1	116	.15
II	21433	do	23	16	1,030	394	.88	3	20	1,255	379	1.15	2	162	.13
Shinnecock: III	21434	June 2	4	15	935	368	.89	0	20	1,080	462	.94	0	137	.12
New York:															
I	21438	do	20	20	915	324	1.34	1							
II	21437	do	16	12	895	520	.50	1	17	985	606	.61	0	170	.29
III	21436	do	12	16	980	466	.75	0	21	1,080	551	.83	0	133	.14
IV	21435	do	9	20	915	334	1.30	0	22	1,050	419	1.14	0	122	.09
Barnegat: I	21439	June 3	1	19	815	336	1.23	1							

TABLE 17.—*Record of oblique hauls made by 1-meter nets during cruises I to VII, inclusive, in 1932*—Continued

Cruise, locality, and haul	Station	Date	Hour	Upper net					Lower net						
				Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Depth (4)	Time (5)	Flow (10)	S factor (12)	Clogging (7)	Time (13)	C factor (15)
CRUISE V															
Atlantic City:															
I	21440	do	5	20	885	437	0.99	0	----	----	----	----	----	----	----
II	21441	do	7	13	840	425	.66	0	20	930	502	0.87	0	140	0.16
III	21442	do	10	14	985	458	.66	0	19	1,090	544	.76	0	131	.15
IV	21443	do	13	16	905	428	.81	0	21	1,005	510	.90	0	142	.15
Cape May:															
II	21447	June 4	4	17	910	171	2.16	0	----	----	----	----	----	----	----
III	21446	do	1	11	690	300	.80	1	20	1,200	563	.77	0	122	.13
IV	21445	June 3	23	14	915	416	.73	0	19	1,060	519	.80	0	150	.17
V	21444	do	20	18	915	366	1.07	0	22	1,050	456	1.05	0	120	.10
Winterquarter:															
I	21448	June 4	11	18	1,050	497	.79	0	----	----	----	----	----	----	----
II	21449	do	14	16	890	358	.97	----	20	985	396	1.10	----	143	.13
III	21450	do	17	15	905	450	.72	1	20	1,020	542	.80	0	135	.17
Chesapeake:															
I	21453	June 5	6	18	930	300	1.30	----	----	----	----	----	----	----	----
II	21452	do	2	18	900	346	1.13	2	----	----	----	----	----	----	----
III	21451	June 4	23	16	910	447	.78	1	20	1,025	538	.81	0	150	.18
CRUISE VI															
Martha's Vineyard:															
I	21468	June 8	7	11	725	480	.50	1	15	855	512	.64	2	97	.16
II	21467	do	4	16	845	232	1.50	2	20	975	166	2.62	3	139	.04
III	21466	do	1	18	865	403	.97	0	22	1,005	503	.95	0	142	.14
Montauk:															
I	21464	June 7	15	9	710	307	.64	2	13	805	342	.82	1	93	.16
II	21465	do	19	15	985	335	.97	2	20	1,195	282	1.54	3	131	.06
Shinnecock: II	21463	do	9	16	955	398	.87	0	20	1,105	453	.96	1	124	.11
New York:															
II	21460	June 6	21	17	905	330	1.12	2	22	1,030	368	1.30	1	124	.11
III	21461	June 7	1	18	895	218	1.80	2	22	1,000	180	2.65	2	144	.05
IV	21462	do	4	21	835	420	1.09	0	24	1,030	553	.94	0	136	.13
Atlantic City:															
I	21459	June 6	14	22	1,075	530	.90	0	----	----	----	----	----	----	----
II	21458	do	11	15	855	387	.84	0	20	975	475	.92	0	132	.14
III	21457	do	9	15	950	449	.73	0	19	1,065	540	.76	0	113	.13
Cape May:															
II	21454	June 5	20	21	905	214	2.14	----	----	----	----	----	----	----	----
III	21455	do	23	11	855	438	.55	0	15	1,015	555	.59	0	118	.19
IV	21456	June 6	2	16	855	359	.97	0	41	985	446	2.00	0	131	.06
CRUISE VII															
Martha's Vineyard:															
I	21490	June 19	16	10	890	511	.42	0	10	1,050	638	.34	0	73	.19
II	21491	do	20	16	865	496	.70	1	16	980	556	.63	1	127	.21
III	21492	do	24	17	910	473	.78	0	17	1,085	601	.61	0	104	.15
IV	21493	June 20	6	15	830	484	.67	0	16	975	602	.58	0	100	.17
Montauk:															
I	21489	June 19	10	12	725	393	.66	0	12	830	444	.59	1	86	.16
II	21488	do	6	16	895	484	.72	0	16	1,040	598	.58	0	113	.18
III	21487	do	2	15	930	523	.62	1	16	1,175	700	.50	0	141	.24
Shinnecock:															
I	21485	June 18	16	25	1,040	[1] 401	1.35	----	----	----	----	----	----	----	----
II	21486	do	21	17	900	345	1.07	1	17	1,015	382	.97	1	121	.12
New York:															
I	21484	do	7	20	930	[1] 415	.98	0	----	----	----	----	----	----	----
II	21483	do	4	14	975	275	1.11	----	15	1,150	324	1.01	----	135	.12
III	21482	June 17	23	13	860	[1] 457	.62	0	14	990	559	.54	0	128	.22
IV	21481	do	20	15	965	422	.77	0	16	1,130	532	.65	0	110	.14
Atlantic City:															
I	21469	June 15	14	15	825	[1] 411	.79	0	----	----	----	----	----	----	----
II	21477	June 17	6	15	900	435	.75	1	20	1,045	498	.87	1	120	.13
III	21478	do	9	16	940	496	.70	0	20	1,050	590	.74	0	149	.18
IV	21479	do	12	21	925	356	1.28	0	24	1,035	434	1.20	0	135	.10
Cape May:															
III	21476	June 16	23	16	960	438	.79	0	20	1,080	530	.82	0	192	.19
IV	21475	do	20	13	820	388	.73	----	18	930	440	.89	----	154	.12
V	21474	do	18	14	830	365	.83	0	19	925	438	.94	0	----	----
Winterquarter:															
I	21471	do	5	17	750	[1] 242	1.53	2	22	990	507	.94	0	----	----
II	21472	do	8	18	895	428	.91	0	----	----	----	----	----	----	----

TABLE 18.—*Record of oblique hauls made with a 2-meter net during cruises VIII and IX, 1932*

Locality	Station	Date	Hour	Depth (4)	Time (5)	Flow (10)	S Factor (12)
CRUISE VIII							
Martha's Vineyard:							
I	1283	July 1	20	28	1,440	1,128	0.135
II	1282	do	16	27	1,500	1,075	.135
Montauk:							
I	1276	June 30	7	21	1,620	2,349	.048
IV	1259	June 25	11	28	1,740	1,131	.135
Shinnecock:							
I	1275	June 29	13	26	1,260	987	.141
II	1274	do	18	34	1,620	729	.256
New York:							
I	1270	June 28	21	29	1,440	1,128	.137
II	1271	June 29	2	25	1,440	1,536	.088
III	1272	do	7	24	1,440	1,728	.074
V	1260	June 26	2	21	1,740	2,526	.043
VI	1261	do	4	25	1,440	1,632	.083
Barnegat: I	1269	June 28	16	17	960	704	.131
Atlantic City:							
I	1262	June 26	20	14	780	572	.131
II	1263	do	24	39	1,680	812	.256
III	1264	June 27	4	34	1,500	725	.256
IV	1265	do	7	34	1,380	667	.268
Cape May:							
II	1266	do	18	22	1,260	987	.119
III	1267	do	21	33	1,560	884	.196
IV	1268	do	24	25	1,560	1,664	.080
CRUISE IX							
Cape Ann: II	1319	July 23	5	43	2,460	2,050	.112
Boston: II	1318	July 22	13	27	1,260	504	.282
Cape Cod Bay: I	1316	do	17	31	1,800	1,440	.114
Race Point: I	1315	do	13	31	1,920	1,152	.145
Chatham: II	1328	July 24	23	40	1,740	841	.256
Western Georges: III	1308	July 21	8	63	1,980	1,551	.214
South Channel: IV	1307	do	4	72	1,680	588	.680
Martha's Vineyard:							
I	1303	July 20	6	39	2,280	1,900	.110
II	1302	do	1	49	1,620	1,053	.256
Montauk:							
I	1288	July 16	13	18	960	960	.101
III	1290	July 17	10	38	1,800	1,080	.194
Shinnecock: I	1294	July 18	3	18	1,500	1,925	.050
New York: II	1296	do	16	23	1,380	1,021	.122

NOTE:—The above table does not include hauls failing to take mackerel larvae. For a list of these see foot of table 19 and table 20.

RECORDS OF TOW NETTING AND CATCHES OF 1932

Since the methods of reducing catches of eggs and larvae to the standard basis on which the conclusions of this paper rest, are, to a considerable extent, novel, and therefore have not stood the test of usage, and since techniques may be altered in the future in such a way as to require recalculation of present results to provide material for comparison, there are given in tables 17 to 20, inclusive, the more pertinent of the records of the cruises of 1932.

Tables 17 and 18 give the conditions under which the hauls were made, and the relation of the data to each other may be understood by consulting table 15. Similarly, tables 19 and 20, giving the counts of examined portions of catches and the standardized total catches, were based on computations illustrated by table 14.

Since the data on hydrographic conditions have already been published (Bigelow, 1933, pp. 124–128 and 131–133) they are omitted from this paper.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*

[Numbers following the locality designation are the serial numbers of the stations. Numbers in parenthesis are the fractions of the haul sorted for eggs and larvae. The entire haul was sorted for large larvae. The numbers given in the table are the actual counts in the sorted fractions; numbers given on the adjusted total lines are these counts converted to total catch and adjusted to represent the number per 17.07 square meter of sea surface]

CRUISE I

Item	Number of eggs by stages			Number of larvae by millimeter classes						
	A	B	C	3	4	5	6	7	8	9
New York II 21335:										
Upper haul:										
Eggs and larvae (0.0250)	179	4								
Lower haul:										
Eggs and larvae (0.0250)	43	3								
Adjusted total	5,806	206								
New York III 21334:										
Upper haul:										
Eggs and larvae (0.0500)	19	15	2							
Lower haul:										
Eggs and larvae (0.0500)	9	10	1							
Adjusted total	344	314	37							
New York IV 21333:										
Upper haul:										
Eggs and larvae (0.0100)	8	3	1							
Lower haul:										
Eggs and larvae (0.2000)	6									
Adjusted total	66	17	5							
New York V 21332 [1]:										
Upper haul:										
Eggs and larvae (0.1000)		1								
Adjusted total		6								
Barnegat I 21336:										
Upper haul:										
Eggs and larvae (0.1000)	18									
Adjusted total	254									
Atlantic City I 21337:										
Upper haul:										
Eggs and larvae (0.1000)	9	1								
Adjusted total	105	12								
Atlantic City II 21338:										
Upper haul:										
Eggs and larvae (0.0600)	31	4	1							
Lower haul:										
Eggs and larvae (0.0500)	3									
Adjusted total	621	72	18							
Atlantic City III 21339:										
Upper haul:										
Eggs and larvae (0.0500)	10	47	14	1						
Lower haul:										
Eggs and larvae (0.0500)		13	1							
Adjusted total	194	1,189	291	19						
Atlantic City IV 21340:										
Upper haul:										
Eggs and larvae (0.0500)	1	49	12							
Lower haul:										
Eggs and larvae (0.0500)		19	2							
Adjusted total	19	1,388	278							
Cape May II 21345:										
Upper haul:										
Eggs and larvae (0.0500)	177	26	10	3						
Adjusted total	3,503	515	198	59						
Cape May III 21344:										
Upper haul:										
Eggs and larvae (0.1070)	32	220	134	30						
Lower haul:										
Eggs and larvae (0.1000)	22	80	37	13						
Adjusted total	491	2,635	1,485	381						

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE I—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes						
	A	B	C	3	4	5	6	7	8	9
Cape May IV 21343:										
Upper haul:										
Eggs and larvae (0.1000)		43	59	2						
Lower haul:										
Eggs and larvae (0.1070)		9	18	1						
Adjusted total		541	830	34						
Cape May V 21343:										
Upper haul:										
Eggs and larvae (0.0500)		29	38	42						
Lower haul:										
Eggs and larvae (0.0500)		3	7	1						
Adjusted total		706	991	955						
Fenwick I 21346:										
Upper haul:										
Eggs and larvae (0.1000)	1	20	6	12						
Adjusted total	12	250	75	150						
Winterquarter I 21347:										
Upper haul:										
Eggs and larvae (0.0533)		2	2	55						
Adjusted total		44	44	1,197						
Winterquarter II 21348:										
Upper haul:										
Eggs and larvae (0.0867)			28	25	30	3				
Large larvae						1	3	1		
Lower haul:										
Eggs and larvae (0.1333)			7	1	4	2	1			
Adjusted total			294	224	289	42	11	1		
Winterquarter III 21349:										
Upper haul:										
Eggs and larvae (0.0533)			5	49	66	6				
Large larvae						7	4	9	3	1
Lower haul:										
Eggs and larvae (0.1300)			3	5	9	4				
Large larvae								1		
Adjusted total			121	993	1,355	149	4	11	4	1
Chesapeake I 21352:										
Upper haul:										
Eggs and larvae (0.3000)				1	4	7	2			
Adjusted total				5	20	35	10			
Chesapeake II 21351:										
Upper haul:										
Eggs and larvae (0.3333)					8	4	4			
Adjusted total					26	13	13			
Grand adjusted total	11,415	7,895	4,667	4,017	1,690	239	38	12	4	1

CRUISE II

Item	A	B	C	3	4	5	6	7	8	9
Martha's Vineyard I 21381: [1]										
Upper haul:										
Eggs (0.0187) larvae (0.0373)	4									
Adjusted total	246									
Montauk I 21375:										
Upper haul:										
Eggs (0.0280) larvae (0.0560)	25									
Adjusted total	1,170									
Montauk II 21376: [1]										
Upper haul:										
Eggs and larvae (0.0560)	1									
Adjusted total	18									

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE II—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes						
	A	B	C	3	4	5	6	7	8	9
Shinnecock I 21374: [1]										
Upper haul:										
Eggs (0.0280) larvae (0.1120)	66	6								
Adjusted total	2,662	242								
Shinnecock II 21373:										
Upper haul:										
Eggs and larvae (0.0560)	5	6								
Adjusted total	56	68								
New York I 21369:										
Upper haul:										
Eggs (0.0187) larvae (0.0373)	22	162	182							
Adjusted total	1,157	8,510	9,560							
New York II 21370:										
Upper haul:										
Eggs (0.0124) larvae (0.0248)	76	14	3	4						
Lower haul:										
Larvae (0.0448)				9						
Adjusted total	5,802	1,068	229	342						
New York III 21371: [1]										
Upper haul:										
Eggs and larvae (0.0560)	2		3							
Adjusted total	42		63							
Barnegat I 21368:										
Upper haul:										
Eggs and larvae (0.0280)	191	40	71	61						
Adjusted total	9,420	1,972	3,500	3,010						
Atlantic City I 21367:										
Upper haul:										
Eggs (0.0187) larvae (0.0373)	15	23	23	5						
Adjusted total	965	1,480	1,480	161						
Atlantic City II 21366:										
Upper haul:										
Eggs and larvae (0.0560)	1	3	9	7						
Adjusted total	25	75	225	175						
Atlantic City III 21365: [2]										
Upper haul:										
Eggs and larvae (0.0373)		2	2							
Large larvae								1		
Adjusted total		50	50					1		
Atlantic City IV 21364: [3]										
Upper haul:										
Eggs and larvae (0.0373)			2							
Adjusted total			43							
Cape May I 21359:										
Upper haul:										
Eggs and larvae (0.0560)			3	2						
Adjusted total			68	45						
Cape May II 21360:										
Upper haul:										
Eggs (0.0280) larvae (0.0560)			74	21						
Adjusted total			2,665	379						
Cape May III 21361:										
Upper haul:										
Eggs and larvae (0.0560)		4	5	1						
Adjusted total		120	150	30						

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE II—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes						
	A	B	C	3	4	5	6	7	8	9
Cape May IV 21362:										
Upper haul:										
Eggs and larvae (0.0560)			1	23	1					
Lower haul:										
Larvae (0.0560)					1					
Adjusted total			22	463	42					
Cape May V 21363: [1]										
Upper haul:										
Eggs and larvae (0.0560)					1					
Adjusted total					1					
Winterquarter I 21358:										
Upper haul:										
Eggs and larvae (0.0373)			2	17						
Large larvae					2	1				
Adjusted total			121	1,030	5	2				
Winterquarter II 21357:										
Upper haul:										
Eggs and larvae (0.0373)			2	26	13	6				
Large larvae						2	3			
Lower haul:										
Larvae (0.0373)			9	2	5	2				
Large larvae						1	1			
Adjusted total			52	675	520	227	5			
Winterquarter III 21356:										
Upper haul:										
Eggs and larvae (0.0560)						2	5			
Large larvae							4	2		
Lower haul: [3]										
Large larvae							3	6		
Adjusted total						43	111	12		
Chesapeake I 21353:										
Upper haul:										
Eggs and larvae (0.0560)						3	1			
Large larvae								1		
Adjusted total						55	18	1		
Chesapeake II 21354:										
Upper haul:										
Eggs and larvae (0.0373)					9	14	6			
Large larvae						3	4	3	2	1
Adjusted total					270	420	174	3	2	1
Chesapeake III 21355: [3]										
Upper haul: [4]										
Large larvae						3	2	3		
Adjusted total						4	3	4		
Grand adjusted total	21,563	13,585	18,228	6,310	838	751	311	21	2	1

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE III

Item	Number of eggs by stages			Number of larvae by millimeter classes								
	A	B	C	3	4	5	6	7	8	9	10	11
Martha's Vineyard I 21382: [1]												
Upper haul:												
Eggs (0.0280) larvae (0.0560)	81											
Adjusted total	2,060											
Montauk I 21387: [3]												
Upper haul:												
Eggs (0.0187) larvae (0.0373)	88	25										
Adjusted total	3,774	1,072										
Montauk II 21386: [2]												
Upper haul:												
Eggs and larvae (0.0560)	3	3										
Adjusted total	74	74										
Shinnecock I 21388:												
Upper haul:												
Eggs (0.0224) larvae (0.0448)	327	95	25	2								
Adjusted total	15,470	4,500	1,183	47								
Shinnecock II 21389: [1]												
Upper haul:												
Eggs and larvae (0.0560)	1	12	5									
Adjusted total	20	240	100									
New York I 21393:												
Upper haul:												
Eggs (0.0224) larvae (0.0448)	16	84	6	13								
Lower haul:												
Larvae (0.0373)				1								
Adjusted total	786	4,130	295	312								
New York II 21392:												
Upper haul:												
Eggs (0.0224) larvae (0.0448)	3	30	21	24								
Lower haul:												
Larvae (0.0373)				2								
Adjusted total	94	940	658	363								
New York III 21391: [2]												
Upper haul:												
Eggs and larvae (0.0373)		2	5	1								
Adjusted total		40	99	17								
New York IV 21390: [1]												
Upper haul:												
Eggs and larvae (0.0373)		2	1									
Large larvae									1			
Adjusted total		51	25						1			
Barnegat I 21394:												
Upper haul:												
Eggs and larvae (0.0280)		18	9	38	2							
Adjusted total		1,479	739	3,120	164							
Atlantic City I 21395:												
Upper haul:												
Eggs and larvae (0.0448)		10	1	10	3							
Adjusted total		286	29	286	86							
Atlantic City II 21396:												
Upper haul:												
Eggs and larvae (0.0373)		4	27	58	9							
Large larvae					1							
Lower haul:												
Larvae (0.0448)				6	2							
Adjusted total		160	1,070	2,250	383							
Atlantic City III 21397: [2]												
Upper haul:												
Eggs and larvae (0.0373)		2	3	2								
Adjusted total		72	109	66								

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE III—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes								
	A	B	C	3	4	5	6	7	8	9	10	11
Atlantic City IV 21398:[3]												
Upper haul:												
Eggs and larvae (0.0840)		2	1									
Adjusted total		21	11									
Cape May II 21402:												
Upper haul:												
Eggs and larvae (0.0747)	1	28	46	2	21	19	3					
Large larvae							9					
Adjusted total	16	454	746	32	341	308	49					
Cape May III 21401:												
Upper haul:												
Eggs and larvae (0.0373)			7	17	1							
Large larvae				1		2						
Lower haul:												
Larvae (0.0448)				1								
Adjusted total			202	470	25	2						
Cape May IV 21400:[3]												
Upper haul:												
Eggs and larvae (0.0747)				25	20	3						
Large larvae					4	26	4					
Adjusted total				362	289	39	5					
Cape May V 21399:[5]												
Lower haul:												
Larvae (0.0560)				1								
Adjusted total				13								
Fenwick I 21403:												
Upper haul:												
Eggs and larvae (0.0560)					21	7	3					
Large larvae							24	15	2			
Adjusted total					495	165	47	20	3			
Winterquarter I 21404:												
Upper haul:												
Eggs and larvae (0.1000)					34	81	41	10	1			
Large larvae						2	6	16	7			
Adjusted total					268	640	324	79	7			
Winterquarter II 21405:												
Upper haul:												
Eggs and larvae (0.1000)					11	30	5	1				
Large larvae						1	9	5	2			
Adjusted total					148	402	67	10	3			
Winterquarter III 21406:[3]												
Upper haul:												
Eggs (0.1000) larvae (1.0000)					10	50	52	15	7	1		1
Adjusted total					8	39	40	11	5	1		1
Chesapeake I 21409:[6]												
Upper haul:												
Large larvae								3				
Adjusted total								3				
Chesapeake II 21408:												
Upper haul:												
Eggs and larvae (0.1000)						1	2	5			1	
Large larvae						7	11	14	15	10	3	3
Adjusted total						11	18	26	21	14	5	4
Chesapeake III 21407:												
Upper haul:												
Eggs and larvae (0.1000)							1				1	
Large larvae						1	5	2	1	1		
Lower haul:												
Larvae (0.0448)							1	1				
Large larvae										1	1	
Adjusted total						1	4	2	1	2	2	
Grand adjusted total	22, 294	13, 519	5, 266	7, 338	2, 207	1, 607	554	151	40	18	7	5

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE IV

Item	Number of eggs by stages			Number of larvae by millimeter classes								
	A	B	C	3	4	5	6	7	8	9	10	11
Martha's Vineyard I 21431: [7]												
Upper haul:												
Eggs (0.0187) larvae (0.0373)	27	88	131	28								
Adjusted total	1,574	5,140	7,650	753								
Martha's Vineyard II 21430:												
Upper haul:												
Eggs and larvae (0.0373)	8	18	12	10								
Lower haul:												
Larvae (0.0560)				11								
Adjusted total	499	1,122	748	972								
Martha's Vineyard III 21429: [1]												
Upper haul:												
Eggs and larvae (0.0560)	14	14	2									
Adjusted total	283	282	40									
Montauk I 21426:												
Upper haul:												
Eggs (0.0280) larvae (0.0560)	103	16	15	15								
Adjusted total	4,416	686	643	322								
Montauk II 21427:												
Upper haul:												
Eggs and larvae (0.0224)	1	8	57	68								
Lower haul:												
Larvae (0.0448)				3								
Adjusted total	36	289	2,061	2,203								
Montauk III 21428: [1]												
Upper haul:												
Eggs and larvae (0.0560)	1		15	24								
Adjusted total	16		241	347								
Shinnecock I 21425:												
Upper haul:												
Eggs and larvae (0.0187)	55	75	64	40	2							
Adjusted total	3,953	5,380	4,600	2,875	144							
Shinnecock II 21424:												
Upper haul:												
Eggs and larvao (0.0224)	8	2	23	52								
Lower haul:												
Larvae (0.0560)				9								
Adjusted total	285	71	820	1,754								
New York I 21420:												
Upper haul:												
Eggs and larvae (0.0373)		1										
Adjusted total		41										
New York II 21421:												
Upper haul:												
Eggs and larvae (0.0280)	7	27	108	149	51							
Lower haul:												
Larvae (0.0373)				37	19	1						
Adjusted total	300	1,155	4,630	6,861	2,549	31						
New York III 21422:												
Upper haul:												
Eggs and larvae (0.0373)	5	2	1	22	1							
Lower haul:												
Larvae (0.0448)				1								
Adjusted total	135	54	27	546	24							
New York IV 21423: [1]												
Upper haul:												
Eggs and larvae (0.0448)	19	1		3								
Adjusted total	563	30		83								

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE IV—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes								
	A	B	C	3	4	5	6	7	8	9	10	11
Barnegat I 21419:												
Upper haul:												
Eggs (0.0187) larvae (0.0373)		1	1	1	1							
Adjusted total		36	36	72	72							
Atlantic City I 21418:												
Upper haul:												
Eggs and larvae (0.0373)				8	10	12	2					
Large larvae						2	8					
Adjusted total				382	477	573	95					
Atlantic City II 21417:												
Upper haul:												
Eggs and larvae (0.0373)	2	2		7	2							
Large larvae						1						
Lower haul:												
Larvae (0.0560)				13	15							
Adjusted total	80	79		820	731	1						
Atlantic City III 21416: [1]												
Upper haul:												
Eggs and larvae (0.0747)	2		1	4								
Adjusted total	32		16	60								
Atlantic City IV 21415: [2]												
Upper haul:												
Eggs and larvae (0.1120)			1				1					
Large larvae								2				
Adjusted total			10				1	2				
Cape May II 21411:												
Upper haul:												
Eggs and larvae (0.0448)		26	2		2	1	2					
Large larvae							5	1				
Adjusted total		922	71		71	36	70	1				
Cape May III 21412:												
Upper haul:												
Eggs and larvae (0.0747)			7	15	15	7	2					
Large larvae						6	14	2				
Lower haul:												
Larvae (0.0560)				1	1							
Adjusted total			119	247	247	107	31	2				
Cape May IV 21413:												
Upper haul:												
Eggs and larvae (0.0896)				6	10							
Lower haul: [3]												
Large larvae								1				
Adjusted total				88	147			2				
Cape May V 21414: [1]												
Upper haul:												
Eggs and larvae (0.1120)				1								
Adjusted total				7								
Chesapeake II 21410:												
Upper haul:												
Eggs and larvae (0.0896)								1	1		2	
Large larvae						2	2	10	28	17		1
Adjusted total						3	3	18	48	28	3	2
Grand adjusted total	12,172	15,287	21,712	18,392	4,462	751	200	25	48	28	3	2

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE V

Item	Number of eggs by stages			Number of larvae by millimeter classes											
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14
Montauk I 21432:															
Upper haul:															
Eggs (0.0187) larvae (0.0373)	40	5	1	5											
Lower haul:															
Larvae (0.1056)				2											
Adjusted total	1,456	182	36	95											
Montauk II 21433:															
Upper haul:															
Eggs and larvae (0.0280)	6	10	160	158											
Lower haul:															
Larvae (0.0896)				31											
Adjusted total	188	314	5,030	4,665											
Shinnecock III 21434:															
Upper haul:															
Eggs and larvae (0.0448)	5	8	4	12	29	17									
Lower haul:															
Larvae (0.0896)				4	6	4									
Adjusted total	99	159	79	253	574	342									
New York I 21438:															
Upper haul:															
Eggs and larvae (0.0373)			4				5	1							
Large larvae								19	1						
Adjusted total			144				180	35	1						
New York II 21437:															
Upper haul:															
Eggs (0.0187) larvae (0.0373)	29	37	21	2	6	5	11	4	2						
Large larvae								1	12	2					
Lower haul:															
Larvae (0.0373)				2	9	6	3								
Large larvae						1	16	3							
Adjusted total	776	990	563	55	214	154	168	41	18	1					
New York III 21436:															
Upper haul:															
Eggs and larvae (0.0672)	11	14	6	11	12	8									
Large larvae							6								
Lower haul:															
Larvae (0.0747)					1	5									
Large larvae					1	5	2								
Adjusted total	123	156	67	105	128	129	5								
New York IV 21435:															
Upper haul:															
Eggs and larvae (0.1120)	19	22	1	1	16	6									
Lower haul:															
Larvae (0.0896)				1											
Adjusted total	221	256	12	23	169	64									
Barnegat I 12439:															
Upper haul:															
Eggs and larvae (0.0747)					1	9	19	20							
Large larvae								18	10						
Adjusted total					16	148	312	317	12						
Atlantic City I 21440:															
Upper haul:															
Eggs and larvae (0.0896)	4			1			2	2							
Large larvae									2	2					
Adjusted total	44			11			22	18	2	2					
Atlantic City II 21441:															
Upper haul:															
Eggs (0.0280) larvae (0.1120)			2		1		6	10							
Large larvae								1	2						
Lower haul:															
Larvae (0.0896)					2	8	2		12						
Large larvae						11	8	11	6	1					
Adjusted total			47		24	78	38	59	7	1					

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE V—Continued

Item	Number of eggs by stages			Number of larvae by millimeter classes											
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14
Atlantic City III 21442:															
Upper haul:															
Eggs and larvae (0.0896)			3		3	7	50	44	6						
Large larvae							1								
Lower haul:															
Larvae (0.0560)					5		1								
Large larvae				1	9	15	32	15	4						
Adjusted total			22	1	96	57	346	290	41						
Atlantic City IV 21443:															
Upper haul:															
Eggs and larvae (0.0747)			1	1	1										
Large larvae				1	13										
Lower haul:															
Larvae (0.0747)					1	2									
Large larvae						1									
Adjusted total			11	7	22	20									
Cape May II 21447:															
Upper haul:															
Eggs and larvae (0.0747)						1	1		1					1	
Large larvae							1					2	1		
Adjusted total						29	29		1			2	1	1	
Cape May III 21446:															
Upper haul:															
Eggs and larvae (0.0747)						1	1	4							
Large larvae								1	2		4	2			
Lower haul:															
Larvae (0.0373)										1					
Large larvae								2	1	1					
Adjusted total						10	10	32	3	2	3	2			
Cape May IV 21445:															
Upper haul:															
Eggs and larvae (0.0747)						2	2	11	11	4					
Large larvae										7					
Lower haul:															
Larvae (0.0960)								4	4						
Large larvae							6	15	11	6					
Adjusted total						17	22	108	104	38					
Cape May V 21444: [8]															
Upper haul:															
Large larvae								1							
Lower haul: [9]															
Large larvae						1									
Adjusted total						1		1							
Winterquarter I 21448: [10]															
Upper haul:															
Large larvae								5		2					1
Adjusted total								4		2					1
Winterquarter II 21449: [11]															
Upper haul:															
Large larvae								1				1	1		1
Adjusted total								1				1	1		1
Winterquarter III 21450:															
Upper haul: [8]															
Large larvae									2	4	1				
Lower haul: [9]															
Larvae (0.0112)										1					
Large larvae									1	2					
Adjusted total									2	5	1				
Chesapeake III 21451:															
Upper haul:															
Eggs and larvae (0.0747)									1		1				
Large larvae								7	10	5	3				
Lower haul:															
Larvae (0.1120)									1		1				
Large larvae								1	1			1			
Adjusted total								5	9	3	3	1			
Grand adjusted total	2,907	2,057	6,011	5,215	1,243	1,049	1,132	911	200	54	7	6	2	1	2

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE VI

Locality	Number of eggs by stages			Number of larvae by millimeter classes												
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14	15
Martha's Vineyard I 21468:																
Upper haul:																
Eggs and larvae (0.0187)	77	28	20	10	5	7										
Large larvae					12	13	4									
Lower haul:																
Larvae (0.0373)				1	1	1										
Large larvae						1										
Adjusted total	2,062	751	536	251	138	184	2									
Martha's Vineyard II 21467:																
Upper haul:																
Eggs (0.0373) larvae (0.0224)			2	21	40	16	2									
Large larvae				1	1	34	60	24	1							
Lower haul:																
Larvae (0.0373)				6	4	2										
Large larvae					5	22	6	5								
Adjusted total			80	1,934	3,198	1,278	119	46	2							
Martha's Vineyard III 21466:																
Upper haul:																
Eggs (0.0448) larvae (0.0224)				42	81	10		1								
Large larvae					1	3										
Lower haul:																
Larvae (0.0672)				17	23	1										
Large larvae				1	10	4										
Adjusted total				1,822	3,366	388		1								
Montauk I 21464:																
Upper haul:																
Eggs (0.0187) larvae (0.0373)	22	5	1	19	4											
Large larvae						5	13									
Lower haul:																
Larvae (0.0672)				31	24	9	1									
Large larvae						5	14									
Adjusted total	753	171	34	663	343	113	19									
Montauk II 21465:																
Upper haul:																
Eggs (0.0448) larvae (0.0224)		3	21	75	11	1										
Large larvae				2	4	24	4		1							
Lower haul:																
Larvae (0.0747)				6	3	1										
Large larvae						1										
Adjusted total		65	455	3,145	495	58	4		1							
Shinnecock II 21463:																
Upper haul:																
Eggs and larvae (0.0560)		1	13	46	22	2										
Large larvae				1	1	17	34	9								
Lower haul:																
Larvae (0.0896)				4	3		1									
Adjusted total		16	202	682	319	14	38	7								
New York II 21460:																
Upper haul:																
Eggs and larvae (0.0448)		1	1	1	2	2	3	8	13	2						
Large larvae									41	83	10					
Lower haul:																
Larvae (0.0896)						3	1		3	5						
Large larvae					1	11	3	13	34	15	3	1				
Adjusted total		25	25	22	45	84	79	191	280	106	14	1				
New York III 21461:																
Upper haul:																
Eggs and larvae (0.0373)		2	1	13	3	1										
Large larvae					1	21	14	9	2							
Lower haul:																
Larvae (0.0747)				1	4	2										
Large larvae						8	3	1								
Adjusted total		97	48	611	237	88	30	16	4							

See footnotes at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE VI—Continued

Locality	Number of eggs by stages			Number of larvae by millimeter classes												
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14	15
New York IV 21462:																
Upper haul:																
Eggs and larvae (0.0896)		3	15	8	1		12	1								
Large larvae								21	4							
Lower haul:																
Larvae (0.0407)					3	2										
Large larvae						10	13	8								
Adjusted total		36	182	84	66	28	127	28	3							
Atlantic City I 21459:																
Upper haul:																
Eggs and larvae (0.0560)											1					
Large larvae						1	2	1	3	13	13	1				
Adjusted total						1	2	1	3	12	13	1				
Atlantic City II 21458:																
Upper haul:																
Eggs and larvae (0.1120)								7	14							
Large larvae						1	5	41	84	6						
Lower haul:																
Larvae (0.0747)					1	8	4	2	4							
Large larvae					5	33	42	35	30	15	1	1				
Adjusted total					12	99	45	69	99	18	1	1				
Atlantic City III 21457:																
Upper haul:																
Eggs (0.0747), larvae (0.1120)					1			1	16	1						
Large larvae					4	11	14	20	65	31	1					
Lower haul:																
Larvae (0.0560)					1	3	1	1								
Large larvae					2	32	23	15	7	7						
Adjusted total					17	34	27	26	66	26	1					
Cape May II 21454:																
Upper haul:																
Eggs and larvae (0.0560)										1						
Adjusted total										2						
Cape May III 21455:																
Upper haul:																
Eggs and larvae (0.0560)							1				1			1	1	
Large larvae						2	8	12	1	10	4	11	3	2	3	1
Lower haul:[12]																
Large larvae									1	1	2	1		1		
Adjusted total						1	4	6	2	6	4	6	2	3	2	1
Cape May IV 21456:																
Upper haul:																
Eggs and larvae (0.0560)								1		1						
Large larvae						1	5	7	10	11	6	3	2	1		
Lower haul:																
Larvae (0.0560)											1					
Large larvae									1	3						
Adjusted total						1	5	8	10	16	8	3	2	1		
Grand adjusted total	2,815	1,161	1,562	9,214	8,236	2,371	501	399	470	186	41	12	4	4	2	1

See footnote at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE VII

Locality	Number of eggs by stages			Number of larvae by millimeter classes																			
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Martha's Vineyard I 21490:																							
Upper haul:																							
Eggs and larvae (0.0224)	31	48	44	192	1		1																
Large larvae					3	8	12	7	6	1													
Lower haul:																							
Larvae (0.0560)				12		1																	
Large larvae								2	2														
Adjusted total	583	901	827	3,135	15	11	4	3	3	1													
Martha's Vineyard II 21491:																							
Upper haul:																							
Eggs (0.0140) larvae (0.0560)			2	27	12	15	11	2															
Large larvae							10	20	6														
Lower haul:																							
Larvae (0.0747)				8	4	6	1	1															
Large larvae						1	2	3															
Adjusted total			100	361	164	214	122	27	3														
Montauk I 21489:																							
Upper haul:																							
Eggs and larvae (0.0200)	6	7	21	32	3	3																	
Large larvae					2	12	5	7	2														
Lower haul:																							
Larvae (0.0167)				36	7	3	1																
Large larvae					1	2	7	6	1														
Adjusted total	198	231	693	2,230	337	186	35	8	3														
Montauk II 21488:																							
Upper haul:																							
Eggs and larvae (0.0896)									2		1												
Large larvae							1	4	6	7	3	1	1										
Lower haul:																							
Larvae (0.1120)						1			1	2			1										
Large larvae						1	4		2	7	6	2	2										
Adjusted total						1	3	2	7	10	6	2	3										
Montauk III 21487:																							
Upper haul:																							
Eggs and larvae (0.0747)														1									
Large larvae										2	4	5	7	4	3				1				
Lower haul:																							
Larvae (0.0747)						1																	
Large larvae								2	1			1	3	1									
Adjusted total								1		1	2	3	5	3	2				1				
Shinnecock I 21485:																							
Upper haul:																							
Eggs and larvae (0.0267)		2	13	59	4	2																	
Large larvae				2	5	10	14	2															
Adjusted total		101	658	2,985	202	78	20	3															
Shinnecock II 21486:																							
Upper haul: [13]																							
Large larvae					1	3	3							1	6	2		2	5	3	1	1	1
Lower haul: [14]																							
Large larvae					2	2	1	1									2						
Adjusted total					3	5	4	1						1	5	2	2	2	4	3	1	1	1
New York I 21484:																							
Upper haul:																							
Eggs (0.0280) larvae (0.0560)	2	2	13	4																			
Large larvae								1															
Adjusted total	70	70	455	70				1															
New York II 21483:																							
Upper haul:																							
Eggs and larvae (0.1120)					2																		
Large larvae					4	6	3		1														
Lower haul:																							
Larvae (0.0747)							1																
Large larvae					1	1	2									1							
Adjusted total					7	7	6		1							1							

See footnote at end of table.

TABLE 19.—*Record of mackerel eggs and larvae caught during cruises I to VII in 1932*—Continued

CRUISE VII—Continued

Locality	Number of eggs by stages			Number of larvae by millimeter classes																					
	A	B	C	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
New York III 21482:																							
Upper haul:																							
Eggs and larvae (0.1667)													1	1									
Large larvae						1							1	4	1	1							
Lower haul:																							
Larvae (0.2500)					3	17	3																
Large larvae						2	6	1															
Adjusted total					6	38	5	1					1	2	1	1							
New York IV 21481:																							
Upper haul:																							
Eggs and larvae (0.2000)						2	1																
Large larvae						2	3	3			1												
Lower haul:																							
Larvae (0.0500)								1															
Large larvae							1	1															
Adjusted total						3	4	3			1												
Atlantic City I 21469:																							
Upper haul:																							
Eggs and larvae (0.0667)				2																			
Large larvae														1									
Adjusted total				24										1									
Atlantic City II 21477: [15]																							
Lower haul:																							
Large larvae [16]																		1					
Adjusted total																		1					
Atlantic City III 21478: [17]																							
Lower haul: [18]																							
Large larvae									1														
Adjusted total									1														
Atlantic City IV 21479: [19]																							
Upper haul:																							
Large larvae									1														
Adjusted total									1														
Cape May IV 21475:																							
Upper haul:																							
Large larvae [5]						1	2	2			1												
Lower haul:																							
Large larvae [1]										1						1							
Adjusted total [20]						3	5	5		1	3					1							
Grand adjusted total	851	1,303	2,733	8,805	734	546	208	55	19	13	12	5	9	7	8	5	2	3	5	3	1	1	1

NOTE.—The above given table does not include stations at which hauls were made and no eggs or larvae of mackerel found. All these hauls were completely sorted for large larvae, but only fractions for eggs and small larvae. In the following enumeration that includes all such stations, the fractions of hauls sorted are included in parentheses, and the letters U and L refer to upper and lower hauls, respectively. Unless otherwise specified, the fraction given for upper haul was sorted for both eggs and larvae, those of the lower haul for larvae only. Cruise I: Martha's Vineyard I 21327 (U 0.0187 for eggs) (0.0747 for larvae); Martha's Vineyard II 21328 (U 0.0747) (L 0.0747); Martha's Vineyard III 21329 (U 0.0747) (L 0.0560); Martha's Vineyard IV 21330 (U 0.0747) (L 0.0560); New York VI 21331 (U 0.1120) (L 0.0747); Cape May VI 21341 (U 0.0500); Chesapeake III 21350 (U 0.2500) (L 0.1000). Cruise II: Martha's Vineyard II 21380 (U 0.0373) (L 0.0560); Martha's Vineyard III 21379 (U 0.2800 for eggs) (0.0560 for larvae) (L 0.0323); Montauk III 21377 (U 0.0373) (L 0.0373); New York IV 21372 (U 0.0560) (L 0.0747). Cruise III: Martha's Vineyard II 21383 (U 0.0560) (L 0.0560); Martha's Vineyard III 21384 (U 0.0373) (L 0.0448); Montauk III 21385 (U 0.0560) (L 0.0448). Cruise V: Chesapeake I 21453 (U 0.0187 for eggs) (0.0373 for larvae); Chesapeake II 21452 (U 0.0560). Cruise VII: Martha's Vineyard III 21492 (U 0.0373) (L 0.0747); Martha's Vineyard IV 21493 (U 0.1120) (L 0.0896); Cape May II 21470 (U 0.0373); Cape May III 21476 (U 0.2000) (L 0.2000); Cape May V 21474 (U 1.0000) (L 1.0000); Winterquarter I 21471 (U 0.0373 for eggs) (0.0187 for larvae); Winterquarter II 21472 (U 0.0448 for eggs) (0.0224 for larvae) (L 0.0896).

1 No larvae found in 0.0560 of lower haul.
2 No larvae found in 0.0448 of lower haul.
3 No larvae found in 0.0373 of lower haul.
4 No larvae found in 0.0373 of upper haul.
5 No eggs or larvae found in 0.0747 of upper haul.
6 No eggs or larvae found in 0.0250 of upper haul.
7 No larvae found in 0.0320 of lower haul.
8 No eggs or larvae found in 0.0407 of upper haul.
9 No larvae found in 0.1120 of lower haul.
10 No eggs found in 0.0448 of upper haul or larvae in 0.0224 of upper haul.
11 No eggs or larvae found in 0.0747 of upper haul and no larvae in 0.0747 of lower haul.
12 No larvae found in 0.0280 of lower haul.
13 No eggs or larvae found in 0.1120 of upper haul.
14 No larvae found in 0.0747 of lower haul.
15 No eggs or larvae found in 0.1120 and no large larvae in entire upper haul.
16 No small larvae found in 0.1667 of lower haul.
17 No eggs or larvae found in 0.1000 of upper haul and no large larvae in entire upper haul.
18 No larvae found in 0.2000 of lower haul.
19 No eggs or larvae found in 0.1120 of upper haul, no larvae found in 0.1667 of lower haul, and no large larvae in entire lower haul.
20 Before applying the regular adjustments the count in the upper haul was multiplied by 4 to adjust for the accidental loss of ¾ (estimated) of the plankton.

TABLE 20.—*Record of mackerel larvae caught on cruises VIII and IX*

[Column A gives the actual count, Column B the standardized total. Sizes under 7 mm. in length have been omitted on account of their incomplete retention by the 2-meter stramin net used on this cruise]

CRUISE VIII, JUNE 26 TO JULY 1, 1932

Length in millimeters	Martha's Vineyard				Montauk		Shinnecock				New York									
	I (1283)		II (1282)		IV (1259)		I (1275)		II (1274)		I (1270)		II (1271)		III (1272)		V (1260)		VI (1261)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7	5	0.68					81	11.41			21	2.88	8	0.70			1	0.04		
8	6	.81					96	13.54			18	2.47	7	.62	1	0.07	1	.04		
9	4	.54	5	0.68			46	6.48			32	4.39	11	.97	2	.15				
10			1	.14			29	4.09			21	2.88	11	.97	6	.44	1	.04		
11			1	.14	2	0.27	9	1.27			8	1.10	25	2.20	3	.22	2	.09	1	0.08
12							8	1.13			2	.27	15	1.32	3	.22	2	.09		
13							1	.14	1	0.26			3	.26	1	.07				
14					1	.14							5	.44						
15							2	.28					1	.09						
16													1	.09			2	.09		
17																				
18													1	.09						
19							1	.14					1	.09						
20									1	.26										
21																				
22							1	.14												
Total	15	2.03	7	.96	3	.41	274	38.62	2	.52	102	13.99	89	7.84	16	1.17	9	.39	1	.08

Length in millimeters	Barnegat		Atlantic City								Cape May						Total	
	I (1269)		I (1262)		II (1263)		III (1264)		IV (1265)		II (1266)		III (1267)		IV (1268)			
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7	3	0.39	156	20.45													275	36.55
8	2	.26	87	11.40	1	0.25			2	0.54	1	0.12					222	30.12
9	2	.26	14	1.84			4	1.02	1	.27							121	16.60
10			4	.52			1	.25	1	.27							75	9.60
11					1	.25									2	0.16	54	5.78
12					1	.25	1	.25	1	.27							33	3.80
13															1	.08	7	.81
14					1	.25									3	.24	10	1.07
15													1	0.20	1	.08	5	.65
16													1	.20	1	.08	5	.46
17													1	.20			1	.20
18																	1	.09
19																	2	.23
20																	1	.26
21																		
22																	1	.14
Total	7	.91	261	31.21	4	1.00	6	1.52	5	1.35	1	.12	3	.60	8	.64	813	106.36

TABLE 20.—*Record of mackerel larvae caught on cruises VIII and IX*—Continued

CRUISE IX, JULY 16–24, 1932

Length in millimeters	Cape Ann		Boston		Cape Cod Bay		Chatham		Western Georges		South Channel		Martha's Vineyard				Montauk				Shinnecock		New York		Total	
	II (1319)		II (1318)		I (1316)		II (1328)		III (1308)		IV (1307)		I (1303)		II (1302)		I (1288)		II (1290)		I (1294)		II (1296)			
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7			8	2.26							1	0.21	10	1.10			5	0.50			96	4.80			120	8.87
8			13	3.67					1	0.68			10	1.10			2	.20			232	11.60			258	17.25
9			10	2.72					1	.68			10	1.10							74	3.70			95	8.20
10			7	1.97	1	0.11	2	0.51					5	.55							6	.30			21	3.44
11			3	.85									2	.22	3	0.77					1	.05			9	1.89
12			2	.56			2	.51					1	.11											5	1.18
13													1	.11											1	.11
14	1	0.11					1	.26																	2	.37
15							1	.26																	1	.26
16	1	.11							1	.68															2	.79
17																							1	0.12	1	.12
19	1	.11																							1	.11
20							1	.26																	1	.26
21							2	.51																	2	.51
22							1	.26																	1	.26
23							4	1.02							1	.26									5	1.28
24							1	.26																	1	.26
25							3	.77																	3	.77
26							3	.77											1	0.19					4	.96
27							5	1.28																	5	1.28
28							5	1.28																	5	1.28
30							1	.26																	1	.26
37							1	.26																	1	.26
51	1	.11																							1	.11
Total	4	.44	43	12.03	1	.11	33	8.47	3	2.04	1	.21	39	4.29	4	1.03	7	.70	1	.19	409	20.45	1	.12	546	50.08

NOTE.—In addition to the above, hauls which yielded no mackerel material were made during cruise VIII at New York IV on June 29, Montauk I, II, and III on June 30, and Martha's Vineyard III and IV on July 1; and during cruise IX at Montauk II and IV and Shinnecock II and III on July 17, at New York I, III, and IV on July 18, at New York V and Martha's Vineyard III and IV on July 19, at Nantucket Shoals I, II, and III on July 20, at South Channel II and Western Georges I and II on July 21, at South Channel I, Chatham I, Nanset I, Race Point I and Boston Light I on July 22, at Cape Anne I, Newburyport I, Boone Island I, and Cape Elizabeth I and II on July 23, at Boone Island II, Cape Anne III, and Race Point II on July 24, 1932.

SIZES OF YOUNGEST POST-PLANKTONIC MACKEREL

To afford comparison between the largest tow-netted mackerel and smallest sizes caught by other gear, there are given in table 21 the length frequencies of several samples selected for their pertinence to this subject. The measurements were taken to the nearest half centimeter on a straight line from the snout to the fork of the tail.

TABLE 21.—*Sizes of young mackerel in the earliest available samples of post-planktonic stages in 1926, 1927, and 1932*

[The sample of July 22, 1926, was taken by dip net in the boat basin at the Fisheries Biological Station at Woods Hole, Mass. The other samples of 1926 and those of 1927 were taken by dip net in pound nets in the vicinity of Woods Hole, Mass.; and the 1932 sample came from the commercial catch of a pound net in the vicinity of Montauk, N. Y.]

Length in millimeters	July 22, 1926	Aug. 4, 1926	Aug. 8, 1926	July 28, 1927	Aug. 3–4, 1927	Aug. 30, 1932
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
35	1					
40	8					
45	5			2		
50	5			1		
55	8					
60	7					
65	1				2	
70		1	1		6	
75		2	1		6	
80			1		3	
85		2			1	
90		1			5	
95			1		32	
100		1			96	
105					100	
110					30	
115					2	
145						1
150						1
155						10
160						5
165						6
170						3
Total	35	7	4	3	283	26

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UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

FISH AND WILDLIFE SERVICE
Ira N. Gabrielson, Director

Fishery Bulletin 39

FLUCTUATIONS IN ABUNDANCE OF RED SALMON, *Oncorhynchus nerka* (WALBAUM), OF THE KARLUK RIVER, ALASKA

By JOSEPH T. BARNABY

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ABSTRACT

Karluk River red salmon migrate to the ocean in their first to their fifth year. The majority migrate during their third or fourth year. They mature, and return to fresh water to spawn in their third to eighth year. The 5-year age group is dominant, with the 6-year age group next in importance. In the period from 1921 to 1936, the spawning escapements have fluctuated from 400,000 to 2,533,402 with an average escapement of 1,113,594. The fluctuations in the ratio of return to escapement have been considerable, and no correlation has been found to exist between escapement and return.

Certain adverse environmental conditions in the lake and tributary streams appear to have a deleteriou effect upon the young red salmon. Insufficient amounts of phosphorus and silica present in the lake waters is one such condition. This shortage of essential chemicals indirectly affects the production of zooplankton of the lake, and thus appears to indirectly affect the growth and survival of young salmon which depend upon zooplankton for food. A marked change is occurring in the percentage of fish of a given fresh-water history in the escapement, in relation to the percentage of fish of the same fresh-water history in the return. A higher percentage of fish spend 3 years in fresh water in the escapement than in the return, and a higher percentage of fish spend 4 years in fresh water in the return than in the escapement. Unless this relationship changes, the majority of salmon in the Karluk River runs will be fish that have spent 4 years in fresh water, whereas, formerly, the dominant age group was composed of fish that had spent 3 years in fresh water.

Seaward migration takes place during the last week of May and the first 2 weeks in June. The percentage of 4-year fingerlings decreased, and the percentage of 3-year fingerlings increased during the period of migration. Growth rate affects the time of migration, as the fastest growing individuals migrate first. Marking experiments at Karluk River have shown the amputation of the adipose and right, left, or both ventral fins to be better methods of marking than those which included the pectoral fins. The fresh-water mortality of Karluk River red salmon was found to be in excess of 99 percent. The average ocean mortality was 79 percent. The older and larger 4-year seaward migrants experienced a lower ocean mortality than the 3-year migrants; the average mortality of the former was 76 percent as compared to 83 percent for the younger age-group. Returns from marking experiments on the red salmon of Karluk River have been consistently greater than returns from similar experiments in other areas.

FLUCTUATIONS IN ABUNDANCE OF RED SALMON, *ONCORHYNCHUS NERKA* (WALBAUM), OF THE KARLUK RIVER, ALASKA

By Joseph T. Barnaby, A. M., *Aquatic Biologist, Division of Fishery Biology, Fish and Wildlife Service*

CONTENTS

INTRODUCTION

One of the major problems of the Federal Government on the Pacific coast is the conservation of the Alaska salmon resources which yield more than 280 million pounds of salmon to the commercial fisheries each year. In order to conserve these resources, so as to provide for an optimum yield each season, it has been found necessary to impose certain regulations on the fishing industry. These regulations aim primarily to provide an adequate escapement of the salmon to the streams each season so that they may reproduce and maintain the supply.[1]

Knowledge of fluctuations in the abundance of salmon populations provided the basis upon which the regulations were formulated. Since the commercial catch records gave insufficient and frequently unreliable information on the abundance of salmon, picket weirs were established in a number of important salmon rivers through which the fish were counted on their upstream migration to the spawning grounds. The count of the number of salmon migrating into a river, together with the record of the commercial catch in the locality of the river, furnished information

[1] Pacific salmon spend the early part of life in fresh water, the time spent there depending on the species and locality. They then migrate to the ocean and after a varying period of time return to fresh water to spawn. Fishery Bulletin 39. Approved for publication May 6, 1940.

on the magnitude of the total run during a particular season. It was soon evident, however, that information on the fluctuations in abundance was not sufficient. A knowledge of the causes of the fluctuations was both desirable and valuable in promulgating sound and adequate regulations.

The Karluk River on Kodiak Island, Alaska, was selected as an appropriate site for the study of the causal factors responsible for the yearly fluctuations in the abundance of a single population of red salmon, *Oncorhynchus nerka* (Walbaum). This river supports a commercial red-salmon fishery of considerable importance. The area in which the Karluk River red salmon are caught is confined to a readily delineated zone near the mouth of the river within which very few red salmon from other watersheds are taken, consequently the commercial catch can be determined quite accurately. The stream bed and water flow of the river are of such a nature that a counting weir for determining the number of salmon migrating upstream can be operated successfully throughout the season. Karluk Lake, the source of the river, and its tributaries are fairly accessible. Thus, this watershed fulfills admirably the requirements essential for a study of the biological background of the red salmon.

The White Act (43 Stat. 464–467; June 6, 1924) provided that there should be a 50 percent escapement of all salmon populations. Subsequent to the passage of that act, commercial fishing in the Karluk area has been so regulated that the catch of red salmon for a season has never exceeded the escapement. Unfortunately, this restriction of the commercial catch has not increased the size of the runs of red salmon in the river to the level of abundance that existed during the early years of the fishery. Factors other than the total number of salmon spawning in the river system each season have played an important role in the abundance of the runs. In this paper a statistical review is presented of the Karluk River red-salmon fishery from its inception in 1822 to 1936, together with a report on the major biological studies carried on to date.

STATISTICAL HISTORY OF THE FISHERY

Statistics of the catch of Karluk red salmon presented in this report are not always identical with those published by Gilbert and Rich (1927) but do agree for the years 1882 to 1920 with those given by Rich and Ball (1931) as these latter statistics are considered more reliable for this period. From 1921 to 1927, the statistics of the catch given herein are not identical with those presented by Rich and Ball, who include in their figures for the Karluk catch only those fish caught between Cape Karluk and Cape Uyak, although they mentioned that a large part of the fish caught to the northeast of Karluk in later years were Karluk fish. The development of the fishery between Cape Uyak and Uganik Bay resulted in the capture of a part of the Karluk run before it reached the mouth of the Karluk River. That fish caught as far north as Uganik Bay were chiefly derived from the Karluk run was shown by a tagging experiment (Rich and Morton 1929) carried on at West Point. The Karluk area, as defined in this report, includes all of the coast line between Cape Karluk and West Point on Kodiak Island.

TABLE 1.—*Catch of Karluk River red salmon from beginning of the canning industry in 1882 to 1936*

Year	Number of fish	Year	Number of fish	Year	Number of fish	Year	Number of fish
1882	58, 800	1896	2, 638, 976	1910	1, 492, 544	1924	890, 839
1883	188, 706	1897	2, 204, 425	1911	1, 723, 132	1925	1, 323, 302
1884	282, 184	1898	1, 534, 064	1912	1, 245, 275	1926	2, 386, 335
1885	468, 580	1899	1, 399, 117	1913	868, 422	1927	714, 790
1886	646, 100	1900	2, 594, 774	1914	540, 455	1928	1, 000, 774
1887	1, 004, 500	1901	3, 985, 177	1915	828, 429	1929	227, 399
1888	2, 781, 100	1902	2, 981, 112	1916	2, 343, 104	1930	167, 091
1889	3, 411, 730	1903	1, 319, 975	1917	2, 324, 492	1931	751, 889
1890	3, 148, 796	1904	1, 638, 949	1918	1, 094, 665	1932	674, 407
1891	3, 500, 588	1905	1, 787, 642	1919	1, 089, 809	1933	845, 423
1892	2, 852, 458	1906	3, 382, 913	1920	1, 368, 526	1934	919, 200
1893	2, 909, 508	1907	2, 929, 886	1921	1, 643, 119	1935	654, 817
1894	3, 349, 976	1908	1, 608, 418	1922	658, 159	1936	1, 077, 831
1895	2, 055, 984	1909	923, 501	1923	730, 170		

Table 1 gives the yearly catch of Karluk red salmon from the beginning of the commercial fishery in 1882 up to and including the season of 1936. There has been a marked decline in the abundance of the run of fish. The total runs (catch plus escapement) for the past 16 years (table 19) have averaged slightly over 2,000,000 fish per year, and the average yearly run for 12 of these years was less than 1,600,000 fish, whereas for the 7-year period, 1888 to 1894, inclusive, the catch alone averaged over 3,000,000 fish per year.

In table 2 are presented, for the period 1895 to 1921,[2] the coefficients of correlation[3] between the catches during the years of escapement and the catches 4, 5, and 6 years later, together with corresponding values of P.[4]

The values of P for 4-year and 6-year intervals are such that the coefficients of correlation cannot be considered statistically different from zero. The value of P for the 5-year interval is such that the coefficient of correlation can be considered statistically significant. It can be concluded from the fact that a statistically significant correlation of over 0.6 exists between the catches at 5-year intervals and that no statistically significant correlation exists between the catches at 4-year or 6-year intervals that the runs of Karluk red salmon from 1895 to 1921, inclusive, were composed largely of 5-year fish. Such a conclusion is verified by the age determinations based on examinations of scale samples taken during 1916, 1917, 1919, and 1921.

TABLE 2.—*Values of coefficients of correlation between catches during year of escapement and catches 4, 5, and 6 years later for the period 1895 to 1921, inclusive*

Yearly interval between catches	Number of pairs of catches correlated	r [1]	z [2]	t [3]	P [4]
4	23	0. 236	0. 241	1. 076	0. 2–0. 3
5	22	. 644	. 765	3. 341	. 01
6	21	. 375	. 394	1. 669	0. 1–0. 2

[1] Coefficient of correlation.
[2] Transformed coefficient of correlation.
[3] Ratio of z to the standard deviation of z.
[4] Probability that z is not different from zero.

[2] The data for the years 1895 to 1921 were used in this analysis as the fishing effort was fairly constant during this period.

[3] Where the relationship between two variables is found or assumed to be linear, the coefficient of correlation r measures the proportion of the variation in one variable which is associated with the second variable. As the number of pairs of observations are relatively small the method of analysis given by Fisher (1930, p. 163) was used.

[4] P is the probability that the value of the transformed coefficient of correlation z would have been obtained by chance, i. e., a value of P of 0.01 indicates that if the true value of z was 0.0 a value as large as the one obtained would occur only once in 100 random samples. The relationship between z and r is such that the values of P also indicate the statistical reliability of r.

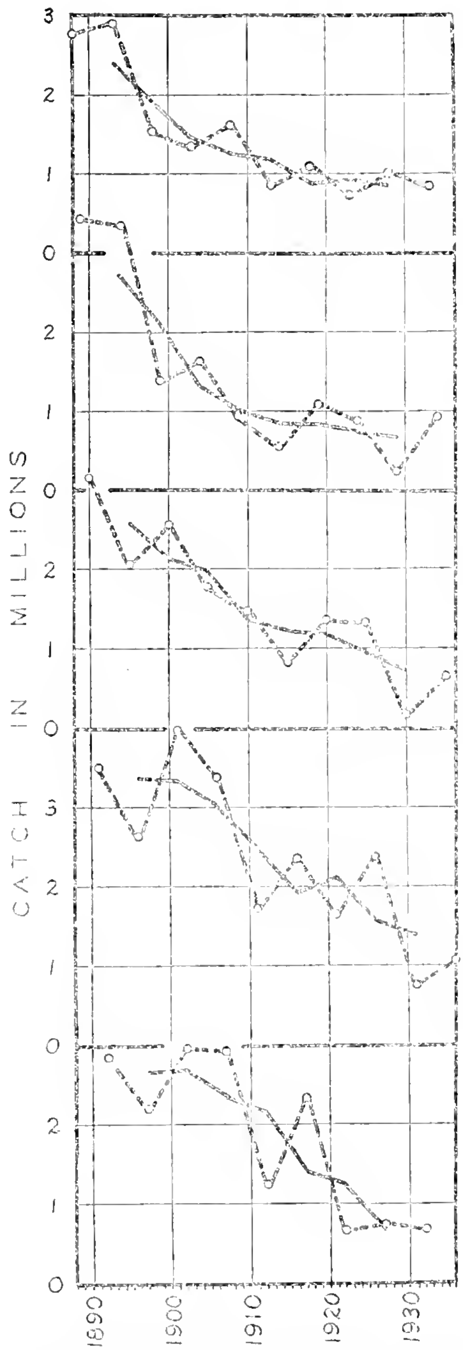

FIGURE 1.—Catch of red salmon at Karluk from 1888 to 1936, inclusive, arranged according to 5-year cycles. Solid line indicates trend.

It is evident from the statistical study of the catches of Karluk River red salmon and also from the analysis of the scale samples that the majority of the fish comprising the runs during the early years of the fishery were 5 years of age on attaining maturity. Therefore, the annual catches have been divided into five groups and the data are presented in figure 1. This method of presenting the data gives a clearer indication of the trend of catches from one cycle-year to another, as the catch of a particular year can be easily compared with the catch during a year 5 years previous to, or 5 years following that year. While these data represent the catches of red salmon, not the size of the runs for the various years, the nature of the fishing operations at Karluk from 1895 to 1921 was such that the fishing effort was fairly constant from year to year; hence the catches, in a measure, depict the relative size of the runs. The trend for each of the 5 cycles has been downward since the beginning of intensive fishing, and although such a condition might be due to a long period of unfavorable environmental conditions, it seems probably that overfishing must be largely responsible.

AGE AT MATURITY

One of the major problems involved in the study of the Karluk River red salmon is the determination of the approximate number of fish derived from each spawning population. This necessarily involves the determination of the approximate number of fish of each age group [5] found each year, but such a determination is by no means a simple matter. Karluk red salmon vary from 3 to 8 years in age, and the percentage occurrence of the various age groups changes throughout the season.

In addition to the wide spread in time of maturity of the Karluk River red salmon there is a further complication, in that fish of a given age have different combinations of fresh-water and ocean histories. Thus of the fish maturing in their fifth year, some migrate to the ocean in their second year, some in the third year, some in their fourth year, and some in their fifth year. These four groups of fish, with different fresh-water histories, may stay in the ocean 3, 2, 1, and 0 years (a few months), respectively, and all return in the fifth year as mature fish. This diversity in fresh-water and ocean history also occurs in the fish of other ages, so that 20 different age groups have been found in the samples collected for age determination, the complete list being as follows: 3_1, 3_2, 3_3, 4_1, 4_2, 4_3, 4_4, 5_2, 5_3, 5_4, 5_5, 6_2, 6_3, 6_4, 6_5, 7_3, 7_4, 7_5, 8_4, and 8_5.

The age of a fish may be determined with substantial accuracy by an examination of some of its scales under a microscope, but it is impossible to examine scales from every fish in the run. Recourse must be had to a process of sampling so that by the examination of the scales of a few thousand fish the age-group composition of the escapement and commercial catch can be calculated. Samples of scales are obtained for this purpose several times a week during each season from the fish caught in the seine fishery near the mouth of the river. It is fairly certain that the fish so caught are representative of the population of fish congregated near the mouth of the river

[5] The method, first used by Gilbert and Rich (1927), for designating the age of salmon is as follows: A fish resulting from an egg laid in the spawning gravels in 1930 and which migrated to the ocean in 1933 and returned to the river in 1935 is called a "five-three" and designated thus "5_3". Such a fish would have emerged from the gravels of the spawning beds in the spring of 1931 and would have spent two growing seasons, i. e., the summers of 1931 and 1932, in fresh water. In referring to its fresh-water history it is called a "three-fresh-water fish" because it migrated seaward in its third year. It would have spent two full growing seasons, i. e., 1933 and 1934, and part of a third year in the ocean; but in referring to its ocean history it is called a "two-ocean fish," because it returned as an adult in the second year following its seaward migration. A fish which migrated to the ocean in its fourth year and which returned in its sixth year is called a "six-four" and designated thus "6_4".

on the day of capture. Each scale sample contains scales from about 100 fish, these fish being taken at random from the day's catch. The scales are cleaned, mounted in sodium silicate between glass slides, examined under a microscope, and the age of the fish in the sample determined.

A preliminary study of the age-group composition of the various samples showed that the composition of the run changes throughout a season, and consequently it was found advisable to divide the season into a series of short successive periods of time. For the purpose of comparison these units of time should begin and end on the same dates each year, and so the scale samples, escapements, and runs have been grouped in 7-day periods which coincide from year to year.

Tables 3 to 16 give the age-group analyses of the several weekly samples taken in 1922, and in the years 1924 to 1936, inclusive. It will be seen from these tables that the age-group composition of the run changes considerably during the season, and also that the percentage occurrence of any one age group varies from year to year.

In considering the three principal age groups, 5_3, 6_3, and 6_4, it will be noted that 5_3 usually is the dominant age group present in the run. The percentage occurrence of the 6_3 age group always decreases as the season progresses, this age group never being important toward the end of the run. The percentage occurrence of the 6_4 age group generally increases as the season progresses. This age group, while seldom of importance in the early part of the season, usually is quite important in the latter part of the season.

The data included in tables 3 to 16 are of further value in that they are essential in calculating the percentage occurrence of the various age groups in the yearly escapements and in the returns from these escapements as given in tables 18 and 25, respectively. Since the salmon returning to Karluk each year from each of the previous spawning populations, or escapements, can be segregated according to age, the data in tables 3 to 16 are likewise essential in calculating the returns from known escapements. These returns are given in table 20.

TABLE 3.—*Percentage occurrence of each age group, during week, in the Karluk red-salmon run of 1922, determined by analyses of scale samples collected from a total of 2,469 fish*

Week ending—	Age groups											
	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_3	6_4	6_5	7_4
June 7	0.7				1.4	31.0			66.9			
June 14	.7	0.7			2.1	34.4			60.7	1.4		
June 21	.6	.7			.7	36.1	1.3		58.7	1.9		
June 28			2.2		1.3	32.3	.9		60.3	3.0		
July 5		.7				37.3	.7		56.0	5.3		
July 12						36.0	2.7		51.3	10.0		
July 19		.6	.6			62.0	.7		26.7	8.7		0.7
July 26		.6				76.0	.7		18.0	4.0		.7
Aug. 2						69.3			21.3	8.0	0.7	.7
Aug. 9		.7	1.3			72.0			16.6	8.7		.7
Aug. 16		.7	.7			87.2	.7		8.7	2.0		
Aug. 23		1.3				85.3	.7		6.7	6.0		
Aug. 30		1.4	.7			77.0	2.0		2.7	16.2		
Sept. 6		.7	.7	0.7		80.1	3.3		3.3	11.2		
Sept. 13		.6	2.7			91.1	2.1		1.4	2.1		
Sept. 20		2.0	2.7	1.4		87.8	2.0	0.7	1.4	2.0		

TABLE 4.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1924, determined by analyses of scale samples collected from a total of 5,132 fish*

Week ending—	Age groups										
	3_3	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_3	6_4	7_4
June 14			0.7	1.7		0.9	80.8	0.2	11.0	3.6	1.1
June 21			.6	2.2		.8	81.4	1.1	6.1	7.2	.6
June 28			.2	1.9		.2	84.3	.6	6.3	6.1	.4
July 5				5.0		.8	76.2	1.7	6.3	9.6	.4
July 12		0.2	.4	.4		1.1	75.3	.4	5.7	16.3	.2
July 19			.3			.1	73.1		5.7	19.9	.9
July 26			.9	.3			73.5	.2	4.8	19.7	.6
Aug. 2			.3	.6			77.6	.1	3.4	17.7	.3
Aug. 9				1.6		.3	71.0	.3	2.4	24.4	
Aug. 16				.9			81.0		.9	17.2	
Aug. 23			.3	4.2			75.8	4.7		15.0	
Aug. 30	0.2			2.9	0.7		77.3	2.2	1.0	15.7	
Sept. 6	.2			9.2	.4		63.3	15.1		11.8	
Sept. 13				6.9	2.8		66.1	13.2	.1	10.9	
Sept. 20				9.7	2.8		64.9	11.4	.9	10.3	

TABLE 5.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1925, determined by analyses of scale samples collected from a total of 5,513 fish*

Week ending—	Age groups										
	3_1	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_4
June 7			0.8	0.8		69.2		26.7	2.5		
June 21			.9	2.4	0.5	72.4		18.1	5.2		0.5
June 28			6.5	2.0	.2	69.1	0.2	13.9	7.7		.4
July 5		0.2	3.8	4.4		70.4	.8	10.5	9.0		.9
July 19	0.2	.2	3.3	1.2	1.0	69.6	.4	3.7	19.6		.8
July 26		1.1	1.5	.9		69.2	.2	1.5	25.2		.4
Aug. 2	2.0	.2	1.8	1.5	.1	72.7	.2	.7	20.7		.1
Aug. 9	.5		1.2	1.1	.2	75.1	.7	1.9	18.4		.9
Aug. 16	1.5	.3	1.3	3.9	.4	77.2	1.0	.6	13.0		.8
Aug. 23	.4	.3	.4	9.5	.2	70.7	1.6	.4	16.3		.2
Aug. 30			.3	10.2		69.3	2.8		17.4		
Sept. 13				10.6		52.1	7.6		29.5	0.2	

TABLE 6.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1926, determined by analyses of scale samples collected from a total of 8,172 fish*

Week ending—	Age groups													
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_4
May 24			4.8	0.8		4.8	77.6		9.6	1.6		0.8		
May 31			4.5	.6		1.3	79.0		12.0	2.1		.5		
June 7			4.4	.8		.4	83.2		8.0	2.8		.4		
June 21			3.9	.7		2.3	77.9		13.4	1.5		.3		
June 28			5.3	1.9		2.4	75.8	0.2	10.9	3.0		.5		
July 5		0.3	7.5			3.4	71.7		9.9	6.8		.4		
July 12		.2	5.9	.4		2.4	75.4		9.1	5.2		1.2		0.2
July 19	0.4	.9	3.8			7.7	69.2		8.3	8.4		1.3		
July 26	.9	1.3	2.4			2.0	74.5		4.5	12.1		2.0	0.3	
Aug. 2	.4	.4	.6	.2		.8	81.5		4.0	11.2		.9		
Aug. 9			.6	.2		.2	82.4		3.0	12.3		1.1	.2	
Aug. 16	.3	1.0	.3	.7		.3	81.9	.5	2.4	10.2		1.9	.5	
Aug. 23	.2	1.1	.3	.2	0.2		86.1	.3	1.0	9.7	0.2	.7		
Aug. 30	.4	.7	.2	.5			84.3	.5	.7	12.3		.4		
Sept. 6	.2	.2		.2			83.6	.2	.2	15.1			.3	
Sept. 13		.2	.3	.2			79.0	.8	.3	18.9	.1	.1	.1	
Sept. 20			2.0	1.0			79.6			16.4	1.0			

TABLE 7.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1927, determined by analyses of scale samples collected from a total of 4,963 fish.*

Week ending—	Age groups													
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_5
May 31				3.0		10.6	69.7	1.5	15.2					
June 7			0.4	.4		13.1	69.9		15.3			0.9		
June 14				.4		9.1	77.3		12.2	0.3		.7		
June 21				1.0		13.0	79.0		7.0					
June 28			.2	2.2		5.7	80.3	.4	10.8	.4				
July 5			.8	.6		9.4	73.8	.8	12.6	1.4		.6		
July 12			.8	.8		5.6	79.6	.3	11.2	1.5		.2		
July 19			1.5	1.0		4.5	76.5	1.0	9.5	6.0				
July 26				4.0		3.0	78.0	3.0		10.0		2.0		
Aug. 2				1.7		1.4	78.2	1.0	3.1	13.6		1.0		
Aug. 9				2.7		1.9	76.9	1.7	3.4	11.2		1.7	0.5	
Aug. 16		1.0	.2	4.4		1.4	69.9	3.6	4.8	12.7	0.2	1.0	.6	0.2
Aug. 23	0.2	1.0	.5	6.3		.5	66.0	2.8	2.5	20.0		.2		
Aug. 30		.2	.4	7.4		.6	58.1	8.4	.8	23.5		.6		
Sept. 13				6.7	0.4	.4	49.2	14.4	1.5	25.9	.4		1.1	

TABLE 8.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1928, determined by analyses of scale samples collected from a total of 4,247 fish.*

Week endiug—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_4	7_5
June 14		0.5			54.5		44.5	0.5		
June 21			1.0		60.0		36.0	3.0		
June 28		.8		0.3	44.8		51.6	2.5		
July 5		.5	.4		49.7		44.5	4.9		
July 12			.3		41.8		51.4	6.2	0.3	
July 19	0.3		.3	.7	48.3		35.0	13.0	2.4	
July 26		.5	.5	.5	66.3	0.3	18.2	12.4	1.3	
Aug. 2		1.3		.7	60.7		13.7	19.3	4.0	0.3
Aug. 9		.5			72.0		9.5	15.5	2.5	
Aug. 16			.3		76.7		6.0	16.3	.7	
Aug. 23		1.0			78.5	1.5	3.0	15.0	.5	.5
Sept. 6		.3	.5		64.5	1.2	3.5	29.8	.2	
Sept. 13		1.0	3.0		43.0	2.0	4.0	46.0	1.0	
Sept. 20			.3		42.3	2.0	2.7	51.3	.7	.7
Sept. 27			1.0		35.0	4.0	1.0	59.0		

TABLE 9.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1929, determined by analyses of scale samples collected from a total of 1,602 fish*

Week ending—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_3	7_4
June 21		2.0		2.0	39.9		50.2	3.3	1.3	1.3
June 28		.8	0.8	1.9	40.2	0.4	51.7	3.1		1.1
July 5					40.4		58.9	.7		
July 12		.7			42.4		54.1	2.8		
July 19				.8	35.3		57.2	4.2		2.5
July 26				.8	54.7	.8	31.0	11.9		.8
Aug. 2			6.9		61.4		9.9	19.8		2.0
Aug. 9	0.4		1.4		47.9	.9	16.3	31.2		1.9
Aug. 16		2.3			42.4		30.3	24.2		.8
Aug. 23					50.9		14.8	32.4		1.9
Aug. 30					26.7		6.7	66.6		
Sept. 6					19.6		3.4	75.8		
Sept. 13					12.5			85.0		2.5
Sept. 20					19.4	1.2		78.2		1.2
Sept. 27					26.2	2.4		71.4		

TABLE 10.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1930, determined by analyses of scale samples collected from a total of 3,617 fish*

Week ending—	Age groups									
	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_3	7_4	7_5
May 17		1.7	1.7	17.2		70.8	1.7		6.9	
June 14			1.3	51.9	1.3	33.9	10.3		1.3	
June 21		1.1	1.1	58.9	1.6	23.2	14.1			
June 28	0.5	1.2	3.4	51.2	4.3	29.2	9.7		.5	
July 26		.7		70.7	.8	13.1	13.9		.7	
Aug. 2		.6		76.4	2.3	8.2	11.7		.8	
Aug. 9		1.1	.5	79.2	1.6	10.1	5.7		1.8	
Aug. 16		1.5		73.6	2.0	4.6	14.2		4.1	
Aug. 23		2.3		62.0	3.3	1.9	27.9	0.3	2.3	
Aug. 30	.2	5.0	.2	49.5	10.0	4.1	30.0		1.0	
Sept. 13		10.6		36.9	32.5	.4	18.6		.7	0.3
Sept. 20		12.2		23.8	40.2	1.2	21.4		1.2	

TABLE 11.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1931, determined by analyses of scale samples collected from a total of 7,258 fish*

Week ending—	Age groups												
	3_1	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_3	7_4	7_5
May 31			1.4		0.7	48.6		12.6	34.2			2.5	
June 7			1.6	0.9	1.2	41.8	0.5	20.4	31.5	0.2		1.9	
June 14			4.4	1.3	.6	33.4		22.2	36.6			1.2	0.3
June 21			2.6	.3	1.1	37.5	.3	18.9	35.2		0.3	3.8	
June 28	0.2		1.9	1.4	.4	47.1	1.4	11.5	34.2			1.9	
July 5		0.5	9.9	.5		50.5	.5	8.0	29.2			.9	
July 12			2.5	.2	1.0	51.8	1.7	9.5	31.8			1.3	.2
July 19			1.4			60.3	.3	8.0	28.4			1.4	.2
July 26	.2		1.7	.5	.6	58.5	.3	7.6	29.3			1.1	.2
Aug. 2			.2	.4	.3	64.9	.2	4.9	28.6			.3	.2
Aug. 9			.3	.5	.3	68.7	.2	3.0	26.3			.6	.1
Aug. 16			.3	.6	.3	72.5	.3	1.2	23.9			.9	
Aug. 23						62.9	3.9	.6	32.3			.3	
Aug. 30				.2		56.7	1.8	1.2	40.1				
Sept. 6			.4	.6		43.0	4.1	.2	51.5			.2	
Sept. 13			.4		.9	35.7	9.0		52.9	.7		.4	
Sept. 20			.2	1.1		26.2	13.6		58.5	.4			
Sept. 27			.5	.5		37.0	9.0	.5	51.5	.5			.5

TABLE 12.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1932, determined by analyses of scale samples collected from a total of 4,700 fish*

Week ending—	Age groups									
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	7_4	7_5
May 24			1.0	1.0	73.0	1.0	6.0	7.0	11.0	
May 31		1.0			67.0		11.0	13.0	8.0	
June 7			2.0	1.0	75.0		7.0	8.0	7.0	
June 14		1.5		.5	82.0		4.0	7.5	4.5	
June 21		1.2		.8	78.4		3.6	11.2	4.8	
June 28		3.3	1.0	3.3	65.8	.3	8.7	12.3	5.3	
July 5		4.9	1.3	8.7	54.4	1.3	9.1	15.6	4.0	0.7
July 12		4.0	1.1	7.4	59.5	5.1	6.3	14.3	2.3	
July 19	0.5	2.0	.5	3.5	67.5	1.0	5.5	17.0	2.0	.5
July 26	1.3	1.3		4.7	72.7	.3	5.7	13.0	1.0	
Aug. 2	.2	1.8	.7	1.3	62.2	.4	9.3	21.6	1.6	.9
Aug. 9	.7	1.8	2.3	.5	43.4	1.3	9.0	38.5	1.8	.7
Aug. 16	.5	.2	.2	.5	30.3	1.8	6.0	59.0	.5	1.0
Aug. 23		.5	1.0		15.5	.5	3.5	77.5	.5	1.0
Aug. 30		.3	.5		16.6	1.4	2.6	76.9	.3	1.4
Sept. 20		1.2	.8		16.0	6.0	.8	73.6		1.6

TABLE 13.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1933, determined by analyses of scale samples collected from a total of 3,867 fish*

Week ending—	Age groups											
	4_1	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_3	7_4	7_5
June 7		0.5	0.3	1.3	65.3	0.2	21.3	9.8		0.2	1.1	
June 14	0.2	.3	.3	2.2	54.3	.3	29.6	11.8			1.0	
June 21	.2	1.1	.5	2.8	51.5	.6	26.3	15.7	0.2		.9	0.2
June 28		1.0		4.8	56.6		15.4	21.2			1.0	
July 5		.9	2.8	11.2	44.0	.9	23.4	14.0			2.8	
July 12		.5		4.2	51.1		18.6	22.8			1.9	.9
July 19			.7	1.4	55.6	.7	13.2	27.1			1.1	.2
July 26		.5		2.0	57.4		6.9	31.2			1.0	1.0
Aug. 30				.5	58.6	4.7	1.4	29.6			1.9	3.3
Sept. 6		.7			42.7	2.8		51.7			.7	1.4
Sept. 13			1.2		22.0	4.0	1.0	68.0			.5	3.3
Sept. 20			.5		23.0	1.5	1.5	65.5			2.0	6.0

TABLE 14.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1934, determined by analyses of scale samples collected from a total of 6,551 fish*

Week ending—	Age groups										
	4_2	4_3	5_2	5_3	5_4	6_3	6_4	6_5	7_4	7_5	8_5
May 24	1.3			39.5		47.4	11.8				
May 31			2.9	47.2	2.9	38.2	5.9		2.9		
June 7	.6	0.4	3.2	25.4	.2	53.6	11.4		5.2		
June 14	.8	.3	2.4	27.9	.3	54.3	10.2		3.6		0.2
June 21	.5	.2	1.2	26.0	.5	62.8	6.0		2.6	0.2	
June 28	.5		.7	31.5	.7	48.8	14.7		3.1		
July 5	28.6		3.7	18.8		36.4	8.4		3.9	.2	
July 12	23.9		3.3	23.5		29.4	15.8		4.1		
July 19	5.5		.7	31.4		35.8	23.3		3.3		
July 26	1.5		.7	30.8		27.5	37.2		2.1	.2	
Aug. 2	1.8		.8	36.4	.3	22.4	35.8		2.3	.2	
Aug. 9	1.2			37.3	.4	16.4	42.9		1.8		
Aug. 16	.4			33.7	.8	8.6	54.9		1.6		
Aug. 23				40.3		6.1	52.1		1.5		
Sept. 13		0.4		25.2	1.4	3.2	67.6	0.4	1.4	.4	
Sept. 20				30.2	2.0	3.6	63.8			.4	

TABLE 15.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1935, determined by analyses of scale samples collected from a total of 7,152 fish*

Week ending—	Age groups															
	3_2	4_1	4_2	4_3	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
June 7			4.6	1.0	4.1	20.2	1.7	0.5	40.2	15.1		0.2	12.0	0.2	0.2	
June 14			3.2	1.6	1.8	36.5	1.2		28.2	15.8	0.1	.5	10.7	.3		
June 21			9.0	1.9	3.3	33.2	1.4	.1	21.2	16.0		.2	10.2	.4		0.1
June 28			16.0	6.6	5.8	29.7	2.7		19.3	13.5			6.4	.2		
July 5	0.1		11.5	4.2	7.5	30.7	2.2		20.5	13.6			9.6	.1		
July 12		1.4	3.7	5.1	6.0	35.8	3.7		24.7	11.6	.5		7.0	.5		
July 19		2.4	8.2	.6	9.5	46.3	.6		12.6	15.6	.2		3.4	.6		
July 26		.8	4.7	1.2	4.6	59.2	.7		9.0	17.7			1.6	.3		.1
Aug. 2		.5	1.5	2.1	1.1	55.4	1.5		8.3	25.5	.2		3.2	.6		
Aug. 9			1.7	3.3	.8	54.1	1.7		4.2	31.7			2.5			
Aug. 23		.4	.7	16.6	.2	21.4	3.9		3.0	47.3			.1	2.4		
Aug. 30				16.7		19.2	6.7		.8	54.2	.8		.8	.8		
Sept. 20				8.0		28.0	8.0			44.0				12.0		
Oct. 2						3.0	19.0		3.0	69.0	3.0			3.0		

TABLE 16.—*Percentage occurrence of each age group, during each week, in the Karluk red-salmon run of 1936, determined by analyses of scale samples collected from a total of 7,093 fish*

Week ending—	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
June 7			0.8	2.8		4.9	62.0	0.1		13.4	10.6		0.1	4.9	0.3	0.1	
June 14			2.5	3.8		5.0	58.8	.4	0.1	13.9	11.2		.1	3.7	.4		0.1
June 21			1.5	2.5		7.6	65.6	.4		10.9	8.5			2.7	.4		
June 28			.5	2.7		6.7	66.3	.5		11.5	8.6		.3	2.4	.5		
July 5			1.2	4.9		1.2	64.7	1.2		14.6	3.7		1.2	6.1		1.2	
July 12			4.3	3.6		27.7	49.5	.2	.5	9.7	2.8			1.5			.2
July 19		0.1	2.2	2.1		5.3	57.4	.3		16.6	11.0			4.9	.1		
July 26	0.1	.3	2.0	.7		4.4	75.1		.1	6.8	8.5			1.5	.5		
Aug. 2				.7			82.3	.3		6.8	8.0			1.3	.6		
Aug. 30				.2			75.3	5.6		1.8	14.2			1.6	1.3		
Sept. 6							72.2	7.4		1.9	15.8			1.8	.9		
Sept. 13				1.1	0.5	.3	64.3	6.4		.6	22.3			.3	4.2		
Sept. 20				.6		.6	71.2	1.3		3.2	21.2			1.3	.6		
Sept. 27				.9			61.5	5.6		1.5	22.8	0.3		1.2	6.2		
Oct. 4				1.4			60.6	2.8		1.4	29.6			1.4	2.8		

SPAWNING POPULATIONS

The determination of the size of the escapement, or spawning population, of a river or district is of vital importance in intelligently administering the fishery. In a self-perpetuating salmon population an adequate part of the yearly run must be allowed to escape the fishery and continue uninterrupted to the spawning grounds in order to insure future supplies of fish. Not only must a proper number of fish be allowed to escape in a given area or district, but each individual salmon stream, and in large watersheds, each small area in the watershed, must receive a sufficient escapement if adequate runs of fish are to be maintained. Under natural conditions, an extremely high percentage of the fish returning to spawn proceed to the same area where they emerged from the spawning gravel as fry. There is a slight degree of straying, but the fact remains that if a spawning area has not been seeded, there will not be a run of fish returning to that area in one or more subsequent years. Thus, large river systems such as the Kvichak, Copper, Fraser, Columbia, and others, must not only receive an escapement sufficient in number, but the fish must be distributed in the proper proportions to the various tributaries in the river system. If a part of the spawning area in a given watershed be depopulated for a period of time, the chief hope of restoring the productivity of that watershed to its maximum value would be to restock the depleted area by the planting of eggs or fry for a period of several consecutive years, an expensive undertaking which would have no positive assurance of success.

The determination of the magnitude of the escapement of Karluk River red salmon is important not only in regulating the commercial fishery, but is also another of the major problems involved in the biological study of this population. The calculation of the total size of populations, the returns from known spawning populations, the mortality in fresh water, and the mortality in the ocean are based upon a knowledge of the number of fish entering the river each season to spawn.

Table 17 gives the weekly escapements of red salmon to the Karluk River for the years 1921 to 1936, inclusive. The escapement records are complete except for 1921, 1922, 1924, and 1934. In 1921, the first year the weir was operated, it was removed on September 18, as the companies fishing in the Karluk area were about to discontinue canning, and the importance of keeping the weir in to the end of the season was not appreciated. The counted escapement was 1,325,654 and Gilbert and Rich (1927) estimated that the total escapement that year was approximately 1,500,000 red salmon.

TABLE 17.—*Escapements and cumulative totals of the escapements of Karluk red salmon for each week from 1921 to 1936*

Week ending—	1921		1922		1923		1924		1925	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24			60		141		402		19	
May 31	5, 894	6	418		1, 102	1	4, 149	5	30, 249	30
June 7	16, 254	22	9, 921	10	71, 724	73	86, 111	91	32, 733	63
June 14	155, 097	177	8, 355	19	28, 843	102	148, 417	239	20, 440	83
June 21	137, 334	315	56, 739	75	42, 169	144	127, 645	367	263, 029	346
June 28	195, 151	510	29, 897	105	62, 954	207	64, 913	432	211, 021	557
July 5	74, 291	584	46, 770	152	35, 647	243	57, 674	489	34, 298	592
July 12	72, 556	657	24, 336	177	9, 274	252	39, 837	529	39, 927	632
July 19	28, 668	685	19, 660	196	3, 497	255	10, 882	540	25, 447	657
July 26	19, 737	705	6, 877	203	31, 491	287	25, 659	566	24, 482	682
Aug. 2	70, 954	776	8, 035	211	24, 691	312	57, 894	624	64, 752	746
Aug. 9	96, 677	873	19, 403	231	66, 404	380	36, 263	660	110, 570	857
Aug. 16	114, 102	987	7, 919	238	13, 036	391	61, 502	721	95, 862	953
Aug. 23	58, 867	1, 046	5, 595	244	48, 610	440	54, 357	776	19, 705	973
Aug. 30	79, 316	1, 125	(2)		38, 467	478	(1)		33, 797	1, 006
Sept. 6	42, 974	1, 168	(2)		27, 919	506			200, 247	1, 207
Sept. 13	143, 022	1, 311	24, 343	285	61, 389	567			74, 730	1, 281
Sept. 20	14, 760	1, 326	35, 618	321	43, 217	611			100, 431	1, 382
Sept. 27	(1)		61	321	10, 570	621			51, 814	1, 443
Oct. 4			15, 721	336	62, 641	684			182, 763	1, 616
Oct. 11			29, 116	365	9, 110	693			4, 619	1, 621
Oct. 18			34, 336	400	1, 683	695				
Oct. 25			236	400						
Total	[3] 1, 500, 000		[3] 400, 000		694, 576		[3] 1, 109, 161		1, 620, 927	

Week ending—	1926		1927		1928		1929		1930	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24	577	1			41		22		1, 008	1
May 31	80, 704	81	9, 539	10	13, 600	14	838	1	1, 128	2
June 7	479, 455	561	52, 532	62	152, 569	166	75, 305	76	42, 352	44
June 14	437, 051	998	209, 213	271	303, 976	470	85, 347	162	21, 808	66
June 21	127, 537	1, 125	188, 798	460	97, 503	568	116, 624	278	228, 405	295
June 28	45, 520	1, 171	85, 010	545	75, 234	643	50, 171	328	35, 018	330
July 5	41 516	1, 212	51, 492	597	55, 817	699	12, 228	341	22, 427	352
July 12	43, 339	1, 256	13, 965	611	36, 723	735	10, 376	351	10, 064	362
July 19	34, 277	1, 290	7, 064	618	20, 048	756	9, 656	361	6, 901	371
July 26	30, 300	1, 320	2, 926	621	21, 781	777	1, 125	362	4, 706	376
Aug. 2	77, 956	1, 398	12, 454	633	3, 514	781	21, 241	383	42, 939	419
Aug. 9	101, 703	1, 500	53, 219	686	22, 734	804	24, 725	408	82, 949	542
Aug. 16	80, 647	1, 581	19, 461	706	31, 255	835	27, 343	435	62, 714	564
Aug. 23	104, 139	1, 685	7, 421	713	71, 015	906	69, 210	504	98, 491	663
Aug. 30	224, 592	1, 909	8, 456	722	67, 857	971	69, 552	574	6, 162	669
Sept. 6	230, 498	2, 140	15, 392	737	19, 966	994	35, 960	610	118, 970	788
Sept. 13	91, 136	2, 231	10, 007	747	22, 591	1, 016	109, 916	720	65, 392	853
Sept. 20	176, 939	2, 408	43, 245	790	14, 929	1, 031	93, 918	814	60, 590	914
Sept. 27	49, 609	2, 457	1, 294	791	7, 471	1, 039	13, 950	828	135, 468	1, 049
Oct. 4	9, 448	2, 467	72, 559	864	167	1, 039	72, 667	900	1, 488	1, 051
Oct. 11	43, 314	2, 510	8, 491	873	45, 952	1, 085	145	900	45, 531	1, 097
Oct. 18	23, 145	2, 533			9, 074	1, 094				
Oct. 25										
Total	2, 533, 402		872, 538		1, 093, 817		900, 319		1, 096, 511	

See footnotes at end of table.

TABLE 17.—*Escapements and cumulative totals of the escapements of Karluk red salmon for each week from 1912 to 1936*—Continued

Week ending—	1931		1932		1933		1934		1935		1936	
	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands	Escapement for week	Cumulative total, thousands
May 24	1,250	1	34	....	283	....	878	1	7	....	32	....
May 31	11,342	13	1,087	1	2,101	2	1,631	3	22,999	23	38,560	39
June 7	50,382	63	48,191	49	24,581	27	201,544	204	138,867	162	144,208	183
June 14	109,047	172	150,058	199	204,014	231	169,718	374	172,726	335	93,157	276
June 21	34,594	207	55,616	255	84,840	316	233,626	607	64,249	399	82,700	359
June 28	38,913	246	66,583	322	65,221	381	118,167	726	31,440	430	79,290	438
July 5	29,930	275	26,695	348	46,621	428	20,870	746	3,812	434	57,411	495
July 12	9,117	285	11,803	360	61,665	489	6,748	753	3,108	437	11,378	507
July 19	3,167	288	5,903	365	23,519	513	6,325	760	374	438	3,825	511
July 26	1,756	289	6,305	372	5,923	519	5,431	765	3,723	441	11,042	522
Aug. 2	6,191	296	10,878	383	16,454	535	3,196	768	2,836	444	2,201	524
Aug. 9	12,541	308	14,963	398	40,509	576	23,341	791	32,513	477	1,087	525
Aug. 16	54,209	362	23,403	422	5,126	581	3,943	795	30,983	508	34,950	560
Aug. 23	75,989	438	8,877	430	49,972	631	[4] 5,847	....	52,513	560	44,451	604
Aug. 30	106,362	545	12,541	443	100,890	732	(2)	....	10,571	580	130,582	735
Sept. 6	89,360	634	28,062	471	14,218	746	(2)	....	12,631	592	311,917	1,047
Sept. 13	121,464	756	1,778	473	145,879	802	(2)	....	151,051	743	204,980	1,252
Sept. 20	115	756	87,785	561	31,468	923	[4] 1,319	1,103	353	744	27,749	1,280
Sept. 27	64,601	820	120,082	681	1,885	925	43,072	1,146	115,249	859	81,156	1,361
Oct. 4	41,671	862	47,078	728	4,056	929	626	1,146	17,319	876	14,622	1,375
Oct. 11	11,427	873	10,050	738	57,540	987	17	1,146	11	876	361	1,376
Oct. 18	....	....	....	....	....	....	....	....	....	....	....	....
Oct. 25	....	....	....	....	....	....	....	....	....	....	....	....
Total	873,428	....	737,772	....	986,765	....	[3] 1,146,299	....	876,335	....	1,375,659	....

[1] Escapement to end of season estimated; see text.
[2] Escapement for these periods estimated; see text.
[3] Estimated; see text.
[4] Escapement for only a part of these weeks; see text.

In 1922, there was a large escapement of pink salmon in the Karluk River, and toward the end of their spawning season the carcasses of the fish that had finished spawning and died began drifting down stream against the weir. Although a crew was engaged in removing the dead fish from the face of the weir, it finally became impossible to remove them as fast as they accumulated. As the fish piled up against the weir, they obstructed the passage of water until there was danger of the weir collapsing from the weight of the impounded water, and consequently, a number of pickets were removed from the weir so as to allow the pink salmon carcasses to pass downstream. The weir was not in use from August 21 to September 4, inclusive. It was replaced on September 5, and the counting of fish was continued until the end of the season. The counted escapement was 383,446, and it is estimated that the total escapement that year was approximately 400,000 red salmon.

In 1924, there was a tremendous run of pink salmon to the Karluk River and, as in 1922, it was impossible to keep the weir in operation due to the dead pink salmon drifting down against it. The weir was not replaced that season, so that it is necessary to estimate the escapement from August 21 to the end of the season. The counted and partially estimated escapement was 775,705. Gilbert and Rich (1927) estimated that the total run that year was approximately 2,000,000 fish. Subtracting the catch from this figure leaves about 1,100,000 as the number of red salmon in the escapement.

In 1934, it was again impossible to keep the weir in continuous operation due to spawned-out pink salmon damming the weir and to extremely high water in the river caused by the run-off of heavy fall rains. The weir was out from August 22 to September 17, inclusive, a period of 27 days. It was replaced on September 18, and counting was continued until the end of the season. Unfortunately, fishing for that season stopped on August 18, and catch data are not available from which to judge the relative abundance of fish in the run. Data on the trend of abundance of the various age groups in the run up to August 18 have been examined and compared with data for previous years, and from this analysis it is estimated that the escapement during the period was approximately 300,000 red salmon. The counted escapement during the period the weir was in operation was 846,299.

The weir is located approximately 4 miles from the mouth of the river and in this 4-mile stretch the river widens out to form a lagoon, the lower end of which is usually slightly brackish. The fish, after entering the mouth of the river, stay in this lagoon for a varying period of time, averaging about 1 week, before they proceed up the river through the weir. Consequently, in calculating the age-group composition of the escapement, the percentages of the various age groups in one 7-day period, as determined by an analysis of the scale samples, (tables 3 to 16) were applied to the escapement of the following 7-day period.

The percentage occurences of the various age groups in the spring, fall, and total escapements for the years 1922 and 1924 to 1936, inclusive, are presented in table 18. There was a considerable fluctuation in the percentage occurrence of the principal age groups in the escapement from year to year. The percentage of the three principal age groups in the total escapements ranged from 24.1 to 81.1 for the 5_3 group; 4.0 to 38.6 for the 6_4 group; and from 4.5 to 32.8 for the 6_3 group.

This variation in the age composition of the escapements was due mainly to the fact that each year's escapement is composed of returns from several brood years. For example, a single escapement may be composed of 5-year fish from a brood year producing a small run, together with 6-year fish from a brood year producing a large run. In this instance the percentage of 5-year fish would be below average, and the percentage of 6-year fish would be above average. However, if the 5-year fish were from a very productive brood year and the 6-year fish were from a less productive brood year, the results would be just the reverse.

TABLE 18.—*Percentage occurrence of the various age groups in the spring, fall, and total escapements of 1922, and of 1924 to 1936, inclusive*

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_5
1922:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Spring		0.4	0.4	0.5		1.2	34.3	0.8			59.3	3.1					
Fall			1.2	1.7	0.6		83.2	1.7	0.3		6.1	5.0	0.1		0.1		
Escapement for year		.2	.8	1.1	.3	.6	59.3	1.3	.1		32.2	4.0			.1		
1924:																	
Spring			.6	2.0		.8	80.8	.5			9.4	5.0			.9		
Fall			.2	4.3	.8		71.7	5.7			1.5	15.7			.1		
Escapement for year			.4	3.2	.4	.4	76.0	3.2			5.4	10.5			.5		
1925:																	
Spring			1.4	2.0		.3	71.0	.1			19.8	5.0			.4		
Fall	0.3	.1	.6	7.4		.1	63.8	3.8			.5	23.1	.1		.2		
Escapement for year	.2		.9	5.2		.2	66.8	2.3			8.3	15.8			.3		
1926:																	
Spring			4.6	.7		1.4	80.0				10.2	2.6			.5		
Fall	.2	.6	.6	.3		.4	81.8	.4			1.6	13.2	.1		.7	0.1	
Escapement for year	.1	.3	2.6	.5		.9	81.1	.2			6.0	7.6			.6	.1	
1927:																	
Spring			.2	.9		10.8	74.5	.2			12.7	.2			.5		
Fall		.1	.1	5.1	.2	.9	61.0	8.8			2.1	20.4	.2		.5	.6	
Escapement for year			.1	2.1		7.9	70.8	2.7			9.6	6.1			.5	.2	

TABLE 18.—*Percentage occurrence of the various age groups in the spring, fall, and total escapements of 1922, and of 1924 to 1936, inclusive*—Continued

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	5_5	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1928:																	
Spring	----	----	.5	.1	----	----	53.7		----	----	44.4	1.3	----	----	----	----	----
Fall	----	----	.4	.4	----	.1	63.5	1.3	----	----	6.9	26.2	----	----	1.0	.2	----
Escapement for year	----	----	.4	.2	----	----	56.9	.4	----	----	32.8	9.0	----	----	.3	----	----
1929:																	
Spring	----	----	1.9	----	----	1.9	40.0	----	----	----	50.6	3.2	----	1.2	1.2	----	----
Fall	----	----	.4	.3	----	----	31.5	.4	----	----	9.5	56.6	----	----	1.3	----	----
Escapement for year	----	----	1.0	.2	----	.8	34.8	.3	----	----	26.0	35.1	----	.5	----	1.3	----
1930:																	
Spring	----	----	----	.4	----	1.4	51.1	1.6	----	----	33.9	10.2	----	----	1.4	----	----
Fall	----	----	----	5.9	----	.1	51.7	17.2	----	----	4.6	18.9	----	----	1.5	.1	----
Escapement for year	----	----	----	4.0	----	.6	51.5	11.9	----	----	14.5	16.0	----	----	1.5	----	----
1931:																	
Spring	----	----	2.3	.7	----	.9	42.7	.4	----	----	17.3	33.4	.1	----	2.2	----	----
Fall	----	----	.2	.5	----	.1	53.2	4.2	----	----	1.0	40.3	.1	----	.3	.1	----
Escapement for year	----	----	.9	.5	----	.3	49.8	3.0	----	----	6.4	38.1	.1	----	.9	----	----
1932:																	
Spring	----	----	1.1	1.0	----	1.3	74.0	.1	----	----	6.6	9.8	----	----	6.1	----	----
Fall	----	.1	1.1	.8	----	.3	22.6	4.0	----	----	2.4	67.0	----	----	.3	1.4	----
Escapement for year	----	----	1.0	.9	----	.8	48.2	2.1	----	----	4.5	38.6	----	----	3.2	.7	----
1933:																	
Spring	----	.1	.6	.6	----	3.3	57.7	.3	----	----	22.9	13.0	----	.1	1.3	.1	----
Fall	----	----	.3	.2	----	.6	46.2	2.5	----	----	2.4	44.1	----	----	1.2	2.5	----
Escapement for year	----	----	.5	.4	----	2.0	52.3	1.3	----	----	13.1	27.9	----	----	1.3	1.2	----
1934:																	
Spring	----	----	.9	.2	----	2.5	32.2	1.0	----	----	50.6	8.8	----	----	3.6	.1	0.1
Fall	----	----	.2	.2	----	.1	31.7	.9	----	----	6.2	58.9	.2	----	1.4	.2	.2
Escapement for year	----	----	.7	.2	----	1.7	32.0	1.0	----	----	35.7	25.7	----	----	2.9	.1	----
1935:																	
Spring	----	----	4.8	1.2	----	3.7	23.7	1.6	----	0.4	36.9	15.3	----	.3	11.6	.3	----
Fall	----	.1	.5	7.3	----	.4	24.5	9.1	----	----	2.6	50.1	.9	----	.9	3.6	----
Escapement for year	----	.1	2.7	4.2	----	2.0	24.1	5.4	----	.2	19.7	32.8	.5	.1	6.2	1.9	.1
1936:																	
Spring	----	----	1.2	3.0	----	5.6	62.5	.3	----	----	12.9	9.9	----	.2	4.0	.3	.1
Fall	----	----	----	.3	----	.1	71.3	5.0	----	----	2.3	15.0	----	----	1.6	1.4	----
Escapement for year	----	----	.5	1.3	----	2.2	69.9	3.2	----	----	6.2	13.1	----	.1	2.5	1.0	----

The time of the season during which commercial fishing takes its toll also has an effect on the age composition of the escapement due to the fact that the age composition of the fish in a season's run is not constant but varies from week to week. If the commercial catch does not take a constant proportion of each week's run of fish, the age composition of the escapement is very apt to be different from that of the run of fish from which it resulted. Except in instances where an abnormal condition indicates the advisability of giving special protection to a certain part of a run, it is considered preferable to have the commercial catch so regulated that it constitutes the same percentage of the run from week to week throughout the season. When the catch is regulated in such a manner, the age composition of the escapement for a season will closely approximate the age composition of the run from which it is derived.

The escapement data presented in table 17 are used during each season in the regulation of the fishery, and in addition are also used in the study of the number of fish returning from known escapements, a subject discussed in a later section of this publication.

The data presented in table 18 are used together with data presented in table 25 in the study of the change in the age composition of the runs. This subject also is discussed later.

TOTAL POPULATIONS

As the commercial catch of Karluk River red salmon can be ascertained from the records maintained by canneries operating in the Karluk area, and as the escapement can be determined by counting the fish passing upstream through the weir, it is possible to determine the number of fish in the total population or run. In determining the run of a 7-day period the catch of that period has been added to the escapement of the following 7-day period because of the aforementioned lag between the time the fish enter the river and the time they go through the weir. The weekly cumulative totals of the runs for the years 1921 to 1936, inclusive, are presented in table 19.

TABLE 19.—*Cumulative totals of the runs of Karluk red salmon for each week from 1921 to 1936, and percentage of the total run that had cumulated to the end of each week*

[Run based on catch plus escapement of following week, as explained in the text]

Week ending—	1921		1922		1923		1924		1925		1926	
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run
May 24	6	0.2			1	0.1	5	0.2	30	1.0	81	1.6
May 31	22	.7	10	0.9	73	5.1	91	4.6	63	2.1	561	11.4
June 7	177	5.6	23	2.2	102	7.2	257	12.8	83	2.8	998	20.1
June 14	315	10.0	96	9.1	212	14.9	427	21.4	346	11.8	1,125	22.9
June 21	545	17.3	145	13.7	348	24.4	548	27.4	599	20.3	1,406	28.6
June 28	770	24.5	228	21.6	423	29.7	637	31.8	713	24.2	1,561	31.7
July 5	881	28.0	264	25.0	448	31.4	703	35.2	789	26.8	1,619	32.9
July 12	976	31.1	303	28.7	490	34.4	772	38.6	824	28.0	1,715	34.9
July 19	1,134	36.1	345	32.6	554	38.9	862	43.1	875	29.7	1,872	38.0
July 26	1,395	44.4	394	37.3	662	46.5	955	47.8	1,006	34.2	2,100	42.7
Aug. 2	1,636	52.1	452	42.7	791	55.5	1,027	51.4	1,391	47.2	2,415	49.1
Aug. 9	1,871	59.5	502	47.5	854	59.9	1,123	56.2	1,661	56.4	2,753	56.0
Aug. 16	2,066	65.7	561	53.1	961	67.4	1,211	60.6	1,829	62.1	3,010	61.2
Aug. 23	2,342	74.5	637	60.2	1,022	71.7	1,375	68.8	2,011	68.3	3,530	71.7
Aug. 30	2,530	80.5	704	66.6	1,105	77.5	(1)		2,291	77.8	3,894	81.2
Sept. 6	2,809	89.4	833	78.8	1,260	88.4			2,367	80.4	4,348	88.4
Sept. 13	2,913	92.7	956	90.4	1,331	93.4			2,705	91.9	4,783	97.2
Sept. 20	(1)		978	92.5	1,351	94.8			2,757	93.6	4,844	98.5
Sept. 27			994	94.0	1,414	99.2			2,940	99.9	4,853	98.6
Oct. 4			1,024	96.8	1,423	99.9	2,000	100.0	2,944	100.0	4,897	99.5
Oct. 11			1,058	100.0	1,425	100.0					4,920	100.0
Oct. 18	3,143	100.0	1,058	100.0								

Week ending—	1927		1928		1929		1930		1931	
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run
May 24	10	0.6	14	0.7	1	0.1	2	0.2	13	0.8
May 31	62	3.9	166	7.9	76	6.7	44	3.5	63	3.9
June 7	271	17.1	470	22.4	162	14.4	66	5.3	177	10.9
June 14	460	29.0	653	31.2	282	25.0	295	23.5	274	16.9
June 21	579	36.5	753	35.9	386	34.2	331	26.4	352	21.7
June 28	680	42.8	869	41.5	415	36.8	412	32.9	421	25.9
July 5	757	47.7	934	44.6	445	39.5	432	34.4	444	27.3
July 12	798	50.3	1,000	47.7	476	42.2	450	35.9	488	30.0
July 19	835	52.6	1,088	51.9	503	44.6	480	38.3	542	33.4
July 26	891	56.1	1,215	58.0	548	48.6	549	43.8	629	38.7
Aug. 2	1,023	64.5	1,350	64.4	603	53.5	655	52.2	727	44.7
Aug. 9	1,157	72.9	1,517	72.4	657	58.2	718	57.3	787	48.4
Aug. 16	1,237	78.0	1,686	80.5	732	64.9	817	65.2	880	54.2
Aug. 23	1,304	82.2	1,770	84.5	801	71.0	823	65.6	1,003	61.7
Aug. 30	1,377	86.8	1,877	89.6	837	74.2	942	75.1	1,105	68.0
Sept. 6	1,431	90.2	1,968	93.9	947	84.0	1,008	80.4	1,374	84.6
Sept. 13	1,505	94.9	2,006	95.8	1,041	92.3	1,070	85.3	1,441	88.7
Sept. 20	1,506	94.9	2,039	97.3	1,055	93.5	1,207	96.3	1,547	95.2
Sept. 27	1,579	99.5	2,040	97.4	1,128	100.0	1,208	96.3	1,612	99.2
Oct. 4	1,587	100.0	2,086	99.6	1,128	100.0	1,254	100.0	1,625	100.0
Oct. 11			2,095	100.0						
Oct. 18										

See footnote at end of table.

TABLE 19.—*Cumulative totals of the runs of Karluk red salmon for each week from 1921 to 1936, and percentage of the total run that had cumulated to the end of each week*—Continued

Week ending—	1932		1933		1934		1935		1936		Average percentage 1921–36
	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	Number of fish in thousands	Percentage of total run	
May 24	1	0.1	2	0.1	3	0.1	23	1.5	39	1.6	0.6
May 31	49	3.5	27	1.5	204	9.9	162	10.6	183	7.5	5.2
June 7	223	15.8	381	21.0	503	24.4	424	27.7	375	15.3	14.1
June 14	369	26.1	575	31.7	897	43.4	625	40.8	585	23.8	23.8
June 21	481	34.1	784	43.2	1,097	53.1	710	46.4	786	32.0	31.0
June 28	541	38.3	895	49.4	1,164	56.4	749	48.9	906	36.9	35.8
July 5	597	42.3	980	54.1	1,244	60.2	809	52.8	917	37.4	38.7
July 12	634	44.9	1,029	56.8	1,309	63.4	836	54.6	979	39.9	41.3
July 19	688	48.7	1,080	59.6	1,385	67.1	878	57.3	1,069	43.6	44.7
July 26	740	52.4	1,163	64.1	1,499	72.6	984	61.9	1,198	48.8	49.9
Aug. 2	829	58.7	1,255	69.2	1,581	76.6	1,038	67.8	1,425	58.1	56.7
Aug. 9	906	64.2	1,307	72.1	1,651	80.0	1,100	71.8	1,573	64.1	62.3
Aug. 16	961	68.1	1,385	76.4	1,700	82.3	1,172	76.5	1,682	68.6	67.8
Aug. 23	1,081	76.6	1,506	83.1	([1])		1,228	80.2	1,813	73.9	72.9
Aug. 30	1,145	81.1	1,520	83.8			1,217	81.4	2,125	86.6	79.3
Sept. 6	1,147	81.2	1,666	91.9			1,398	91.3	2,330	95.0	87.0
Sept. 13	1,235	87.5	1,742	96.1			1,399	91.4	2,357	96.1	92.4
Sept. 20	1,355	96.0	1,752	96.6	2,065	100.0	1,514	98.9	2,439	99.4	96.2
Sept. 27	1,402	99.3	1,756	96.9	2,065	100.0	1,531	100.0	2,453	100.0	98.6
Oct. 4	1,412	100.0	1,813	100.0			1,531	100.0	2,453	100.0	99.7
Oct. 11											100.0
Oct. 18											

[1] The number of fish in the run from here to the end of the season was calculated as explained in the text.

In discussing the time of appearance of the runs, Gilbert and Rich (1927, p. 63) pointed out the apparent "uniformity in the development of the runs" from year to year and stated that if supported by future data the size of the total run could be predicted with some degree of accuracy at least by the end of June. Unfortunately, additional data have shown that there is considerable variation in the cumulative percentage occurrence of the runs from year to year. Up to the week ending July 5 the data indicate that from 25 to 60 percent of the run may have come in. Therefore it is impossible to estimate, with any degree of accuracy, the size of the total run early in the season. The main reason for the variation in the development of the runs from year to year is that the run of any single year is composed of fish of several age groups, and the various age groups do not appear uniformly during the season nor is there a correlation as previously explained between the abundance or scarcity of one age group appearing during one year with the abundance or scarcity of the other age groups appearing during that same year.

Figure 2 shows the average percentage of the run appearing during each 7-day period of the season. There is a definite mode in June, a minimum during the week ending July 12, followed by a second mode. The second mode itself is slightly bimodal; however, the data for any single year clearly show that the minumum occurs during the period of the week ending July 5 to the week ending July 19 and only one mode is present during the fall run. It appears that there are two distinct red salmon runs to the Karluk River each year, the spring run which reaches a maximum during June and the fall run which reaches a maximum between the last week of July and the first week of September.

Overlapping of these two runs cannot be denied, but the bimodality of the runs is evidenced not only in the appearance of the fish at the mouth of the river but also in their appearance on the spawning grounds. The spring run first appears on the spawning grounds during the last of June and the peak of the spawning occurs during the third week of July. These fish populate all the spawning streams entering the lake and, to a slight extent, certain parts of the lake shores where seepage through the gravel promotes conditions suitable for spawning. By the end of July or the first week of August the fish have completed spawning, and there is a definite scarcity of live fish on the spawning grounds. During late August, fish again appear in numbers on

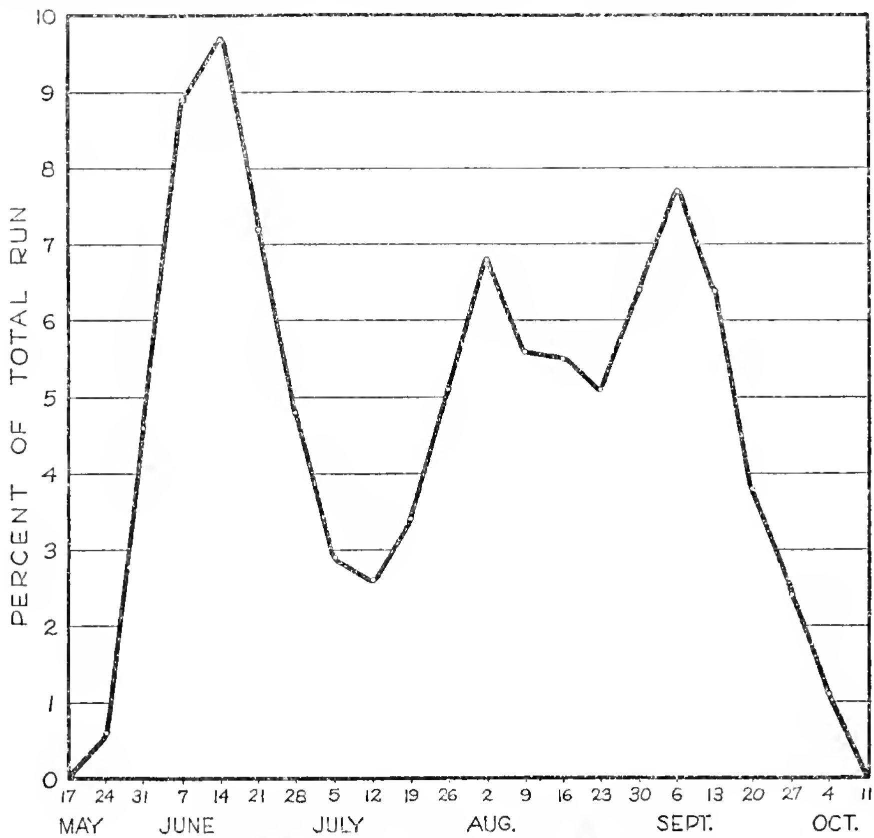

FIGURE 2.—Percentage of total run appearing each week during season.

the spawning grounds. An appreciable percentage of the fall run spawns along the beaches, and some of the fish spawn in the Karluk River for a distance of a mile or two below the lake, an area never populated by fish of the spring run. The majority of the fish in the fall run do spawn, however, in the tributary streams of the lake.

Although the two runs of fish spawn, to a great extent, on the same spawning grounds, the time interval precludes a thorough interbreeding of the two populations. The only interbreeding possible is between the late spawners of the spring run and the early spawners of the fall run. Whether or not the separation between the two groups has been sufficient to produce any anatomical differences that might be detected biometrically has not been determined conclusively. Even though the differences could not be detected biometrically, such an absence of differences would not repudiate the theory of two populations of red salmon inhabiting one watershed and spawning in the same gravel. Environmental conditions undoubtedly do account, in a large measure, for the minor fluctuations in the time of appearance of the runs from year to year and may be the cause of bimodality in the runs. Regardless of the primary cause of this phenomenon, it would seem that there are two self-perpetuating components of the red-salmon population in the watershed, and that each should be given adequate protection.

During the 16 years under consideration the spring runs have ranged from 303,000 fish in 1922 to 1,715,000 fish in 1926, the average being 817,000 fish. The fall runs have ranged from 652,000 fish in 1929 to 3,205,000 fish in 1926, the average being 1,211,000 fish. The total run has ranged from 1,058,000 fish in 1922 to 4,920,000 fish in 1926, the average being 2,028,000 fish. Thus, there has been a rather wide range in the number of fish in the runs from year to year, and the average run has been far below that of the early days of the fishery when for a period of 7 years the catch alone exceeded the run (catch plus escapement) during this period by more than 1,000,000 fish per year.

RETURNS FROM KNOWN SPAWNING POPULATIONS

In order to maintain the salmon runs at a high level, an adequate escapement must be obtained for each and every suitable spawning area. The question at once arises as to what constitutes an adequate escapement. This question has confronted the salmon conservationist since the first attempt was made to regulate a fishery, and it is a question that still needs considerable study. Each small section of a spawning area must have its proper escapement, and in the final analysis, it is necessary to determine, for each small area, the size of an adequate spawning population. The problem is further complicated because an adequate spawning population for a given spawning area is not necessarily constant. Variations in meteorological conditions result in changes in environmental conditions on the spawning grounds during the spawning and incubation periods from year to year, consequently, a spawning escapement which may be adequate in one year may be inadequate, or may be more than adequate, in some other year. As there is no means of predicting what meteorological conditions will prevail during the spawning season and the subsequent incubation period, we can at best determine an average figure for the optimum size of the spawning population for each spawning area.

Most of the progeny from a year's spawning population of Karluk red salmon return as adults in their fourth to seventh year.[6] In order to determine the return from the spawning of 1930, for example, it is necessary to determine the number of 4-year fish in the run of 1934, the number of 5-year fish in the run of 1935, the number of 6-year fish in the run of 1936, and the number of 7-year fish in the run of 1937. The numbers of these several groups are then added together to determine the total return from the spawning of 1930. The returns from the escapements of the spring run, from the fall run, and from the total run of each year are given in table 20.

The escapement of 1921 (1,500,000 fish) produced a very good return both in the ratio of return to escapement and also in the total number of fish produced. While the return from the spring escapement was good, the return from the fall escapement was much better and was largely responsible for the exceptionally good total return.

[6] There are a few 3-year and 8-year fish in the Karluk runs which are included in the tabulations, but their presence is quite unimportant.

TABLE 20.—*Returns from escapements of Karluk River red salmon*

Year and season	Escapement	Return	Ratio of return to escapement	Return minus escapement
1921				
Spring	685, 245	1, 522, 032	2.2: 1	836, 787
Fall	814, 755	2, 970, 272	3. 6: 1	2, 155, 517
Total	1, 500, 000	4, 492, 304	3.0: 1	2, 992, 304
1922				
Spring	196, 186	1, 252, 839	6. 4: 1	1, 056, 653
Fall	203, 814	1, 001, 461	4. 9: 1	707, 647
Total	400, 000	2, 254, 300	5. 6: 1	1, 854, 300
1923				
Spring	255, 351	801, 653	3. 1: 1	546, 302
Fall	439, 228	1, 186, 050	2. 7: 1	747, 722
Total	694, 579	1, 988, 603	2. 9: 1	1, 294, 024
1924				
Spring	540, 030	409, 352	.8: 1	−130, 678
Fall	569, 131	435, 118	.8: 1	−134, 013
Total	1, 109, 161	844, 470	.8: 1	−264, 691
1925				
Spring	657, 154	538, 113	.8: 1	−119, 041
Fall	963, 773	1, 062, 953	1. 1: 1	99, 180
Total	1, 620, 927	1, 601, 066	1. 0: 1	−19, 861
1926				
Spring	1, 289, 976	336, 507	.3: 1	−953, 469
Fall	1, 243, 426	1, 177, 101	.9: 1	−66, 325
Total	2, 533, 402	1, 513, 608	.6: 1	−1, 019, 794
1927				
Spring	617, 613	926, 611	1. 5: 1	308, 998
Fall	254, 925	651, 563	2. 6: 1	396, 638
Total	872, 538	1, 578, 174	1. 8: 1	705, 636
1928				
Spring	755, 511	1, 519, 176	2. 0: 1	763, 665
Fall	338, 306	925, 453	2. 7: 1	587, 147
Total	1, 093, 817	2, 444, 629	2. 2: 1	1, 350, 812
1929				
Spring	360, 567	883, 509	2. 5: 1	522, 942
Fall	539, 752	623, 056	1. 2: 1	83, 304
Total	900, 319	1, 506, 565	1. 7: 1	606, 246

The escapement of 1922 (400,000 fish) was very poor. However, this escapement produced a fair-size run because the ratio of return to escapement was exceptionally high both in the spring and fall.

The escapement of 1923 (694,579 fish), although it produced a good ratio of return to escapement, produced only a moderate run because the size of the escapement itself was below average.

The escapement of 1924 (1,109,161), while considered satisfactory in size, produced a very poor return. In fact there were fewer fish in the return than in the escapement. This was due probably to the tremendous escapement of pink salmon in the Karluk River in 1924. Normally, the pink salmon spawn in the lower half of the river, but in that year, because of population pressure, large numbers of this species continued up the river and occupied the red salmon spawning grounds. Quoting from a report made by Fred R. Lucas in 1924 (Gilbert and Rich 1927):

. . . On August 21st hundreds of thousands of fish died in the twenty miles of river between the weir and the still water at the Larson Bay portage. The mortality included adult red salmon, humpbacks, and trout, as well as young fish. The cause is unknown unless it was due to overcrowding of humpbacks, with a possible fall of the water level in the river . . . it is estimated that over four million humpbacks passed through the weir this season.

Quoting from Lucas' notes taken while visiting the red-salmon spawning grounds at Karluk Lake, September 16 to 24:

. . . Behind every rock and in every eddy piles of humpback eggs lay. Within twenty-two steps the writer counted twelve piles that would average five gallons to a pile; and behind a small island about six feet in diameter there were more than a fifty-gallon barrel full of humpback eggs. These eggs were all dead; . . . a small percentage of red eggs was among them. In fact, more or less red eggs were noticed adrift in every stream where humpbacks had spawned . . . The dead, red eggs . . . were more numerous than the live ones. All of these live eggs will probably be picked up by the birds and trout before they hatch. . . .

It was apparent that there was too large a pink-salmon escapement, and this was borne out by the failure of the pink-salmon run of 1926, the total return from the escapement of over 4,000,000 being less than 100,000 fish. The overcrowded conditions on the spawning grounds in 1924 not only resulted in a very poor return of pink salmon in 1926 but undoubtedly were largely responsible for the poor return from the red-salmon escapement.

The escapement of 1925 (1,620,927), while good, also produced a relatively poor return, and the total return was slightly less than the number of fish in the escapement. Karluk Lake was not visited during the summer of 1925, and consequently no information as to conditions on the spawning grounds during that year is available. The moderately large escapement should not have caused an undue mortality due to overcrowding under normal conditions, and there is no reason to believe environmental conditions were abnormal during the spawning period. It is known that the winter of 1925–26 was exceptionally mild. A mild winter should cause the eggs to hatch earlier than usual, but just what effect this would have on the fry is impossible to state.

The excellent escapement of 1926 (2,533,402) suffered from unfavorable conditions caused by an exceptionally warm, dry summer, and the return was 1,000,000 fish less than the number of spawners in the escapement. The lack of rainfall coupled with a large escapement of red salmon produced conditions somewhat similar to those encountered in 1924. Quoting from notes made by Willis H. Rich in 1926:

On July 18, in Spring Creek . . . it was very noticeable that many of the females were not completely spawned out; six of twelve examined had eggs apparently still in good condition. Most of these were apparently not spawned at all, although ripe . . . Upper Thumb River . . . we saw many dead females, ripe but unspawned, and many others that were not completely spawned out. Causes of death quite unknown, as most of them appeared to be in fine condition.

Observers at Karluk Lake in 1926 considered that "about 25 percent of the females that reached the lake died only partially spawned out." Not only did many fish die before spawning, but large numbers of eggs deposited in the gravels died because the spawning grounds dried up. Again quoting from Rich's notes:

August 9 . . . In Thumb River, where the spawning had been heaviest, many of the nests were exposed by the lowering of the water. We dug in some of them and found mainly dead eggs, although a very few live ones were found.

In many of the other streams similar conditions were noted. Thus, the poor return from the spawning of 1926 might have been due largely to the conditions on the spawning grounds during that year. The spawn of the spring escapement, in the opinion of observers, suffered the greatest loss, and it is significant that the return per fish from the spring escapement was only one-third as great as the return per fish from the fall escapement.

The escapement of 1927 (872,538 fish) produced a moderate-size run and probably would have produced a better run had not the spring run suffered to some extent from unfavorable conditions. Precipitation during the summer of 1927 was in marked contrast to that of 1926. In 1927 the spring spawning population suffered because the streams were at flood stage for a period of time, whereas in 1926 the fish suffered from a lack of sufficient water.

The escapement of 1928 (1,093,817 fish) produced a fairly good run, and the ratio of return to escapement in both the spring and fall was equal to, or greater than, the ratio of return of 2:1 on which the Alaska fishery regulations are based.

The escapement of 1929 (900,319 fish) produced a relatively small run. The spring escapement produced a good ratio of return to escapement, but the fall escapement produced only a few more fish than were in the escapement for that period.

Although fluctuations in the ratio of return to escapement were anticipated, it was expected that some correlation would be found between these two factors. The big escapements to the Fraser River (Rounsefell and Kelez, 1938) every fourth year prior to the rock slide in the river in 1913, always resulted in a large run 4 years later. Observations made on the escapement and returns of pink salmon in Puget Sound and Alaska indicate that usually big runs are produced from good escapements and poor or only fair runs produced by poor escapements. The cyclic nature of the catches at Karluk during most of the history of the fishery also indicates that some correlation exists between escapement and return. These and many other instances which might be cited give reason to believe that, normally, a positive correlation exists between escapement and return.

Figure 3 shows the correlation between the total yearly escapement and the total returns. The most striking point about these data is the utter lack of correlation between the escapements and the returns from the escapements. That such a condition could not have existed during the early days of the fishery is apparent when one considers that for 3 of the 9 years under consideration the ratio of return to escapement did not exceed 1.0 to 1.0. Obviously, unless this ratio is greater than 1.0 to 1.0 a fishery cannot be sustained. For only one of the years under consideration, 1921, did the return exceed the escapement from which it resulted by an amount approximately equal to the catches made during the early days of the fishery.

In the consideration of returns from escapements the most important point is the surplus, or return minus escapement, produced by a given escapement. The aim of every regulatory body governing a self-perpetuating biological resource should be to allow the greatest possible catch without endangering future supplies. The size of the population inhabiting a watershed is, in itself, of little concern. For example, if an escapement of 1,000,000 fish always produced a run of 3,000,000 fish, and an escapement of 4,000,000 fish always produced a run of 5,000,000 fish it would be wasteful to require an escapement of 4,000,000 fish solely on the basis that such an escapement produced the largest run. In this hypothetical example the escapement of 1,000,000 fish would produce a surplus of 2,000,000, and the escapement of 4,000,000 would produce a surplus of only 1,000,000. It is then of considerable importance to determine, for each given area, the size of the escapement which will consistently produce the greatest surplus.

In figure 4 the return minus escapement, or surplus, has been plotted against the escapement. A negative correlation between escapement and surplus is indicated, and it appears that, overlooking the return from the fall escapement of 1921, the

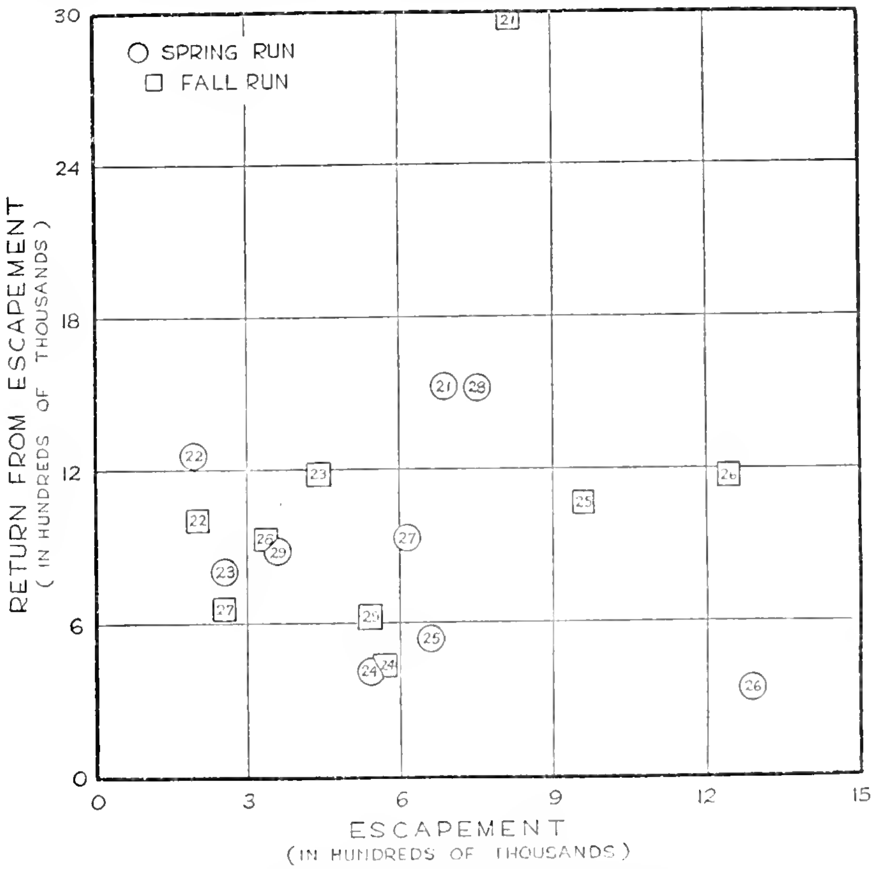

FIGURE 3.—Returns from the spring and fall escapements for the years 1921 to 1929, inclusive.

optimum escapement for the spring and fall runs was approximately 200,000 fish for each period or a total yearly escapement of 400,000 fish. There are several facts, however, that should be considered before drawing conclusions from the data. The escapement of 1921, and especially the fall escapement, produced a very good surplus. The Karluk pink salmon spawning population of 1922 produced an exceptionally large surplus, as did the red salmon spawning population of that year, indicating unusually favorable environmental conditions. Conditions on the spawning grounds were judged to be very unfavorable during 1924 and 1926, and hence the returns from those escapements were likely much lower than if the environment had been normal. Furthermore, only the escapement of 1921 (1,500,000 fish) produced a surplus comparable to the average catch made during the 20-year period from 1888 to 1907. While

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it is obvious that the catches made during the early days of the fishery were such as to cause serious depletion of the population, it would seem likely that the fishery could have been stabilized with a yearly catch of 1,500,000 to 2,000,000 fish.

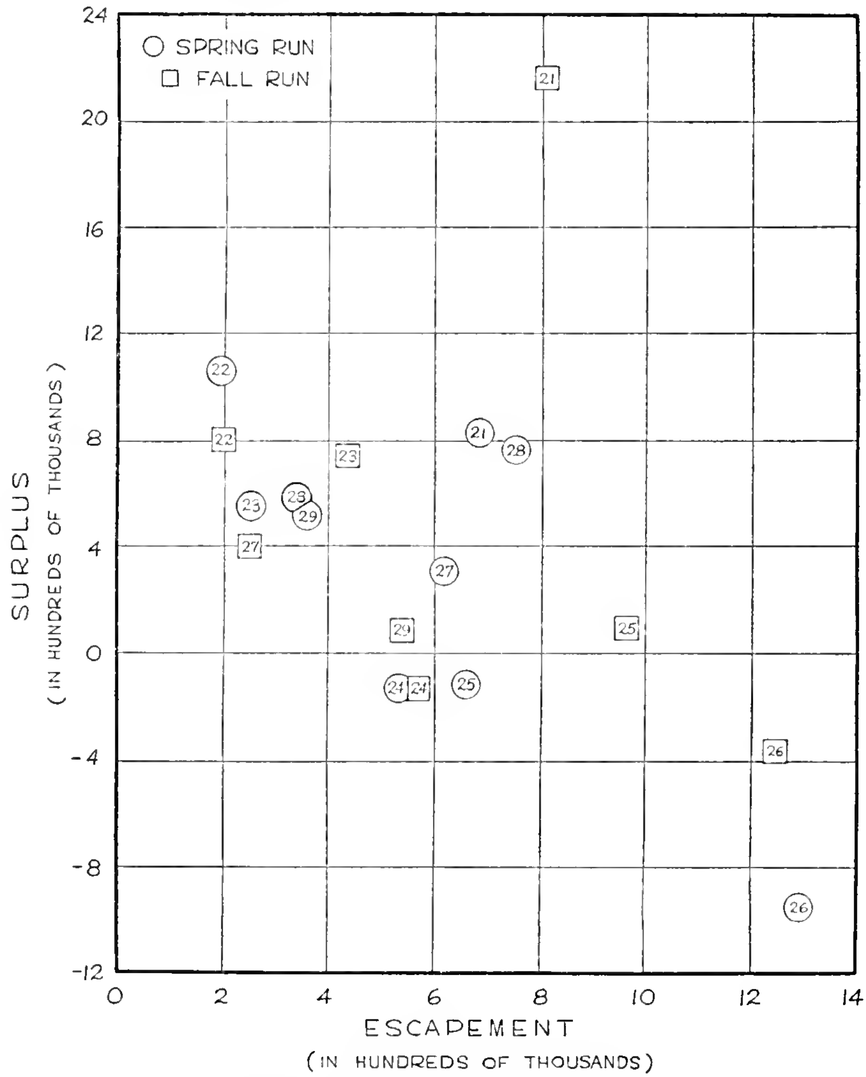

FIGURE 4.—Surplus (return minus escapement) produced by spring and fall escapements for the years 1921 to 1929, inclusive.

CHEMICAL ANALYSES OF LAKE AND STREAM WATERS

A factor to be considered in relation to the optimum magnitude of the escapements of red salmon is the addition to the lake water of phosphorus and other inorganic salts from the bodies of the fish which migrate into the watershed to spawn. Prior to the inception of the commercial fishery, Karluk Lake received a large supply of chemical compounds each year because practically all of each season's run of fish proceeded to the lake and its tributaries to spawn and die. As soon as the commercial fishery began, the spawning escapements became less, and not only were there fewer spawners available to deposit eggs in the gravel, but the yearly increment of chemical compounds to the water was considerably decreased.

That the productivity of bodies of fresh and salt water is controlled in part by the abundance of certain inorganic salts such as phosphorus has long been known and the relationship between the chemical content of the water of ponds, lakes, and the ocean and their productivity has been studied by a large number of investigators. Soluble phosphorus has been considered by most workers to be the chief limiting factor in the productivity of aquatic organisms during the summer months, although nitrogen and carbon dioxide have also been shown to be limiting factors at times.

During the 2 or 3 years that the red-salmon fingerlings spend in fresh water, prior to their sojourn in the ocean, they feed upon certain minute forms of animal life existing in the lake. These animal forms, or zooplankton, are dependent upon the plant forms, or phytoplankton, and they in turn are dependent upon the sunlight and the inorganic salts in the lake water. Hence, fluctuations in the supply of salts in the lake water can indirectly affect the growth and survival of the fish.

In tables 21 and 22 are presented the results of temperature and chemical observations made on the waters of Karluk and Thumb Lakes in 1935 and 1936. Similar data collected in 1927 were presented and discussed by Juday, Rich, Kemmerer, and Mann (1932).

The temperature of both Karluk and Thumb Lakes was higher in 1935 than in 1927 and still higher in 1936. At Station 1, in Karluk Lake (fig. 5), for example, the surface temperature on August 13, 1927, was 11.1° C.; on the same date in 1935 it was 12.2° C.; and in 1936 it was 15.5° C. There was evidently a marked difference in the amount of sunshine during these 3 years, and such a conclusion is confirmed by the precipitation data. The June-July-August precipitation at Kodiak, the nearest recording station, was 22.33 inches in 1927; 13.85 in 1935; and 6.56 inches in 1936. During the 47 years that June-July-August precipitation data has been tabulated at Kodiak, the average precipitation was 13.32 inches.

Soluble phosphorus was found in the water of Karluk and Thumb Lakes in 1927 on the dates samples were taken, and whereas the surface waters of these lakes lacked a measurable amount of phosphorus during the summers of 1935 and 1936, it was not until September, at the end of the salmon growing season, that measurable amounts of phosphorus were found.

Silica was almost entirely absent from the surface waters of Karluk Lake during 1935 and 1936, whereas a small amount was present in 1927.[7] A greater amount of silica occurred in the water of Thumb Lake in 1935 and 1936 than in 1927.

[7] The 1927 silica values should be multiplied by 1.14 to correct a change in the value used in the calculation. The method used for the determination of silica is that described by Dienert and Wandenbulcke (1923), and Juday, Rich, Kemmerer, and Mann (1932) used Dienert and Wandenbulckes value of 36.9 mgs. of picric acid as being equivalent to 50 mgs. of silica. King and Lucas (1928) showed this value to be in error and indicated that 25.6 mgs. of picric acid were equivalent to 50 mgs. of silica. This latter value was confirmed by Robinson and Kemmerer (1930a) and was used in the present analysis.

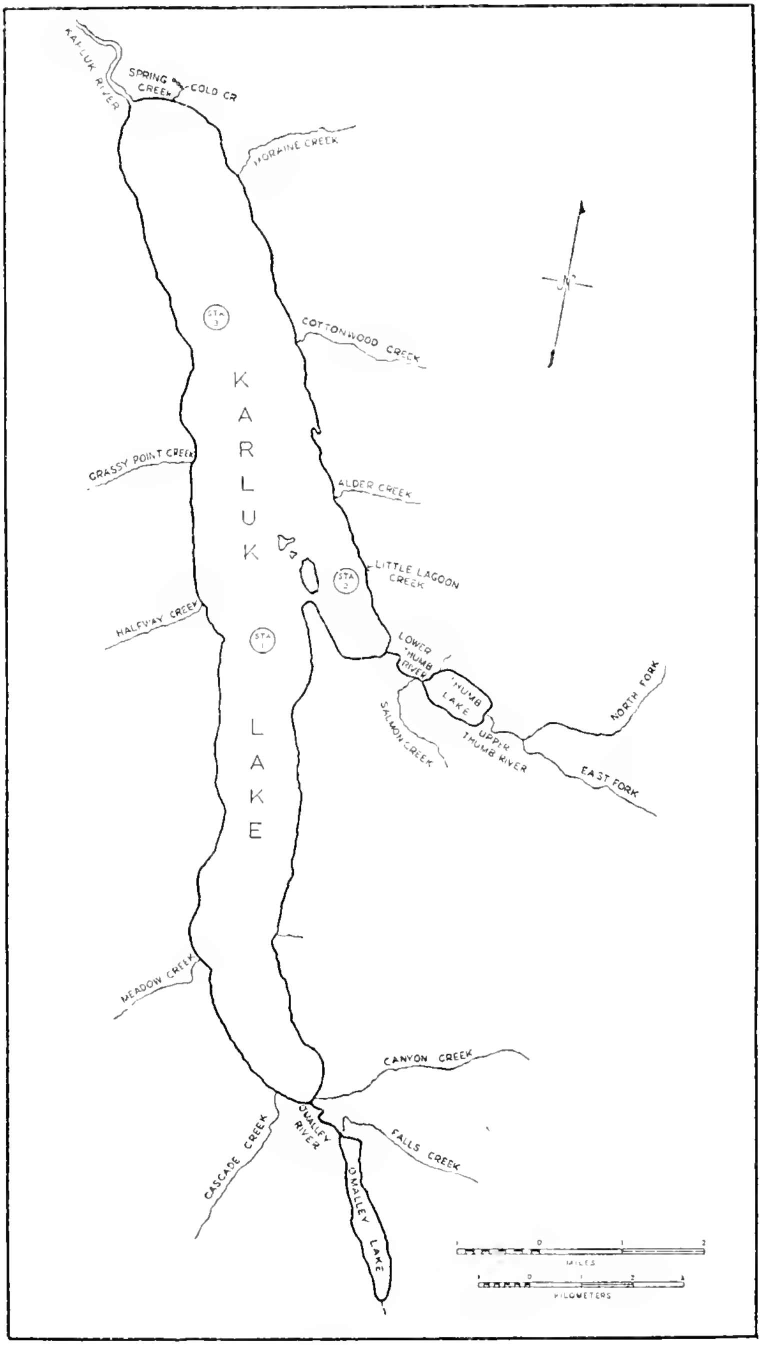

FIGURE 5.—Map of Karluk Lake region.

TABLE 21.—*Results of chemical analyses of the waters of Karluk Lake and Thumb Lake in 1935*

[The results are stated in milligrams per liter of water. Tr.=Trace]

Date	Time[1]	Depth in meters	Temperature, °C.	pH	Carbon dioxide free	Soluble phosphorus	Silica	Nitrite nitrogen
KARLUK LAKE, STATION 1								
May 26	11:15	0	5.0	7.7				
June 28	10:27	0	11.0	8.2		0.000	1.5	0.002
June 28		20	9.8	7.6		.000	1.5	.002
June 28		30	6.0	7.8		.000	0	.002
June 28		100	4.5	7.4		.002	0	.001
July 11	8:30	0	11.6	8.0	0.8	.000	Tr.	.002
July 11		20	8.7	7.7	1.2	.000	0	.001
July 11		30	6.9	7.6	1.8	.000	0	.001
July 11		100	4.8	7.3	1.8	.002	0	.001
July 30	8:21	0	11.9	7.7	.8	.000	0	.002
July 30		100	5.0	7.2	2.0	.002	0	.001
July 30		124	4.9	7.1	2.4	.002	0	.001
Aug. 13	9:45	0	12.2	7.8	.8	.000	Tr.	.001
Aug. 13		20	8.1	7.2	1.2	Tr.	0	.001
Aug. 13		100	5.1	7.0	2.0	.002	Tr.	.001
Aug. 13		122	4.9	7.0	2.5	.002	Tr.	.001
Sept. 6	11:25	0	12.7	7.9		.006	.5	
Sept. 6		20	10.3	7.3		.004	0	
Sept. 6		100	5.3	7.0		.004	0	
Sept. 6		120	5.1	7.0		.010	.5	
Sept. 6		124	5.1	7.0		.008	.5	
KARLUK LAKE, STATION 2 (THE THUMB)								
May 26	10:50	0	5.6	7.6				
July 13	8:30	0	12.8	8.2	0.6	0.000	Tr.	0.003
July 13		10	10.5	8.0	.6	.000	Tr.	.002
July 13		20	6.4	7.5	1.4	.000	0	.001
July 13		35	5.5	7.3	1.6	.000	0	.001
Aug. 13	8:20	0	12.8	8.1	.6	.000	Tr.	.001
Aug. 13		40		7.1	2.2	.008	.5	.002
Sept. 5	[2] 12:50	0	12.9	7.6		.002		
Sept. 5		20	10.4	7.0		.002		
Sept. 5		35	6.9	7.0		.002		
Sept. 5		41	6.4	6.9		.010		
KARLUK LAKE, STATION 3								
July 12	8:30	0	11.8	7.9	0.6	0.000	Tr.	0.003
July 12		20	6.5	7.7	1.0	.000	0	.001
July 12		30	6.0	7.4	1.6	.000	0	.001
July 12		50	4.8	7.2	2.4	.000	Tr.	.001
Sept. 6	9:18	0	12.6	7.1		.002	Tr.	
Sept. 6		20	8.5	7.0		.002	0	
Sept. 6		50		6.9		.010	.5	
Sept. 6		54	5.3	6.9		.008	.5	
THUMB LAKE								
May 26	10:10	0	9.2	8.2				
June 25	[2] 12:01	0	10.6	7		0.000	7.0	Tr.
June 25		8	9.8	7.2		.002	5.5	Tr.
July 9	11:20	0	12.2	7.3	1.6	.000		Tr.
July 21	8:23	0	11.6	7.1	2.2	.002		
July 21		9	11.1	7.1	2.8	.002		
Aug. 14	8:25	0	13.0	9.1	1.6			

[1] Time a. m. except as noted.
[2] Time p. m.

In tables 23 and 24 are presented the results of temperature and chemical analyses made on 15 affluents of Karluk Lake during the summers of 1935 and 1936. These data, with the exception of the silica values, agree with the results presented for 1927 by Juday, Rich, Kemmerer, and Mann (1932). Variations in temperature, pH, carbon dioxide, soluble phosphorus, and nitrite nitrogen depend, in a large degree, on the time of day observations are made, the number of fish in the streams, and the depth of water in the streams.

TABLE 22.—*Results of chemical analyses of the waters of Karluk Lake and Thumb Lake in 1936*

[The results are stated in milligrams per liter of water. Tr=Trace]

Date	Time [1]	Depth in meters	Temperature, °C	pH	Soluble phosphorus	Silica	Nitrite nitrogen
KARLUK LAKE, STATION 1							
June 28	10:30	0	13.6	7.6	0.000	0	0.002
28	...	20	6.1	7.5	.000	0	Tr.
28	...	30	...	7.5	.000	0	Tr.
28	...	100	4.3	7.3	Tr.	0	Tr.
July 11	11:15	0	12.2	7.6	.000	0	.001
11	...	20	7.1	7.5	.000	0	Tr.
11	...	30	5.8	7.5	.000	0	Tr.
11	...	100	4.5	7.3	.000	0	Tr.
18	8:15	0	13.5	7.8	.000	0	...
18	...	30	6.3	7.5	.000	0	...
Aug. 7	9:44	0	17.1	8.4	.000	Tr.	.001
7	...	20	6.5	7.3	.000	0	.001
13	9:26	0	15.5	8.4	.000	0	.001
13	...	20	7.0	8.0	.002	0	Tr.
13	...	100	4.6	7.1	.003	0	.002
13	...	124	4.5	6.7	.018	1.0	.002
27	8:18	0	15.0	7.9	.000	Tr.	.001
27	...	20	8.1	7.3	.000	0	.001
27	...	30	6.1	7.2	.000	0	Tr.
27	...	100	4.8	7.1	.005	.5	Tr.
Sept. 9	9:09	0	12.7	7.6	.000	Tr.	.001
9	...	20	8.3	7.2	.000	0	.000
9	...	30	6.8	7.1	.000	0	.000
9	...	100	4.8	7.1	.004	Tr.	Tr.
KARLUK LAKE, STATION 2							
July 7	10:20	0	13.6	8.0	0.000	0	0.002
13	11:21	0	13.5	7.7	.000	0	.001
13	...	20	6.6	7.7	.000	0	Tr.
13	...	30	5.6	7.5	.000	0	Tr.
13	...	40	4.9	7.3	.000	0	Tr.
18	8:37	0	13.8	8.0	.000	0	...
18	...	30	5.6	7.4	.000	0	...
Aug. 7	8:15	0	16.5	8.5	.000	.5	.002
7	...	20	6.8	7.4	.000	0	.001
7	...	40	5.3	6.8	.036	1.0	...
13	[2] 2:14	0	15.6	8.3	.000	.7	.002
13	...	20	6.6	7.2	.000	0	.001
13	...	40	...	7.2	.006	.5	.001
13	...	41	5.8	6.9	.008	.7	.001
25	8:45	0	15.2	8.1	.000	.5	.001
25	...	20	6.7	7.2	.000	0	.001
25	...	30	5.8	7.0	.004	Tr.	.001
25	...	40	5.5	6.9	.023	1.0	.001
Sept. 6	7:18	0	13.4	7.6	.000	.7	.001
6	...	20	9.8	7.1	.000	0	Tr.
6	...	30	6.3	7.0	.001	0	Tr.
6	...	40	5.8	6.9	.023	.5	.001
THUMB LAKE							
June 30	10:30	0	11.7	7.1	0.000	5.5	Tr.
30	10:25	8	9.9	7.2	.000	5.5	Tr.
July 9	11:50	0	12.5	7.3	.000	5.5	0.001
17	[2] 12:07	0	11.5	8.2	.000	3.5	...
Aug. 10	11:45	0	15.6	8.5	.000	5.0	.001
10	11:50	9	11.9	6.5	.005	3.0	.000

[1] Time a. m. except as noted.
[2] Time p. m.

Applying the correction factor of 1.44 to the 1927 silica values, it is found that the silica content of the various streams ranged from 1.4 to 5.0 milligrams per liter. In 1935, the silica values ranged from 5.0 to 13.0, and in 1936 they ranged from 4.0 to 15.0 milligrams per liter. In both 1935 and 1936, it was noted that the silica content of the water of any one stream varied with the stream flow. In the summer months of 1927 there was 1.6 times as much precipitation as during the same period in 1935, and 3.4 times as much as in 1936; hence, the stream flow in 1927 must have been con-

TABLE 23.—*Results of chemical analyses of stream waters in 1935*

[Results are stated in milligrams per liter of water. Tr.=Trace]

Stream	Date	Time [1]	Temperature °C.	pH	Carbon dioxide		Soluble phosphorus	Silica	Nitrite nitrogen
					Free	Fixed			
Cold Creek [2]	July 1	9:10	3.9	6.3	12.2	10.0	0.012	13.0	
Spring Creek	do	9:15	5.8	6.8	7.8	6.8	.002	11.0	0.001
	July 15	9:00	6.1	6.7					
	Aug. 15	10:00	6.8	6.7	6.7	10.8	.022	9.0	Tr.
	Aug. 29	10:10	6.1	6.7	5.9	11.0	.006	9.0	Tr.
Moraine Creek	July 1	9:25	7.2	7.1	3.2	11.0	.018	7.0	.003
	July 15	9:30	8.3	7.2			.060	9.5	
	Aug. 15	11:15	10.4	7.8	.8	11.0	.022	8.0	.001
	Aug. 29	10:25	9.4	8.4	.0	10.2	.014	11.0	.001
Cottonwood Creek	July 1	10:05	7.2	7.2	2.8	7.8	.016	8.0	.003
	July 15	10:45	9.4	7.3			.080	9.5	
	July 27	9:30	7.8	7.3	1.4	13.4	.030	9.0	.003
	Aug. 15	[3] 12:01	9.2	7.7	1.0	13.6	.020	8.5	.002
	Sept. 7	8:45	6.6	7.8			.008		
Alder Creek [1]	July 7	9:15	6.7	7.3	2.4	14.8	.002	8.5	Tr.
Alder Creek	do	9:40	7.2	7.2	3.2	15.2	.016	9.0	.002
	July 15	11:55	8.3	7.2					
	July 27	9:05	6.7	7.3	1.6	13.8	.025	9.0	Tr.
	Aug. 15	7:40	5.5	7.7	1.6	15.0	.016	8.0	.001
	Sept. 7	9:05	6.1	7.6			.010		
Little Lagoon Creek [2]	May 26	10:42	3.5	7.9					.000
	July 7	10:10	3.6	7.7	1.4	25.0	.004	9.0	.000
Little Lagoon Creek	do	10:00	4.7	7.4	2.4	24.6	.010	9.5	.001
	July 13	10:00					.016		
Little Lagoon Creek [2]	Aug. 15	7:50	3.3	7.8	1.4	23.0	.006	8.5	.000
Little Lagoon Creek	do	8:00	3.9	7.7	2.2	23.8	.010	9.0	.000
Lower Thumb River	May 26	10:20	8.3	8.1					
	June 26	[3] 1:20	10.3	7.5					
	July 9	[3] 12:05	12.2	7.3					
	Aug. 14	9:00	12.2	9.1					
Salmon Creek	May 26	10:12	5.8	7.3					
	June 25	[3] 1:00	7.2	7.3					
	July 9	11:40	8.0	7.2	2.4	12.6	.016	8.0	.004
	July 21	9:45	7.2	7.3	2.0	11.4	.015	7.0	.002
	Aug. 14	8:40	6.1	7.5	.8	13.2	.025	7.5	.002
Upper Thumb River	June 25	11:45	7.2	7.1					
	July 9	11:10	8.3	6.9	3.8	10.0	.022	7.5	.005
	July 21	9:20	8.3	7.0	2.0	10.8	.025	7.0	.004
	Aug. 14	8:20	7.2	6.9	3.4	12.0	.035	8.0	.004
Halfway Creek [2]	July 6	9:00	7.2	7.3	1.6	9.0	.002	9.5	Tr.
Halfway Creek	do	9:15	7.8	7.1	2.4	9.0	.004	10.0	.001
	July 27	10:25	7.8	7.2	1.2	8.8	.025	9.0	Tr.
	Aug. 16	10:00	6.6	7.3	1.2	9.2	.011	10.0	.001
	Sept. 7	8:00	6.1	7.4			.010		
Grassy Point Creek	July 6	9:40	8.9	7.0	3.6	10.8	.036	9.0	.005
	July 27	10:00	7.2	7.2	1.6	10.8	.045	9.0	.005
	Aug. 16	10:25	7.2	7.5	1.0	10.4	.016	8.5	.002
	Sept. 7	8:20	6.1	7.5			.014		
Meadow Creek	July 17	9:55	8.3	7.0					
	Aug. 16	9:10	7.2	7.5	1.0	9.6	.018	7.5	.004
Cascade Creek	July 3	10:35	8.9	7.3	1.6	14.5	.006	6.5	Tr.
	July 17	9:25	8.3	7.1	2.0	15.4	.024	8.0	.005
	Aug. 16	8:50	7.2	7.6	1.2	14.2	.020	7.5	.002
Canyon Creek	July 3	10:15	8.9	6.8	5.1	10.2	.032	5.5	.005
Falls Creek	do	9:30	8.3	7.3	3.8	7.8	.000	5.0	.000
O'Malley River [4]	do	10:00	9.4	7.3	1.6	9.4	.002	5.0	Tr.
	July 17	8:35	8.9	7.3	2.8	10.8	.006	5.5	.002
	July 23	10:50	8.9	7.1	2.6	10.4	.004	6.0	.002
	Aug. 16	8:35	9.2	7.0	2.2	11.0	.012	6.0	.002

[1] Time a. m. except as noted.
[2] Above salmon.
[3] Time p. m.
[4] Above Falls Creek.

siderably greater than in 1935 or 1936. The streams were lower for a part of the summer of 1936 than in 1935, and this is reflected in slightly higher silica values in that year.

Karluk Lake receives silica, in part from the action of the water on the silica bearing rocks on the bottom and on the beaches, and in part from its tributary streams which leach the silica from their respective watersheds. Consequently, the yearly increment of silica, although undoubtedly affected by temperature and precipitation, is probably

TABLE 24. *Results of chemical analyses of stream waters in 1936*

[Results are stated in milligrams per liter of water, Tr.=Trace]

Stream	Date	Time [1]	Temperature ° C.	pH	Soluble phosphorus	Silica	Nitrite nitrogen
Cold Creek [2]	July 1	10.18	3.9	6.2	0.015	15.0	0.000
Spring Creek	do	10:35	7.2	6.7	.006	13.5	.000
	July 15	9:20	6.9	6.7	.005	13.5	Tr
	Aug. 8	9:15	6.1	6.6	.005	13.0	.000
	Sept. 11	10.10	4.6	6.6	.014	11.5	.001
Moraine Creek	July 1	11:05	8.3	7.5	.032	9.5	.002
	July 15	9:55	10.3	7.3	.130	9.5	.024
	Aug. 8	9:30	11.1	6.6	.135	10.0	.018
	Sept. 11	10:35	5.6	7.8	.030	9.0	.002
Cottonwood Creek	July 1	11:40	9.5	7.1	.015	9.5	.002
	July 15	10:35	9.2	7.2	.045	9.5	.004
	Aug. 8	10:00	10.7	7.1	.180	10.0	.018
	Sept. 11	11:25	5.1	7.6	.014	9.5	.001
Alder Creek	July 7	9:40	6.7	7.5	.009	9.5	
	July 15	11:05	7.5	7.3	.020	9.5	.001
	Aug. 8	11:00	10.0	7.3	.050	10.0	.008
	Sept. 11	[3] 12:20	5.1	7.6	.012	8.0	.001
Little Lagoon Creek	June 25	[3] 2:30	8.3		.004	11.0	
Little Lagoon Creek [2]	July 7	10:00	3.6	7.8	.004	10.5	.000
Little Lagoon Creek	do	10.05	4.4	7.6	.008	10.5	.000
Lower Thumb River	June 30	11:35	12.2	7.4	.000	5.5	.000
	July 9	[3] 12:15	12.8	7.4	.000	5.5	.002
	July 17	[3] 1:35	16.7	7.5	.002	4.0	
	Aug. 29	[3] 3:35	17.1	8.9			
	Sept. 6	[3] 12:30	12.3	7.3			
Salmon Creek	June 30	11:20	8.3	7.2	.004	7.5	.000
	July 9	12:00	7.8	7.3	.018	7.5	.002
	July 17	[3] 1:10	12.2	6.9	.060	7.5	
	Aug. 10	[3] 12:40	8.9	7.0	.050	9.0	.007
	Aug. 29	[2] 3:15	11.1	7.1	.018	8.5	.001
	Sept. 6	[3] 12:05	7.8	7.3	.010	8.0	.004
Upper Thumb River	June 30	9:45	8.3	7.2	.007	6.5	.000
	July 9	11:30	8.3	7.0	.020	7.0	.002
	July 17	11:30	11.7	6.7	.045	7.5	
	Aug. 10	11:30	10.0	6.9	.070	8.5	.007
	Aug. 29	[3] 3:05	11.4	7.0	.024	8.0	.001
	Sept. 6	10:03	9.7	6.9	.026	8.0	.008
Halfway Creek [2]	July 6	9:40	7.2	7.4	.004	10.0	.000
Halfway Creek	do	10:00	7.2	7.2	.010	10.0	.000
Halfway Creek [2]	Aug. 11	11:45	8.3	7.6	.004	11.0	.000
Halfway Creek	do	[3] 12:15	8.9	7.3	.040	12.0	.002
	Sept. 11	8:40	4.0	7.3	.012	9.5	.001
Grassy Point Creek	July 6	10:25	7.8	7.2	.056	10.0	.004
	Aug. 11	[3] 12:45	9.2	7.3	.100	11.5	.006
	Sept. 11	9:05	4.4	7.4	.019	8.5	.002
Meadow Creek	July 3	11:00	9.2	7.0	.012	6.5	.001
	July 16	11:05	8.3		.025	7.5	.003
	Aug. 14	[3] 12:35	9.7	7.4	.060	9.5	.007
	Sept. 10	[3] 1:15	6.7	7.3	.008	9.0	.001
Cascade Creek	July 3	10:15	8.3	7.6	.003	6.5	.000
	July 16	10:20	9.2		.006	8.0	.001
	Aug. 14	[3] 12:04	9.9	7.5	.025	9.0	.006
	Sept. 10	[3] 12:10	7.2	7.5	.003	9.0	.001
Canyon Creek	July 3	9:55	7.8	7.4	.004	5.0	.000
	July 16	10:00	8.3		.016	6.5	.003
	Aug. 14	11:34	10.6	7.1	.030	8.5	.006
	Sept. 10	[3] 12:10	8.9	7.0	.014	8.0	.003
Falls Creek	July 3	9:35	8.3	7.4	.000	5.0	.000
	July 16	9:35	9.2		.006	6.0	.000
	Aug. 14	10:07	10.8	7.2		7.5	
	Sept. 10	12:00	8.9	7.2	.006	7.0	.001

[1] Time a. m. except as noted.
[2] Above salmon.
[3] Time p. m.

rather constant from year to year. A shortage of silica in the lake water would act as a limiting factor in the production of diatoms but would not inhibit the production of other forms of phytoplankton.

The yearly increment of soluble phosphorus is dependent, very largely, upon the number of spawning fish which enter the lake each year. There was from 1½ to 10 times the concentration of phosphorus in the water at the mouths of the streams as in the water of the same streams, on the same dates, above the area where spawning and spawned-out salmon were found. Furthermore, a part of the salmon spawn along the beaches of the lake and eventually die, and the carcasses, together with the carcasses which drift downstream into the lake from the tributaries, decompose and the phosphorus contained therein becomes available to the phytoplankton. A shortage of phosphorus in the lake water would inhibit the growth of all forms of phytoplankton.

It is apparent from a study of the chemical analyses of the lake water and of the stream waters that both phosphorus and silica are being absorbed, during the summer months, by the phytoplankton as fast as they become available, for otherwise the concentration of these chemicals in the lake water would approach that found in the streams. Since the concentration of these chemicals in the lake water during most of the summer was less than a measurable amount, it is evident that they must be limiting factors in the production of the phytoplankton and may possibly be affecting indirectly the growth and survival of the red salmon fingerlings of Karluk Lake.

CHANGE IN AGE COMPOSITION OF THE POPULATION

The percentage occurrence of the various age groups in the population, as determined from a study of the scale samples (tables 3 to 16), appears to be changing from year to year. However, a direct comparison of one year's data with another cannot truly represent the change, if any, since a given year's run is composed of the progeny from the escapements of several years.

To determine whether or not a change has been taking place in the age composition of the population, it is necessary to compare the age composition of the escapements with the age composition of the fish returning from the respective escapements. The age compositions of the escapements for a series of years are presented in table 18, and the age compositions of the returns from the escapements appear in table 25.

The percentage of 5_3 fish in the escapements for the years 1922 and 1924 to 1929, inclusive, was 59.3, 76.0, 66.8, 81.1, 70.8, 56.9, and 34.8 while the percentage of 5_3 fish in the returns from these escapements was 50.0, 49.3, 41.2, 52.5, 45.2, 39.5 and 42.0, respectively. There was a lower percentage of 5_3 fish in the return than there was in the escapement for every year with the exception of 1929. A similar condition is found to exist if the returns from the spring and fall escapements are considered separately.

The pairs of percentages for the 6_4 age group for the years 1922 and 1924 to 1929, inclusive, are as follows (the first figure being the percentage of the 6_4 group in the escapement for a given year and the second figure being the percentage of the 6_4 group in the return from the escapement): 4.0:11.3; 10.5:22.8; 15.8:39.3; 7.6:33.2; 6.1:29.4; 9.0:20.3; 35.1:27.7. In all years except 1929 there was a greater percentage of the 6_4 group present in the return from the escapements than there was in the escapements.

In considering these two major age groups there appears to be a decrease in the relative abundance of one, and an increase in the relative abundance of the other. It thus becomes of interest to determine if a change is taking place in the length of ocean residence and in the length of fresh-water residence of these fish.

TABLE 25.—*Percentage occurrence of various age groups in returns from escapements of the spring, fall, and total run for the years 1920 to 1929, inclusive*

Year of escapement	Age groups																
	3_1	4_1	4_2	4_3	4_4	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1920:																	
Spring			0.5	1.8		0.3	69.7	0.1		21.9	5.3			0.4			
Fall			.1	2.8	0.5	.1	69.4	3.1		3.1	20.3	0.1		.3	0.2		
Returns for year			.2	2.5	.4	.2	69.5	2.2		8.6	15.9	.1		.3	.1		
1921:																	
Spring			1.1	1.2		1.8	89.3			6.4	.2						
Fall		0.1	.6	4.5		.7	87.9	.3		.7	4.6			.6			
Returns for year		.1	.8	3.3		1.1	88.4	.2		2.6	3.1			.4			
1922:																	
Spring			6.3	1.1		6.5	47.9	.2		35.9	1.3		0.4	.4			
Fall	1.2	1.8	2.1	.9	.1	1.0	52.6	4.5		11.1	23.8			.9			
Returns for year	.6	.8	4.5	1.0		4.1	50.0	2.1		24.8	11.3		.2	.6			
1923:																	
Spring			.2	1.0			65.9			30.4	1.8			.7			
Fall	.8	.1	.1	3.0	.1	.2	59.7	.7		6.9	27.4			1.0			
Returns for year	.4	.1	.2	2.2		.1	62.2	.4		16.4	17.1			.9			
1924:																	
Spring			1.1	.4		2.0	46.7			36.0	11.2		.1	2.4	.1		
Fall		.1	1.3	.9		.1	51.8	.6		10.2	33.8			1.0	.2		
Returns for year			1.2	.6		1.1	49.3	.4		22.7	22.8			1.7	.2		
1925:																	
Spring			1.5			1.4	43.1	1.7		15.1	30.7			6.4	.1		
Fall			.2	.4		.1	40.2	12.0		2.0	43.7	.1		.5	.8		
Returns for year			.6	.3		.6	41.2	8.5		6.4	39.3	.1		2.5	.5		
1926:																	
Spring			.1	.7		1.2	61.5	.8		11.9	19.4		.2	3.7	.3		0.2
Fall				3.7		.2	49.9	3.9		2.8	37.2			.8	1.5		
Returns for year			.1	3.1		.4	52.5	3.2		4.8	33.2			1.5	1.2		
1927:																	
Spring			1.5	.4		1.4	50.0	.3		25.9	15.1			5.2	.1	0.1	
Fall			.7	.8		.9	38.7	2.8		4.4	49.4			2.1	.2		
Returns for year			1.2	.6		1.2	45.2	1.3		17.1	29.4			3.9	.1		
1928:																	
Spring			.7	.3		2.1	38.7	.2		43.4	8.3		.1	6.0	.1	.1	
Fall		.2	.9	.7		.7	40.9	1.9		11.8	39.9	.1		1.0	1.9		
Returns for year		.1	.8	.5		1.6	39.5	.8		31.4	20.3		.1	4.1	.8		
1929:																	
Spring		.1	.8	.6		3.7	43.6	1.1	0.2	31.0	14.3		.1	4.1	.4		
Fall			.4	.3		.3	39.7	.7		4.8	46.7	.7		3.9	2.5		
Returns for year		.1	.6	.4		2.3	42.0	.9	.1	20.2	27.7	.3	.1	4.0	1.3		

In figures 6 and 7 is presented the relationship between the percentage of fish of a particular ocean history in the escapement and the percentage of fish of the same ocean history in the return. In these and the following figures in this section, lines purportedly fitting the data have been omitted intentionally. The two important questions on which information is desired are (1) whether or not there is a correlation between the percentage occurrence of a particular age group in the escapement and the percentage occurrence of that same age group in the return, and (2) whether or not the values fluctuate around a ratio of 1 to 1. To facilitate observation of the second point, a line representing a ratio of 1 to 1 has been included in each figure.

The relationship between the percentage of fish of a certain ocean history in the escapement and the percentage of fish of the same ocean history in the return, may be considered linear and is such that there will be approximately the same percentage of fish of a single ocean history in the return as there was in the escapement. There appears to be a slight indication that the two-ocean fish are making up a lesser percentage of the returns than they did of the escapements and, conversely, that the three-ocean fish are making up a greater percentage of the returns than they did of the escapements, but the tendency is not marked and probably is not significant.

In figures 8 and 9 is presented the relationship between the percentage of fish of a particular fresh-water history in the escapement and the percentage of fish of the same fresh-water history in the return. There is a positive correlation between the the two variables, although the relationship is very peculiar. For each 1 percent of three-fresh-water fish in the escapement there is approximately 0.75 percent of three-fresh-water fish in the return, and for each 1 percent of four-fresh-water fish in the

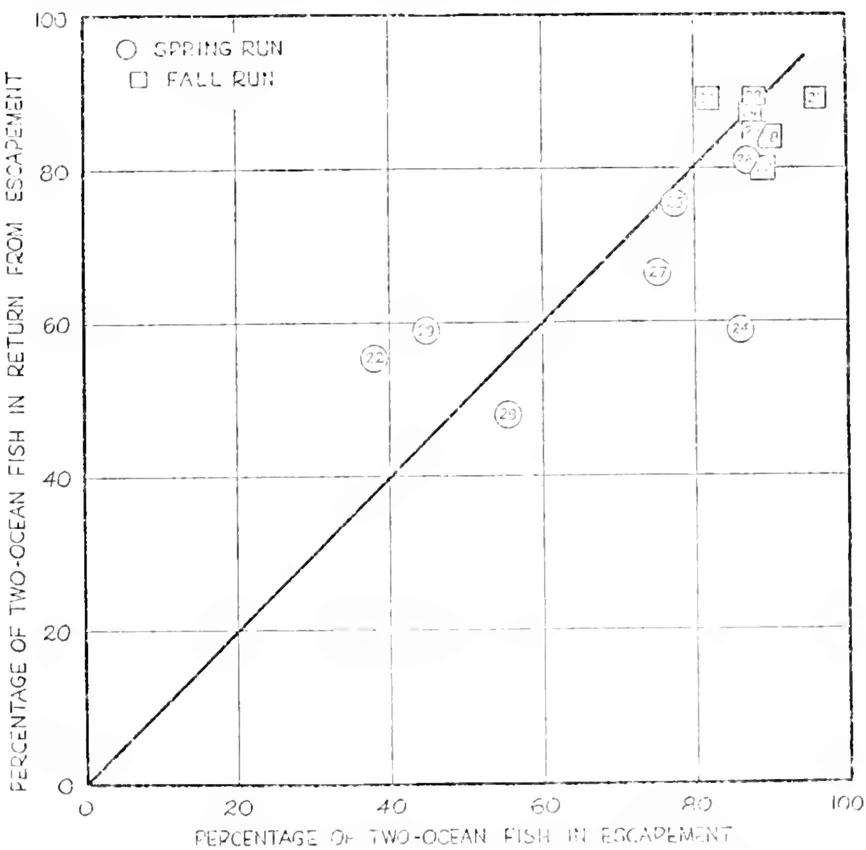

FIGURE 6.—Percentage of two-ocean fish in return plotted against percentage of two-ocean fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

escapement there is more than 2 percent of four-fresh-water fish in the return. Such a condition could not have prevailed for any great length of time. Obviously, if such a relationship had existed for several complete cycles, the three-fresh-water fish would disappear from the population and only those that migrate to the ocean in their fourth year would remain.

The age analysis based on scale samples collected during 1916, 1917, 1919, and 1921 (Gilbert and Rich, 1927), demonstrated 88.5, 88.1, 91.3, and 93.4 percent, respectively, of three-fresh-water fish in the samples. While the percentages of three-fresh-water fish in the small samples taken from the runs of those years are not exactly comparable to the data under consideration, it is evident that the three-fresh-water age group was dominant.

The change in age composition might be due to any one, or a combination, of the following causes: (1) An increase in the ocean mortality of the 3-year seaward

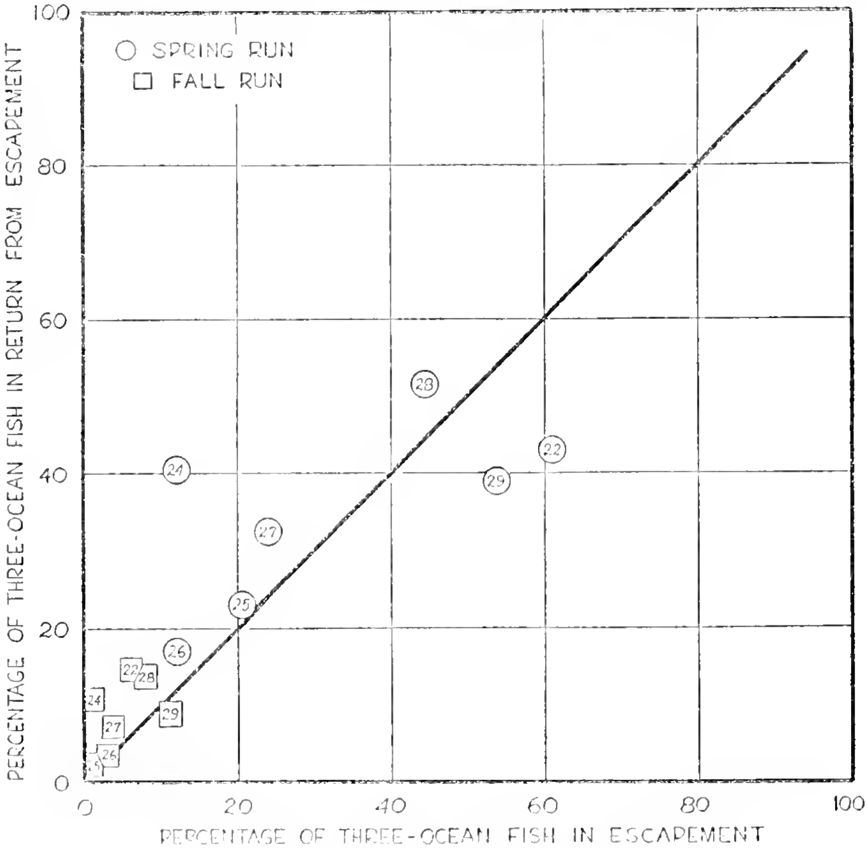

FIGURE 7.—Percentage of three-ocean fish in the return plotted against percentage of three-ocean fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

migrants or a decrease in the ocean mortality of the 4-year seaward migrants; (2) an increase in the fresh-water mortality of the 3-year seaward migrants or a decrease in the fresh-water mortality of the 4-year seaward migrants; (3) an increase in the length of fresh-water residence.

The ocean mortality of the 4-year seaward migrants, as determined by the marking experiments reported in a later section, is less than that of the 3-year seaward migrants. This might be expected as they are larger at the time of migration than the 3-year migrants. There is no evidence that a marked change has taken place in the ocean mortality of either the 3-year or the 4-year seaward migrants.

A change in environment that would increase or decrease the mortality of the fingerlings in the lake should affect each age group of seaward migrants in a similar manner. No data are at hand to indicate that environmental conditions have

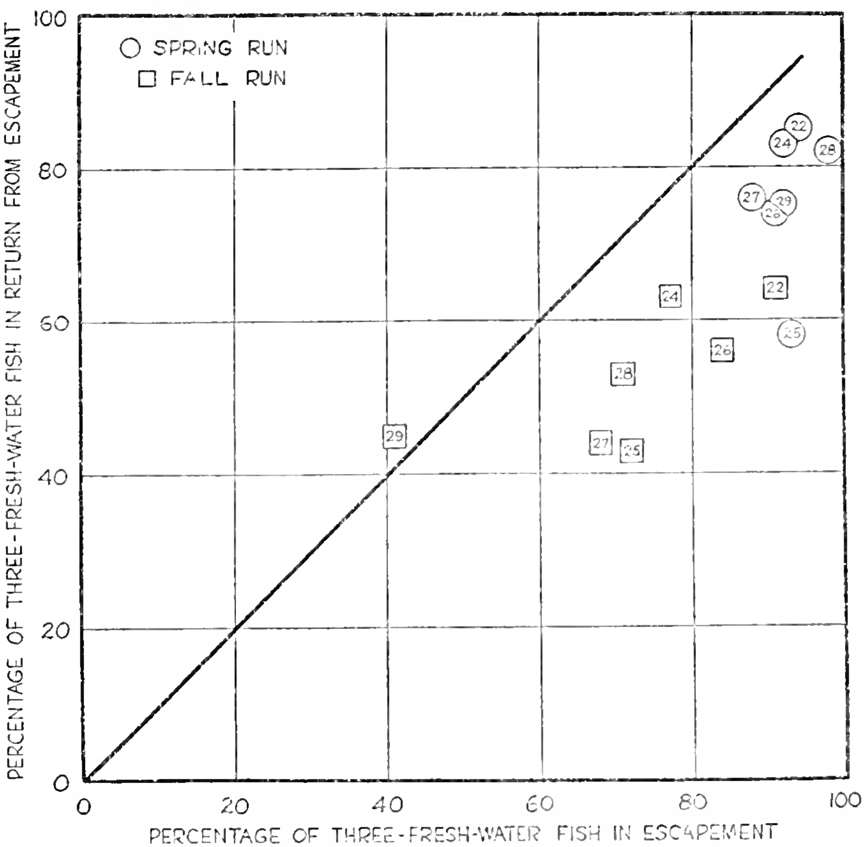

FIGURE 8.—Percentage of three-fresh-water fish in the return plotted against percentage of three-fresh-water fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

altered in such a manner as to affect the mortality of one age group without affecting the mortality of the other age group.

It is probable that the shortage of phosphorus and silica in Karluk Lake during the summer months, which acts as a limiting factor in the production of phytoplankton, also indirectly affects the growth of the red salmon fingerlings. A decrease in the growth rate of the fingerlings may well result in an increase in the length of time spent in fresh water. Data presented in a later section indicate that the fastest growing fingerlings migrate seaward sooner than do the slower growing ones. Consequently, anything affecting the growth rate of the fish would probably cause a change in the time of seaward migration.

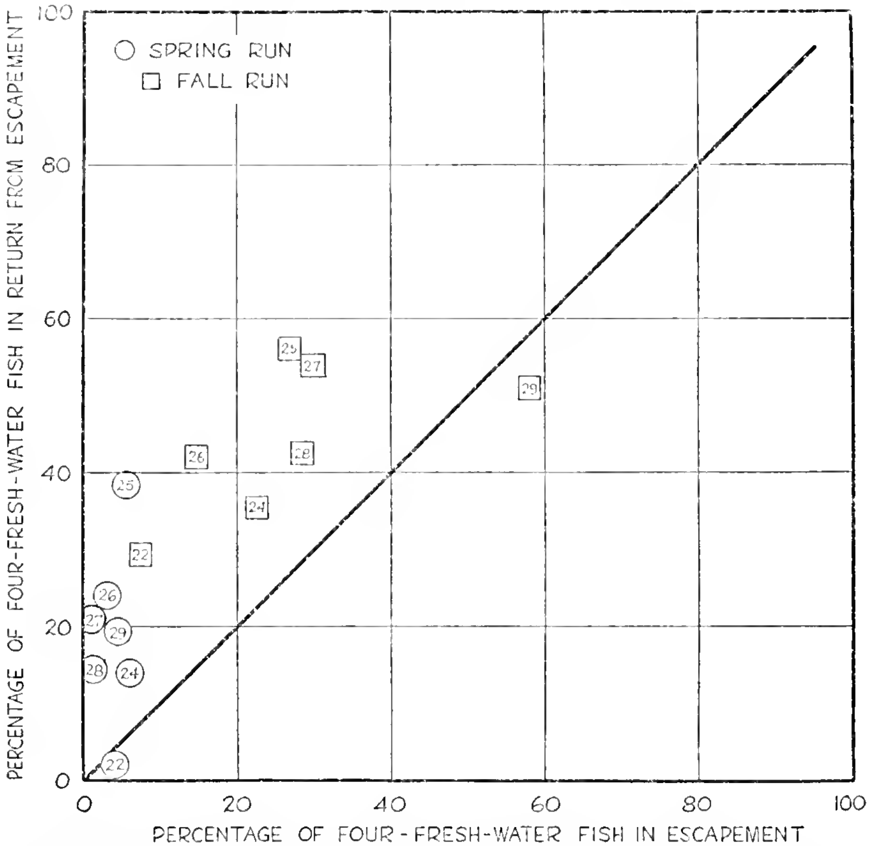

FIGURE 9.—Percentage of four-fresh-water fish in return plotted against percentage of four-fresh-water fish in escapement for the years 1922 and 1924 to 1929, inclusive. The straight line represents a ratio of 1 to 1.

SEAWARD MIGRATIONS

The seaward migration of Karluk River red salmon takes place during the last week of May and the first 2 weeks of June each year. A few fish migrate sometimes a day or two earlier or later than this period but the major part of the migration, and frequently the entire migration, takes place during these 3 weeks. During the migration period the seaward migrants can be observed in front of the counting weir where they congregate in schools of a few hundred to tens of thousands. Only occasionally can they be seen going through the weir during the daytime, but just at dusk the schools above the weir drop downstream and begin to pass through the spaces between the pickets. Where there is any appreciable current, the fish always head upstream even when migrating downstream. Seaward migrants are present in the river above the weir for only 10 to 16 days each year, although the migration period may extend over a period of 3 weeks. They may be quite abundant one day, entirely absent the next, and present again the following day.

The percentage occurrence of the various age groups in the random samples of seaward migrants collected at the weir site is presented in table 26. Samples were not collected every day that migrants were present in the river, but since 1930 samples have been taken every day that fish were abundant.

TABLE 26.—*Percentage occurrence of various age groups in the random samples of seaward migrant red salmon for the years 1925 to 1936, inclusive*

Week ending—	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936
2-YEAR SEAWARD MIGRANTS												
May 31						1.0						
June 7	0.4					1.0	0.3	0.2		0.5	0.1	4.0
June 14		0.9	0.8			1.9	1.0	.2			.7	7.7
June 21			1.7	0.8		1.2	1.0	2.0		1.0		
June 28									3.5			
3-YEAR SEAWARD MIGRANTS												
May 31		67.3			21.0	56.8	73.5	38.8	32.5	83.2	81.0	58.8
June 7	90.0	79.9	46.7	45.0	30.3	52.1	86.2	53.0	45.2	93.3	82.3	79.0
June 14	84.0	73.5	52.1	72.9	70.6	69.8	92.5	75.9	68.7		88.5	80.3
June 21			78.2	86.7		74.1	96.1	81.0		96.0		
June 28								88.0	75.5			
4-YEAR SEAWARD MIGRANTS												
May 31		32.7			77.0	40.2	25.6	60.5	65.0	15.8	19.0	40.2
June 7	9.6	19.7	53.3	54.2	69.3	45.2	13.0	46.2	52.8	6.0	17.6	17.0
June 14	16.0	25.1	47.1	26.7	29.4	27.9	6.5	23.1	30.0		10.7	11.3
June 21			20.1	12.5		24.5	2.9	15.0	21.0	3.0		
June 28								12.0				
5-YEAR SEAWARD MIGRANTS												
May 31					2.0	2.0	0.9	0.7	2.5	1.0		1.0
June 7		0.4		0.8	.1	1.7	.5	.6	2.0	.3		
June 14		.5		.4		.4		.8	1.3		0.1	.7
June 21						.2		2.0				
Number of fish in sample	644	602	358	720	1,025	1,811	2,050	2,007	1,197	900	1,800	1,000

In considering the two major age groups, 3 and 4, it will be noted that the percentage of the 4-year group decreases as the migration proceeds while the percentage of the 3-year group increases. This phenomenon, while not so obvious because of the small numbers in the samples, also appears to exist in the two minor age groups for the percentage of the 5-year group decreases and the percentage of the 2-year group increases as the migration proceeds. There is a tendency for the older age groups to migrate earlier than the younger age groups.

The average sizes of the seaward migrants in the samples collected in the years 1925 to 1936, inclusive, are presented in table 27. There is a marked decrease, especially among the 4-year migrants, in the average size during successive periods of sampling. The decrease in size of the 3-year migrants would probably be more apparent were it not for the fact that the fish are just commencing to grow at the beginning of the migration period, and those fish which migrate late in the season have grown a certain amount as indicated by two or three wide-spaced rings beyond the winter check on their scales. Fish of the 4-year and 5-year groups seldom show any new growth of the year until late in the migration period.

From a study of the rate of growth of the fingerlings, as determined by their scales, and from the above-mentioned data relating to the change in age composition and size of the migrants during each year's seaward migration, the following trend of events is indicated. Of the progeny of a given brood year, the fastest growing individuals (hence the largest) migrate to the ocean in the spring of their second year. In the spring of the third year the largest individuals of the population left in the lake

TABLE 27.—*Average length in millimeters of 2-, 3-, 4-, and 5-year seaward migrants in weekly samples for the years 1925 to 1936, inclusive*

Year	Item	Week ending— May 31	June 7	June 14	June 21	June 28	Year	Item	Week ending— May 31	June 7	June 14	June 21	June 28
	2-YEAR SEAWARD MIGRANTS												
1925	Number		2				1932	Number		3	1	1	
	Mean		112.50					Mean		110.17	96.50	107.5	
	σ		7.07					σ		12.34			
1926	Number			2			1933	Number					7
	Mean			100.00				Mean					113.79
	σ			10.06				σ					4.68
1927	Number			1	2		1934	Number		2		1	
	Mean			127.50	103.00			Mean		119.5		125.5	
	σ				3.53			σ		2.83			
1928	Number				2		1935	Number		1	6		
	Mean				110.50			Mean		107.5	117.5		
	σ				2.83			σ			9.36		
1930	Number	3	6	4	6	17	1936	Number		11	21		
	Mean	118.17	101.17	105.50	109.33	113.85		Mean		109.95	111.07		
	σ	2.58	7.15	4.16	4.26	6.87		σ		3.59	3.43		
1931	Number		2	6	1								
	Mean		99.50	113.17	119.50								
	σ		25.45	21.61									
	3-YEAR SEAWARD MIGRANTS												
1925	Number		90	131			1931	Number	399	632	527	196	
	Mean		135.56	135.09				Mean	128.87	129.96	130.55	128.06	
	σ		8.27	6.92				σ	8.22	7.93	7.06	7.73	
1926	Number	101	183	164			1932	Number	265	286	444	81	88
	Mean	136.47	135.82	134.91				Mean	131.44	131.81	131.73	132.01	135.97
	σ	5.60	6.87	7.56				σ	5.60	5.31	6.34	6.84	5.86
1927	Number		56	62	93		1933	Number	65	226	204		151
	Mean		132.59	135.40	134.11			Mean	136.90	137.68	135.95		131.15
	σ		6.71	6.69	6.04			σ	6.57	6.82	7.10		7.98
1928	Number		108	175	208		1934	Number	333	373		96	
	Mean		129.83	128.34	125.85			Mean	141.83	138.92		140.32	
	σ		5.63	6.21	8.46			σ	7.09	8.17		8.04	
1929	Number	21	23	274			1935	Number	81	660	797		
	Mean	133.21	130.07	127.69				Mean	141.56	141.96	140.86		
	σ	6.32	7.32	7.89				σ	5.01	6.16	8.16		
1930	Number	174	340	185	436	173	1936	Number	235	237	241		
	Mean	124.71	126.66	131.30	128.16	124.63		Mean	136.19	132.70	129.59		
	σ	6.52	6.81	5.71	7.31	7.61		σ	6.60	8.37	9.04		
	4-YEAR SEAWARD MIGRANTS												
1925	Number		47	25			1931	Number	139	95	37	6	
	Mean		147.48	141.70				Mean	143.31	139.68	135.20	132.33	
	σ		6.55	8.05				σ	7.92	8.61	7.14	6.24	
1926	Number	49	45	56			1932	Number	413	249	135	15	12
	Mean	147.13	145.90	139.98				Mean	145.11	142.94	137.83	131.30	138.00
	σ	6.92	7.00	6.22				σ	7.11	7.39	8.43	5.32	5.21
1927	Number		64	56	24		1933	Number	130	264	89		42
	Mean		145.86	146.79	144.17			Mean	149.27	147.24	142.23		138.36
	σ		7.24	4.90	5.45			σ	8.01	7.81	10.12		9.40
1928	Number		130	64	30		1934	Number	63	24		3	
	Mean		143.42	142.20	137.83			Mean	155.34	147.79		142.17	
	σ		6.74	6.02	7.87			σ	10.23	12.02		12.34	
1929	Number	77	96	114			1935	Number	19	139	96		
	Mean	146.47	145.74	137.34				Mean	153.45	153.76	148.95		
	σ	6.49	5.40	11.12				σ	6.88	6.62	11.40		
1930	Number	123	295	74	144	38	1936	Number	161	51	34		
	Mean	140.65	140.13	142.31	136.26	126.68		Mean	149.41	142.62	137.12		
	σ	8.10	7.80	7.30	9.48	9.16		σ	8.19	9.26	7.26		
	5-YEAR SEAWARD MIGRANTS												
1926	Number		1	1			1932	Number	5	3	5	2	
	Mean		150.50	175.50				Mean	152.90	153.50	144.50	132.50	
	σ							σ	4.98	2.00	10.75	2.83	
1928	Number		2	1			1933	Number	5	10	4		
	Mean		150.50	149.50				Mean	145.90	150.90	144.75		
	σ		0.00					σ	2.07	5.72	6.99		
1929	Number	2	1				1934	Number	4	1			
	Mean	149.00	160.50					Mean	161.75	158.50			
	σ	16.26						σ	4.79				
1930	Number	6	11	1	1		1935	Number			1		
	Mean	143.33	138.05	152.50	137.50			Mean			145.50		
	σ	6.14	6.35					σ					
1931	Number	5	4				1936	Number	4		2		
	Mean	146.50	141.75					Mean	149.75		152.00		
	σ	8.34	3.77					σ	3.10		13.44		

migrate seaward. At the end of the migration period a part of this population is present in the lake. These fish remain for another year and obtain more growth. In the fourth year, the largest individuals remaining in the lake proceed seaward, the time of appearance in the migration being correlated with their size. The slowest growing individuals of the entire progeny which have not migrated remain in the lake for another year and then migrate seaward in their fifth year.

The older fish are of a larger average size than those of lesser age and their larger size is due to the longer growing period that precedes migration. Fish in the older age groups are usually the slower growing fish of the progeny from a particular spawning. Thus, the urge to migrate seaward is related to the size and growth rate of fingerlings, and it appears that environmental conditions that affect the growth of the fish during the time spent in the lake also affect the time at which the fingerlings migrate to the ocean.

The data on the percentage of males in the samples of migrants which were examined to determine sex are presented in table 28. The males and females were equally represented. Grouping the 3- and 4-year fish, it was found that the total of 11,080 fish examined consisted of 5,557 males and 5,523 females. The slight variations in the sex ratios from year to year are probably due to chance because there is no significant statistical difference in the ratios.

TABLE 28.—*Number of 3-year and 4-year migrants examined and percentage of males in the samples*

Year	Number of 3-year fish examined	Number of males	Percentage of males	Number of 4-year fish examined	Number of males	Percentage of males
1925	570	296	51.9	72	40	55.6
1926	448	232	51.8	150	71	47.3
1927	211	115	54.5	144	75	52.1
1928	491	262	53.4	224	127	56.7
1929	318	168	52.8	287	161	56.1
1930	1,308	659	50.4	674	335	51.3
1931	1,754	831	47.4	277	132	47.6
1932	1,256	632	50.3	833	401	48.1
1933	646	320	49.5	525	252	48.0
1934	802	401	50.0	90	47	52.2
Total	7,804	3,916	50.18	3,276	1,641	50.09

SEX RATIOS OF ADULT FISH

The sex ratio of the adult fish is in marked contrast to that of the seaward migrants. Data on the percentage occurrence of males in the samples for the years 1922 and 1924 to 1936 are presented in table 29, arranged according to the length of time spent in the ocean. The percentage occurrence of the males decreases with increased ocean residence. All of the zero-ocean fish [8] are males. The average percentages of males in the one-ocean fish, of varying periods of fresh-water residence, range from 100 percent to 75 percent. The average percentages of males in the two-ocean fish range from 62 percent to 32 percent, while the average percentages of males in the three-ocean fish of varying fresh-water residence range from 38 percent to 35 percent.

[8] Fish which spend only a few months in the ocean and return as mature fish in the fall of the same year in which they migrated seaward.

TABLE 29.—*Number of fish of each age group examined, and the percentage of males in samples for the years 1922, 1924, to 1928, and 1930 to 1936, inclusive*

Age group	1922		1924		1925		1926		1927	
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males
3_3			1	100.0						
4_4	3	100.0	18	100.0			1	100.0	1	100.0
5_5	1	100.0								
3_2										
4_3	19	89.5	161	95.0	228	94.7	35	100.0	151	95.4
5_4	27	85.2	176	69.3	71	84.5	15	100.0	136	87.5
6_5	1	100.0			1	100.0	3	100.0	2	50.0
3_1					30	66.7	19	57.9	1	0
4_2	16	18.8	17	23.5	100	45.5	207	46.4	17	29.4
5_3	1,511	48.4	3,845	46.6	3,877	43.6	6,426	43.2	3,476	43.1
6_4	138	57.2	660	46.8	920	43.2	743	46.4	477	46.1
7_5							9	22.2	9	55.6
4_1	3	100.0	1	100.0	12	41.7	35	20.0	10	40.0
5_2	9	44.4	18	38.9	14	35.7	141	34.8	201	27.9
6_3	737	41.9	217	44.2	227	41.4	479	34.0	315	35.6
7_4	4	25.0	18	50.0	23	34.8	67	31.3	32	43.8
8_5									1	100.0
7_3										
8_4							1	100.0		
Total	2,469		5,132		5,513		8,172		4,829	

Age group	1928		1930		1931		1932		1933	
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males
3_3										
4_4										
5_5										
3_2										
4_3	16	93.8	19	100.0	14	100.0	40	97.5	2	100.0
5_4	22	90.9	34	100.0	108	71.3	59	91.5	4	75.0
6_5					6	66.7			1	100.0
3_1										
4_2	18	44.4	2	50.0	51	52.9	71	36.6	2	50.0
5_3	2,391	42.2	601	42.3	1,821	42.8	1,821	40.5	85	52.9
6_4	688	41.9	141	44.7	1,453	39.2	1,314	40.4	91	48.4
7_5	4	50.0			3	33.3	25	28.0	7	28.6
4_1	1	100.0					8	25.0		
5_2	7	42.9	19	42.1	16	37.5	85	42.4	4	50.0
6_3	1,052	38.4	223	41.2	266	36.1	233	32.6	21	25.0
7_4	37	51.4	13	30.8	44	34.1	80	37.5	1	100.0
8_5										
7_3			1	100.0						
8_4										
Total	4,236		1,053		3,782		3,736		221	

Age group	1934		1935		1936		1922–36		
	Number examined	Percentage males	Number examined	Percentage males	Number examined	Percentage males	Total number examined	Number males found	Percentage males
3_3							1	1	100.0
4_4							23	23	100.0
5_5							1	1	100.0
3_2			1	100.0			1	1	100.0
4_3			210	96.2	114	100.0	1,009	970	96.1
5_4	4	75.0	64	79.7	13	92.3	733	593	80.9
6_5			2	100.0			16	12	75.0
3_1							50	31	62.0
4_2	70	38.6	148	49.3	78	48.7	807	359	44.5
5_3	311	51.8	1,312	42.5	3,510	42.2	30,987	13,517	43.6
6_4	273	39.2	898	39.9	492	43.3	8,288	3,523	42.5
7_5	1	100.0	30	23.3	22	45.5	110	36	32.7
4_1			29	41.4			99	35	35.4
5_2	22	59.1	107	30.8	241	39.4	884	317	35.9
6_3	327	43.4	284	35.9	567	35.6	4,942	1,891	38.3
7_4	34	32.4	91	33.0	154	40.9	598	227	38.0
8_5							1	1	100.0
7_3							1	1	100.0
8_4							1	1	100.0
Total	1,042		3,176		5,191		48,552	21,540	

Thus there is a decrease in the percentage of males, and conversely an increase in the percentage of females, with increased length of time spent in the ocean. The males tend to mature after a shorter period of ocean residence than the females, and this precocious development of the males also is apparent from a consideration of the total age of the mature fish. In a group of the same ocean history, with the exception of the three-ocean fish, the younger fish are more predominately male than the older members of that group.

The percentages of males and females returning from the seaward migrations of 1923 to 1933, inclusive, are presented in table 30. These percentages were determined by calculating the number of males and females of various ocean histories returning from a single seaward migration and then adding the several groups together to obtain the total number of males and females returning from that migration. The percentage of males varied from 40.1 to 48.8 percent and the percentage of females from 51.2 to 59.9 percent, and the average for all years was 43.9 percent males and 56.1 percent females.

TABLE 30.—*Percentage of males and females in the returns from the seaward migrations of 1923 to 1933*

Year of seaward migration	Percentage of males in return	Percentage of females in return	Year of seaward migration	Percentage of males in return	Percentage of females in return
1923	44.3	55.7	1930	40.1	59.9
1924	45.3	54.7	1931	48.8	51.2
1925	43.0	57.0	1932	43.5	56.5
1926	45.0	55.0	1933	40.7	59.3
1927	43.3	56.7			
1928	42.0	58.0	Average	43.9	56.1
1929	47.0	53.0			

The sex ratio of these fish changes from approximately 50 percent males and 50 percent females at the time of seaward migration to approximately 44 percent males and 56 percent females on their return from the ocean. Since the males, on the average, spend less time in the ocean than the females, the mortality of the males should be less than that of the females, which should result in a preponderance of males. A part of the Karluk run is intercepted by a gill-net fishery to the north and east of the Karluk River, and because of the size of the gill-net mesh employed, a great percentage of the larger fish in the run is captured. As the average size of the males is slightly greater than the average size of the females, more males than females are captured and thus the percentage of males in the fish arriving at the Karluk River, where the data for table 30 were obtained, is reduced. It is not considered that the selective action by the gill nets accounts entirely for the discrepancy in the sex ratio because the gill-net catches are fairly small in relation to the size of the run as a whole. A differential mortality in favor of the females during the time spent in the ocean does not appear probable. A satisfactory explanation of this phenomenon is lacking at the present time.

MARKING EXPERIMENTS

A series of marking experiments was begun at Karluk River, Alaska, in 1926.[9] In these experiments, red salmon migrating seaward were marked by the removal of

[9] These marking experiments were initiated by the late Dr. C. H. Gilbert, and Dr. W. H. Rich, both of the former United States Bureau of Fisheries.

two or three fins, so that their presence in the future runs of fish could be noted. The experiments were initiated to determine the rate of survival of the fish during their stay in the ocean.

Rich and Holmes (1929), in reviewing the results of previous marking experiments, pointed out that fish occasionally have one fin, or two fins in close proximity to each other (both ventrals), accidentally missing. In the marking experiments carried on at Karluk the adipose and one or two other fins were amputated, as it was considered that the finding of a fish with two widely separated fins missing as a result of an accident would be an extremely rare occurrence.

During the marking of seaward migrants at Karluk and the subsequent examination of the run of adult fish, salmon have been found with the following fins missing: adipose, right ventral, left ventral, both ventrals, right pectoral, and left pectoral. Fish with the dorsal, anal, and caudal, or one of the above mentioned fins badly deformed, have also been observed. More than 400,000 seaward migrant red salmon have been examined at Karluk, and in no case has a fish been found which had both the adipose and some other fin missing or badly deformed.

The results of other marking experiments, in which data on the percentage return of marked fish from the experiments were obtained, are reviewed for the sake of comparison with the results obtained at Karluk. It should be noted that in several instances species other than red salmon were marked, and in no instance were the fish marked as large as the seaward migrants marked in the Karluk experiments.

Rich and Holmes (1928) in their experiemnts in marking chinook salmon on the Columbia River, from 1916 to 1927, had returns ranging from 0.002 to 0.45 percent of the number of fish liberated from a single marking experiment. They pointed out that—

> These figures have very little significance, however, because they represent not the total returns but an unknown and varying proportion of the total.

In four of their experiments the records are believed to be fairly complete, and in their opinion

> . . . the returns that have not come to our attention certainly would not add enough to make the totals more than 1 or 2 percent of the liberation.

Snyder (1921, 1922, 1923, 1924) marked chinook salmon on the Klamath and Sacramento rivers in California, and the proportion of marked fish recovered was approximately the same as in the experiments of Rich and Holmes.

In 1930, Davidson (1934) marked 36,000 seaward migrant pink salmon at Duckabush River, Hoods Canal, Wash., by amputating the adipose and dorsal fins. In 1931, 50,000 seaward migrant pink salmon were similarly marked at Snake Creek, Olive Cove, Alaska. These fish were approximately 40 mm. long at the time of marking. From the first experiment 10 marked fish were recovered, or 0.028 percent of the number marked. From the second experiment 23 marked fish were recovered, and it was calculated that the total number of marked fish in the escapement was 54, or 0.108 percent of the number marked. These data represent only the return of marked fish in the escapement. However, the total return from either experiment could hardly have equaled 1 percent of the number of fish marked.

Pritchard (1934a) marked 8,741 pink-salmon fingerlings at Cultus Lake, British Columbia, in 1932, by the amputation of both ventral fins. These fish were released into the Vedder River below the mouth of Sweltzer Creek which is the outlet stream of Cultus Lake.

One hundred and twenty-four thousand pink-salmon fingerlings of Tlell River (east coast of Graham Island) were marked by the amputation of the adipose and left ventral fins. These fish together with 750,000 unmarked individuals, from the same source, were liberated in McClinton Creek, Massett Inlet.

In 1933, fish with the following fins missing were recovered at various localities in Puget Sound, British Columbia, and Chignik, Alaska: adipose 576, adipose and left ventral 40, both ventrals 64, right ventral 54, adipose and right ventral 20, left ventral 56. No marked fish were recovered in Sweltzer Creek, Tlell River, or McClinton Creek though counting weirs were maintained in these streams.

During 1933, Pritchard (1934b) marked 108,000 pink-salmon fry at McClinton Creek, Massett Inlet, by amputating both ventral fins. The following numbers of fish with fins missing were recovered at various localities in British Columbia during 1934: both ventrals 3,285, left ventral 195, right ventral 139, adipose 100, and left pectoral 15.[10] Of these totals, 2,950 with both ventrals, 66 with left ventrals, 95 with right ventrals, and 2 with adipose fins absent were recovered at McClinton Creek. Thus, of the number of fish marked by removal of both ventrals 2.73 percent returned to McClinton Creek. The total return was possibly higher than 3,285 (3.04 percent of the number marked) because all of the fish bound for McClinton Creek were not sampled.

In 1934, Kelez (1937) initiated two marking experiments on hatchery-raised coho salmon at Friday Creek, a tributary of the Samish River. In the first experiment 26,150 fingerlings were marked by the amputation of the adipose and dorsal fins. The fish were liberated during May when they averaged 47.4 mm. in length. Seven marked fish were recovered as adults, or 0.027 percent of the number marked.

In the second experiment 26,150 fingerlings of the same brood were marked by the amputation of the dorsal and left ventral fins and liberated during November when they averaged 101.6 mm. in length. From this experiment 469 marked fish were recovered, or 1.79 percent of the number marked.

Assuming that there was not a differential mortality caused by the marking in the two groups of fish in the experiments, these data indicate a striking increase in the survival rate of the fingerlings retained in the hatchery ponds for a longer period of time. The returns from these experiments comprise only those fish which escaped the sport and commercial fisheries.

A series of marking experiments has been conducted on the red salmon of Cultus Lake, British Columbia. In 1927 (Foerster, 1934), 91,600 seaward migrants were marked by the amputation of the adipose and both ventral fins. From this marking, 804 fish, or 0.88 percent, were recovered during 1929 and 1930 at the counting weir below Cultus Lake, these being the total number of marked fish returning to Cultus Lake from this experiment. Of the 158,100 unmarked fish, 3,930, or 2.49 percent, returned to Cultus Lake.

During 1928 (Foerster, 1936a), 99,700 seaward migrants were marked by the

[10] The finding of fish with adipose fins missing, and left pectoral fins missing only confirms the long established fact that fish occur in nature with fins missing. The finding of fish with right or left ventral fins missing is due in part to natural deformities, and may be due to regeneration of one or the other of the fins of the fish marked both ventrals. A part of the fish with both ventral fins missing may not be returns from the experiment but may be fish with natural deformities.

amputation of both ventral fins and the posterior half of the dorsal. From this marking, 1,340 fish, or 1.34 percent of the number marked, were recovered at the counting weir below Cultus Lake; and these were the total number of marked fish that returned to Cultus Lake from this experiment. Of the unmarked seaward migrants, 3.2 percent returned to Cultus Lake.

In 1930 (Foerster, 1936b), 104,061 seaward migrants were marked by the amputation of both ventral fins. A total of 3,821 fish, or 3.67 percent of the number marked, was recovered from the commercial fishery and at the counting weir below Cultus Lake. It was considered that the recovery was at least 90 percent of the total number of marked fish returning from the experiment, so that the actual return ". . . probably lay somewhere between 3.67 and 4.1 per cent."

During 1931 (Foerster, 1936b), 365,265 seaward migrants were marked by the amputation of the adipose and both ventral fins. A total of 12,803 fish, or 3.51 percent of the number marked, was recovered from the commercial fishery and at the counting weir below Cultus Lake. The recovery was at least 95 percent of the total number of marked fish returning from the experiment so that the actual return ". . . lies between 3.5 and 3.7 percent."

In Foerster's experiments of 1927 and 1928 a greater survival was found among the unmarked fish than among the marked fish. Three factors were considered in an endeavor to account for the disparity.

> . . . infiltration of unmarked adults from other areas, the straying of marked individuals to other spawning regions or a definite differential mortality among marked groups.

Evidence was produced to show cause for ruling out the first two factors, and it was concluded that—

> There remains, therefore, only the factor of differential mortality among the marked individuals, and on the data available this is held to be the one largely responsible for the lower return of marked adults when compared with that for the unmarked.

The differential mortality was calculated to be 65 percent for the 1927 experiment and 58 percent for the 1928 experiment, and the probable value was considered to be the mean of the two values or 62 percent. Thus there was a 186 percent greater survival among the unmarked fish than among the marked fish of the first experiment, and a 138 percent greater survival among the unmarked fish than among the marked fish of the second experiment, and the probable value was considered to be approximately 163 percent.

Based on the information on differential mortality between marked and unmarked fish derived from the 1927 and 1928 marking experiments and on the data collected from the marking experiments of 1930 and 1931, Foerster considered that the survival of Cultus Lake red salmon during the time spent in the ocean ranged between 3.5 percent (his lowest percentage return uncorrected for differential mortality) and 11.7 percent (his highest percentage return, 4.1 percent, multiplied by 2.86 to correct for differential mortality). The most probable value was considered to be 9.9 percent (the mean probable value of the recoveries, 3.75 percent, multiplied by a mean value, 2.63, to correct for differential mortality).

MARKING OF KARLUK RIVER RED SALMON

The Karluk River is relatively shallow, and as the seaward migrant fingerlings tend to congregate above the counting weir, they can easily be captured. A pen about 5 feet square of ½-inch bar wire netting, having a gate for the fish to enter, was constructed in the river. A seine was passed around a school of fish, and an end of the seine brought to each side of the gate. By gradually drawing in the ends of the seine, the fish were induced to enter the pen, and the gate was closed. Several thousand migrants can be held in the pen at one time without injury. Two or three hundred migrants were caught and transferred to a wash tub partially filled with water. The tub of fish was then carried from the pen to the marking shed below the weir. The fish were removed from the tub one at a time, the adipose and one or two other fins removed by means of a nail clipper, and the fish dropped into the river free to proceed downstream. During the entire operation the fish are out of water for less than 10 seconds. Samples of marked fish have been held in tanks for several days after marking, and the fish have shown no ill effects from the operation, though some of the fish marked by the removal of either of the pectoral fins appeared to have a slight list.

The age group composition of the marked migrants was determined by multiplying the number of migrants marked each day by the percentage of the various age groups in the migration for that day as determined by the analysis of data obtained from scale samples of the fish.

RECOVERY OF MARKED FISH

Owing to the magnitude of the run of Karluk red salmon, it was impossible to examine every fish to search for marked individuals. The method employed to determine the total number of marked fish was as follows:

As large a portion as possible of each day's catch of red salmon, taken by means of beach seines near the mouth of the Karluk River, was examined for the presence of marked fish by an employee of the Fish and Wildlife Service who, during the examination, was stationed in the cannery. Each red salmon was examined and counted as it passed along the chute. All fish with missing or mutilated fins were put aside and re-examined later to determine whether they were marked fish. Scale samples were taken from all marked fish found, and scale samples were taken at random from the catch to determine the age composition. The number of marked fish of each age found and the number of fish of that same age examined were determined at weekly intervals throughout the season. The total number of marked fish of each age found was divided by the total number of fish of the same age group examined to determine the percentage occurrence of marked fish in that age group. Data were collected on the number of Karluk red salmon in the commercial catch and also the number in the escapement, hence, the total number of fish of each age group in the run can be determined for the season. Multiplying the number of fish of a given age in the run by the percentage occurrence of marked fish in that age group gave the calculated number of marked fish of that age group returning.

Since it is considered that there are two runs of red salmon to the Karluk River, it would be preferable to divide each marking experiment into two parts, i. e., spring run and fall run. Unfortunately, there is no way of determining which are spring run or which are fall run seaward migrants. The percentage occurrence of marked fish of each age group is fairly constant throughout the season, indicating that proportionate numbers of the two runs are marked.

EXPERIMENTS IN 1926

A total of 47,691 seaward migrant red salmon were marked by the amputation of two fins. Two combinations were used, the adipose and right ventral, and the adipose and left ventral. Since approximately the same number of fish were marked each day by each mark, the data can be grouped together and considered as one experiment or divided according to the marks used and considered as duplicate experiments. Although the experiments were carried on simultaneously, the one in which the fish were marked by the amputation of the adipose and right ventral fins will be referred to as the first experiment, and the one in which the fish were marked by the amputation of the adipose and left ventral fins will be referred to as the second experiment.

Commercial fishing was limited in 1929 and the run of that year could not be adequately sampled to detect the presence of marked fish. Consequently, no accurate means of determining the number of three-ocean fish returning from these experiments is available. The number of marked fish returning and the percentage return, as presented, are lower than they would have been had information on the three-ocean fish been available.

In the first experiment (table 31), 25,000 seaward migrants were marked, 740 marked fish were recovered and a calculated total of 5,151 marked fish returned from this experiment, not counting the marked fish returning during 1929. The return from this experiment was at least 20.6 percent.

TABLE 31.—*Data for the first 1926 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1926 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	92	4_2	1,509	1	0.066	9,934	7	7.6	[1] 7.6
		5_2				8,836			
3	19,196	4_3	2,690	5	.186	43,551	81	.4	[1] 19.5
		5_3	168,042	498	.296	1,236,953	3,661	19.1	
		6_3				325,643			
		7_3				20			
4	5,641	4_4				1,040			[1] 24.3
		5_4	4.527	11	.243	47,298	115	2.0	
		6_4	44,264	219	.495	254,138	1,258	22.3	
		7_4				14,294			
5	71	6_5				895			40.8
		7_5	279	6	2.151	1,325	29	40.8	
Total	25,000		221,311	740		1,943,927	[1] 5,151		

[1] Based on incomplete data, see text.

The incomplete returns from the marked 2-, 3-, 4-, and 5-year seaward migrants were 7.6, 19.5, 24.3, and 40.8 percent, respectively. Very few 2- and 5-year seaward migrants were marked, and the returns from those age groups are based on the recovery of only one and six fish, respectively; hence, the percentage returns are unreliable. As the size of the migrants increases with age, the data indicate that the larger migrants have the highest survival value.

In the second experiment (table 32) 21,791 migrants were marked, 659 were recovered, and a calculated total of at least 4,582 marked fish returned from this experiment (at least 21.0 percent). The incomplete returns from the marked 2-, 3-, 4-, and 5-year seaward migrants were 0.0, 20.5, 23.0 and 28.6 percent, respectively.

The returns from the two experiments agree closely except for the 2- and 5-year fish of which few were marked. If the data are combined as one experiment, 46,791 seaward migrants were marked, 1,399 were recovered, and a calculated total of at least 9,733 fish returned (a minimum of 20.8 percent).

TABLE 32.—*Data for the second 1926 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1926 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	52	4_2	1,509			9,934			[1] 0.0
		5_2				8,836			
3	16,730	4_3	2,690	3	0.112	43,551	49	0.3	[1] 20.5
		5_3	168,042	458	.273	1,236,953	3,377	20.2	
		6_3				325,643			
		7_3				20			
4	4,925	4_4				1,040			[1] 23.0
		5_4	4,527	5	.110	47,298	52	1.1	
		6_4	44,264	188	.425	254,138	1,080	21.9	
		7_4				14,294			
5	84	6_5				895			28.6
		7_5	279	5	.792	1,325	24	28.6	
Total	21,791		221,311	659		1,943,927	[1] 4,582		

[1] Based on incomplete data, see text.

EXPERIMENTS IN 1927 AND 1928

Fifty thousand seaward migrants were marked in both 1927 and 1928. However, the curtailment of commercial fishing in 1929 and 1930 made it impossible to adequately sample the runs of those years for the presence of marked fish, and the data are consequently not included here.

EXPERIMENTS IN 1929

In 1929 (table 33), 50,061 seaward migrants were marked by the amputation of the adipose and both ventral fins, 1,315 fish were recovered, and a calculated total of 11,157 marked fish returned from this experiment (22.3 percent). The return from the 3-, 4-, and 5-year marked seaward migrants was 18.3, 24.4, and 13.5 percent, respectively. As very few 5-year seaward migrants were marked and only 3 recovered, the latter figure cannot be considered reliable; however, considering the returns of the 3- and 4-year seaward migrants, it is again apparent that the older and larger migrants had the highest survival value.

TABLE 33.—*Data for the 1929 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1929 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	----------	3_1	57	----------	----------	311	----------	----------	----------
		4_1	204	----------	----------	1,938	----------	----------	----------
2	----------	4_2	2,734	----------	----------	18,573	----------	----------	----------
		5_2	1,990	----------	----------	19,133	----------	----------	----------
		4_3	212	3	1.415	46,344	656	3.0	
3	21,858	5_3	100,844	366	.363	793,931	2,882	12.2	18.3
		6_3	8,308	51	.614	73,293	450	2.1	
		7_3	92	----------	----------	752	----------	----------	
		5_4	679	5	.736	136,159	1,002	3.5	
4	28,041	6_4	96,863	826	.853	628,663	5,362	19.1	25.4
		7_4	3,110	61	1.961	39,920	783	2.8	
5	162	7_5	176	3	1.705	1,308	22	13.5	13.5
Total	50,061	----------	215,260	1,315	----------	1,760,325	11,157	----------	----------

EXPERIMENTS IN 1930

Three marking experiments were carried on simultaneously (tables 34–36). Although the experiments were simultaneous they have been designated first, second, and third for reference purposes and to provide for facility in discussion.

In the first experiment (table 34), 25,000 seaward migrants were marked by amputation of the adipose and right ventral fins, 631 of these were recovered, and a calculated total of 5,177 fish returned (20.7 percent).

In the second experiment (table 35), 25,000 seaward migrants were marked by amputation of the adipose and left ventral fins, 666 of these were recovered, and a calculated total of 5,350 marked fish returned (21.4 percent). Two marked fish of the 7_3 age group were recovered, but according to the data, no fish of that age group were examined or were present in the return from the migration. The 7_3 age group, undoubtedly, was present among the fish examined, but its numbers were so few that representation was not afforded in the samples from which scales were secured for age determination.

TABLE 34.—*Data for the first 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	----------	4_1	130	----------	----------	804	----------	----------	----------
2	252	4_2	2,078	----------	----------	18,664	----------	----------	4.8
		5_2	3,212	1	0.031	38,624	12	4.8	
		4_3	1,252	4	.319	8,764	28	.2	
3	14,676	5_3	67,451	163	.242	714,745	1,730	11.8	16.9
		6_3	32,251	87	.270	268,334	725	4.9	
		5_4	8,669	26	.300	48,829	146	1.5	
4	9,773	6_4	72,392	322	.445	502,844	2,238	22.9	26.8
		7_4	1,769	19	1.058	21,838	231	2.4	
5	299	6_5	325	1	.308	1,507	5	1.7	22.4
		7_5	1,146	8	.698	8,835	62	20.7	
Total	25,000	----------	190,675	631	----------	1,633,788	5,177	----------	----------

TABLE 35.—*Data for the second 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	130			804			
2	237	4_2	2,078			18,664			0.0
		5_2	3,212			38,624			
3	14,923	4_3	1,252	6	0.479	8,764	42	0.3	16.3
		5_3	67,451	150	.222	714,745	1,587	10.6	
		6_3	32,251	97	.301	268,334	808	5.4	
		7_3		[1] 2					
4	9,554	5_4	8,669	37	.427	48,829	230	2.4	29.2
		6_4	72,392	345	.477	502,844	2,399	25.1	
		7_4	1,769	13	.735	21,838	161	1.7	
5	286	6_5	325		1.396	1,507			41.6
		7_5	1,146	16		8,835	123	41.6	
Total	25,000		190,675	666		1,623 788	5,350		

[1] See p. 284.

TABLE 36.—*Data for the third 1930 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1930 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	130			804			
2	46	4_2	2,078			18,664			0.0
		5_2	3,212			38,624			
3	2,956	4_3	1,252	1	0.080	8,764	7	0.2	15.2
		5_3	67,451	31	.046	714,745	329	11.1	
		6_3	32,251	14	.043	268,334	115	3.9	
4	1,939	5_4	8,669	8	.092	48,829	45	2.3	20.8
		6_4	72,392	50	.069	502,844	347	17.9	
		7_4	1,769	1	.057	21,838	12	.6	
5	59	6_5	325			1,507			25.4
		7_5	1,146	2	.175	8,835	15	25.4	
Total	5,000		190,675	107		1,633,788	870		

In the third experiment, 5,000 seaward migrants were marked by amputating the adipose and right pectoral fins, 107 of these were recovered, and a calculated total of 870 marked fish returned (17.4 percent).

The data for the first and second experiments are considered more reliable than those of the third, because more fish were marked and more fish recovered, and because there is the possibility that an unusual mortality occurred among the fish of the third experiment. Some of the seaward migrants, marked by removal of the adipose and right pectoral fins appeared to have a slight "list" and appeared to be maintaining balance with difficulty.

Grouping the data for the first and second experiments, 50,000 were marked, 1,297 were recovered, and a calculated total of 10,495 marked fish returned (21.0 percent). The return from the marked 2–, 3–, 4–, and 5–year seaward migrants was 2.4, 16.6, 28.0, and 32.0 percent, respectively.

EXPERIMENTS IN 1931

Two marking experiments were conducted in 1931 (tables 37 and 38). For easy reference they have been designated first and second although they were simultaneous.

In the first experiment, 50,000 seaward migrants were marked by amputating the adipose and both ventral fins, 1,549 of these fish were recovered, and a calculated total of 11,790 fish returned (23.6 percent of the number marked). The return from the 2-, 3-, 4-, and 5-year marked fish was 54.8, 21.2, 34.5, and 40.8 percent, respectively.

In the second experiment, 5,000 seaward migrants were marked by amputating the adipose and dorsal fin, 124 were recovered, and a calculated total of 1,016 fish returned (20.3 percent). The return from this experiment, although slightly lower, agrees closely with results of the first experiment. Amputation of the entire dorsal fin close to the base results in a large wound that may have a deleterious effect on the fish. The results of the first experiment are believed to be more reliable than those of the second.

TABLE 37.—*Data for the first 1931 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1931 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	84	4_2	786	2	0.254	9,191	23	27.4	54.8
		5_2	5,947	4	.067	34,756	23	27.4	
		6_2	49			2,143			
3	41,403	4_3	1,166	4	.343	11,516	39	.1	21.2
		5_3	86,623	345	.398	966,015	3,845	9.3	
		6_3	136,439	863	.633	767,240	4,857	11.7	
		7_3	249	5	2.008	2,276	46	.1	
4	8,145	5_4	1,434	8	.558	21,291	119	1.5	34.5
		6_4	48,318	246	.509	461,549	2,349	28.8	
		7_4	10,669	58	.544	62,249	339	4.2	
		8_4	17			1,016			
5	368	7_5	1,721	14	.813	18,407	150	40.8	40.8
		8_5				671			
Total	50,000		293,418	1,549		2,358,320	11,790		

TABLE 38.—*Data for the second 1931 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1931 migration	Calculated number of each age group examined	Number of marked fish of each of age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
2	9	4_2	786			9,191			0.0
		5_2	5,947			34,756			
		6_2	49			2,143			
3	4,131	4_3	1,166	1	0.086	11,516	10	0.2	18.0
		5_3	86,623	37	.043	966,015	415	10.0	
		6_3	136,439	57	.042	767,240	322	7.8	
		7_3	249			2,276			
4	824	5_4	1,434			21,291			30.1
		6_4	48,318	24	.050	461,549	231	28.0	
		7_4	10,669	3	.028	62,240	17	2.1	
		8_4	17			1,016			
5	36	7_5	1,721	2	.116	18,407	21	58.3	58.3
		8_5				671			
Total	5,000		293,418	124		2,358,320	1,016		

EXPERIMENTS IN 1932

Four marking experiments were conducted (tables 39–42). The fish marked in the first experiment were captured on May 27 and 28; those in the second experiment on May 30, 31, June 3, and 4; the fish for the third experiment on June 6, 7, 8, and 9; and the fish in the fourth experiment on June 11, 12, and 22. The experiments were planned, in part, to determine whether or not a differential mortality in the ocean existed between fish marked by the amputation of the adipose and one ventral fin and fish marked by the amputation of the adipose and one pectoral fin, and to determine if a correlation existed between the time of occurrence of fish in the migration period and the time of their occurrence in the runs on their return as adults.

In the first experiment (table 39), 15,000 seaward migrants were marked by amputation of the adipose and right ventral fins, 341 fish were recovered, and a calculated total of 2,957 marked fish returned (19.7 percent). The return from the 3-, 4-, and 5-year marked seaward migrants was 19.1, 20.5, and 3.0 percent, respectively.

TABLE 39.—*Data for the first 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225			53,258			
2		5_2	5,525			41,299			
		6_2	148			790			
		4_3	1,041	2	0.192	6,771	13	0.2	
3	6,275	5_3	88,164	116	.132	632,884	835	13.3	19.1
		6_3	26,912	30	.111	304,079	338	5.4	
		7_3	113	1	.885	1,281	11	.2	
		5_4	2,077	11	.530	20,626	109	1.3	
4	8,593	6_4	56,666	139	.245	494,716	1,212	14.1	20.5
		7_4	9,551	39	.408	100,909	412	4.8	
		8_4	57	2	3.509	664	23	.3	
		6_5	60			418			
5	132	7_5	171			1,778			3.0
		8_5	46	1	2.174	207	4	3.0	
Total	15,000		203,593	341		1,662,491	2,957		

TABLE 40.—*Data for the second 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225			53,258			
2		5_2	5,525			41,299			
		6_2	148			790			
		4_3	1,041			6,771			
3	6,029	5_3	88,164	97	0.110	632,884	696	11.5	20.7
		6_3	26,912	49	.182	304,079	553	9.2	
		7_3	113			1,281			
		5_4	2,077	1	.048	20,626	10	.1	
4	8,824	6_4	56,666	91	.161	494,716	796	9.0	14.6
		7_4	9,551	46	.482	100,909	486	5.5	
		8_4	57			664			
		6_5	60			418			
5	147	7_5	171	1	.585	1,778	10	6.8	9.8
		8_5	46	1	2.174	207	4	3.0	
Total	15,000		203,593	286		1,662,491	2,555		

TABLE 41.—*Data for the third 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225			53,258			
2		5_2	5,525			41,299			
		6_2	148			790			
		4_3	1,041			6,771			
		5_3	88,164	175	0.198	632,884	1,253	13.4	23.7
3	9,381	6_3	26,912	82	.304	304,079	924	9.8	
		7_3	113	4	3.540	1,281	45	.5	
		5_4	2,077	5	.241	20,626	50	.9	
		6_4	56,666	68	.120	494,716	594	10.7	17.3
4	5,580	7_4	9,551	29	.304	100,909	307	5.5	
		8_4	57	1	1.754	664	12	.2	
		6_5	60			418			
5	39	7_5	171			1,778			0.0
		8_5	46			207			
Total	15,000		203,593	364		1,662,491	3,185		

TABLE 42.—*Data for the fourth 1932 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1932 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1		4_1	837			2,811			
		4_2	12,225	2	0.016	53,258	9	(1)	
2		5_2	5,525			41,299			(1)
		6_2	148			790			
		4_3	1,041			6,771			
		5_3	88,164	99	.112	632,884	709	6.2	16.2
3	11,420	6_3	26,912	101	.375	304,079	1,140	10.0	
		7_3	113			1,281			
		5_4	2,077			20,626			
		6_4	56,666	20	.035	494,716	173	7.2	12.0
4	2,416	7_4	9,551	11	.115	100,909	116	4.8	
		8_4	57			664			
		6_5	60			418			
5	164	7_5	171	1	.585	1,778	10	6.1	6.1
		8_5	46			207			
Total	14,000		203,593	234		1,662,491	2,157		

[1] See text.

In the second experiment (table 40), 15,000 seaward migrants were marked by amputation of the adipose and right pectoral fins, 286 fish were recovered, and a calculated total of 2,555 fish returned (17.0 percent). The return from the 3-, 4-, and 5-year marked fish was 20.7, 14.6, and 9.8 percent, respectively.

In the third experiment (table 41), 15,000 seaward migrants were marked by amputation of the adipose and left ventral fins, 364 fish were recovered, and a calculated total of 3,185 marked fish returned (21.2 percent). The return from the 3-, 4-, and 5-year marked fish was 23.7, 17.3, and 0.0 percent, respectively.

In the fourth experiment (table 42), 14,000 seaward migrants were marked by the amputation of the adipose and left pectoral fins, 234 fish were recovered, and a calculated total of 2,157 fish returned (15.4 percent). The return from the 3-, 4-, and 5-year marked fish was 16.2, 12.0, and 6.1 percent, respectively.

Two marked fish of the 4_2 age group were recovered (table 42). However, according to the data presented, no 2-year seaward migrants were marked. Some 2-year seaward migrants, undoubtedly, were marked but their numbers probably were so few that they were not represented in the samples of fish from which scales were taken for age determination.

From the results of these experiments it appears that there was a differential mortality between the fish marked by excising the adipose and one ventral fin, and those marked by excising the adipose and one pectoral fin. The average survival from the first and second experiments was 18.4 percent, and the average survival from the last two experiments was also 18.4 percent. However, the average survival from the first and third experiments was 20.5, while the average survival from the second and fourth experiments was only 16.2 percent. Hence, there was only 79.2 percent as good a return from the fish marked by removing the adipose and one pectoral fin as there was from the fish marked by removing the adipose and one ventral fin. These results agree closely with those obtained in the 1930 experiment in which the total return from the the fish marked by amputing the adipose and one ventral fin was 21.0 percent, and the total return from the fish marked by amputating the adipose and one pectoral fin was 17.4 percent. In the 1930 experiments, there was only 89.2 percent as good a survival of fish marked by excising the adipose and one pectoral fin as there was of fish marked by removing the adipose and one ventral fin.

The percentage occurrence of marked fish of a single age and one type of mark remained fairly constant throughout the seasons in which they were sampled. However, from the marking of 3-year seaward migrants, the ratio between the return of two-ocean fish and the return of three-ocean fish was 2.38 to 1, 1.25 to 1, 1.37 to 1, and 0.62 to 1 for the first, second, third, and fourth experiments, respectively. Thus, of the 3-year seaward migrants the early migrating fish spent, on the average, a shorter time in the ocean than the late migrating fish. From the marking of 4-year seaward migrants, the ratio between the return of two-ocean fish and the return of three-ocean fish was 2.94 to 1, 1.64 to 1, 1.95 to 1, and 1.5 to 1 for the first, second, third, and fourth experiments, respectively. The returns from the marking of 4-year seaward migrants and the returns from the marking of 3-year seaward migrants both demonstrated a positive correlation between the time of occurrence during the migration period, and the length of time spent in the ocean.

As there appears to be a differential mortality between fish marked by removal of the adipose and one ventral fin, and fish marked by removal of the adipose and one pectoral fin, in comparing the results of the 1932 experiments with experiments of other years, it seems advisable to consider only the two experiments in which the fish were marked by the amputation of the adipose and one ventral fin. Grouping the data of the first and third experiments, 30,000 migrants were marked, 705 fish were recovered, and 6,142 marked fish returned (20.5 percent). The returns from the marked 3-, 4-, and 5-year seaward migrants were 21.9, 19.1, and 2.3 percent, respectively, giving evidence for the first time contrary to the hypothesis that there is no positive correlation between age at time of migration, and survival.

EXPERIMENTS IN 1933

In 1933 (table 43) 40,000 seward migrants were marked by the amputation of the adipose and both ventral fins, 959 fish were recovered, and a calculated total of 8,212 marked fish returned (20.5 percent of the number marked). The return from the 2-, 3-, 4-, and 5-year marked seaward migrants was 18.8, 18.3, 24.9, and 15.6 percent, respectively.

TABLE 43.—*Data for the 1933 marking experiment*

Age of seaward migrants marked	Calculated number of each age marked	Age of fish returning from 1933 migration	Calculated number of each age group examined	Number of marked fish of each age group found	Percentage occurrence of marked fish in fish examined	Calculated number of fish of each age group returning	Calculated number of marked fish returning	Percentage return at various ages	Total percentage return
1	...	4_1	166	...	...	474	...	...	...
2	250	4_2	7,614	2	0.026	58,018	15	6.0	18.8
		5_2	9,942	4	.040	80,153	32	12.8	
3	25,394	4_3	548	1	.171	3,654	6	0.0	18.3
		5_3	64,728	453	.700	458,344	3,208	12.6	
		6_3	24,536	189	.770	187,190	1,441	5.7	
		7_3	...	...	...	...	...	...	
4	13,692	5_4	901	3	.333	13,655	45	0.3	24.9
		6_4	34,756	202	.581	417,073	2,423	17.7	
		7_4	6,244	98	1.570	59,934	941	6.9	
5	664	6_5	...	...	...	638	77	11.6	15.6
		7_5	1,037	4	.386	20,043	26	4.0	
		8_5	51	3	5.882	499	...	...	
Total	40,000	...	150,523	959	...	1,299,675	8,212	...	...

DISCUSSION OF MARKING EXPERIMENTS

In comparing results of the several years marking experiments, it seems advisable to consider the returns from only those experiments in which the fish were marked by the amputation of the adipose and one, or both, ventral fins. It also seems advisable to combine the results in those years when duplicate experiments were run.

In those experiments in which the adipose and one, or both, of the ventral fins were amputated, the returns from the experiments of the years 1926, and 1929 to 1933, inclusive, are 20.8 (incomplete), 22.3, 21.0, 23.6, 20.5 and 20.5 percent, respectively. These results are remarkably uniform and indicate that the survival rate of the fish, during their stay in the ocean, has been quite constant.

Grouping the data of all experiments wherein the fish were marked by the amputation of the adipose and left, right, or both ventral fins gives a total of 169,836 three-fresh-water fish marked and a calculated return of 29,560 marked fish, or a 17.4 [11] percent return. For the four-fresh-water fish it is found that 93,944 were marked, and 24,142 marked fish returned, or a 25.7 percent return.

While combining the data in this manner may be subject to some criticism, it is quite evident that a differential mortality exists between the three-fresh-water fish and the older and larger four-fresh-water fish. The greater survival of the four-fresh-water fish during their stay in the ocean would seem to indicate that a longer lake residence was advantageous. However, this greater ocean survival may be drastically over-balanced by the mortality during the extra year spent in fresh water.

The percentage occurrence of marked fish in the different age groups examined varied considerably, and while a certain amount of the variation is due to random errors in sampling, it cannot all be ascribed to that factor. The age-group composition of the seaward migration changes considerably during the migration period, and as there is no means of determining, actually or relatively, how many migrants pass downstream each day, it is impossible to mark a constant proportion of the migration.

[11] Does not include the three-ocean fish from the experiments of 1926. However, this omission would not materially affect the results.

Since a constant proportion of the migrating population cannot be marked day by day during the migration period, and as the 1932 experiments indicated that early migrating fish tended to return after a shorter period of ocean life, it is apparent that critical comparisons of the returns of any two or more years cannot be made. The longer the period of time spent in the ocean the greater the mortality will be, consequently, for exact comparisons between marking experiments of 2 or more years, it is necessary that the fish of one experiment have remained in the ocean the same length of time as the fish of the other experiments.

In view of the possible errors in the calculated percentage return from the marking of any one age of seaward migrants, especially in the returns of the 2- and 5-year age groups, it is believed that the best average value for the ocean survival is the mean of the several yearly values, i. e., 21.45 percent.

Unfortunately, there is no way of knowing whether or not a differential mortality exists between marked and unmarked fish, although a differential mortality was found to exist between fish marked by the amputation of the adipose and one pectoral fin, and the fish marked by the amputation of the adipose and one of the ventral fins. This might be caused by any one, or a combination, of the following:

1. Regeneration of the pectoral fins. The pectoral fins were amputated as close to the body of the fish as possible, and it does not seem probable that any of the amputated fins could have regenerated to such an extent as to be unrecognizable. None of the marked fish recovered showed the slightest sign of regeneration of this fin.

2. Mortality of the fish as a direct result of the operation. Some of the fish were held in a pen for several days after being marked and then carefully examined. The wounds had begun to heal and the fish showed no ill effects other than that a few specimens appeared to have a slight "list." Consequently, the marking probably did not have a direct influence on the mortality.

3. Mortality caused by the inability of the fish to elude their enemies to as great an extent as could the fish marked by the amputation of the adipose and one ventral fin. The pectoral fins are used, almost entirely, for maintaining equilibrium, and it is possible that fish marked by the amputation of the adipose and one pectoral fin were handicapped. Such a handicap should not hinder fish feeding on plankton. However, it might be a serious disadvantage when being pursued by predators. This is considered the most likely of the several possible explanations for the differential mortality found between the two groups.

There may have been a differential mortality between the unmarked fish and those marked by the amputation of the adipose and one, or both, of the ventral fins. It is not believed that the differential mortality could have been very great in view of the relatively good returns from all the experiments. If the factor used by Foerster at Cultus Lake, to correct for differential mortality, were applied to the Karluk data, the survival of unmarked Karluk fish would be in excess of 56 percent.

MORTALITY IN FRESH WATER

Having ascertained the probable average ocean mortality of Karluk red salmon to be 78.55 percent, as determined by the marking experiments, it is of interest to calculate the mortality of this species between the egg stage and the seaward migrant stage. The average number of eggs per female, as reported by Gilbert and Rich (1927), is approximately 3,700. If the spawning fish are 56 percent females (table 30), then there would be an average of 2,072 eggs per fish in the escapement. With a ratio of return to escapement of 2 to 1 the mortality between eggs and seaward migrants would be 99.55 percent, while with a ratio of return to escapement as high as 4 to 1 the mortality between eggs and seaward migrants would still be over 99 percent. Thus the mortality rate of these salmon, during the fresh-water stage of their life history, is extremely high.

There are a number of factors which contribute to this terrific loss in fresh water. Many eggs are destroyed by the spawning fish which, during their spawning activities, dig out eggs laid by earlier spawners. While the eggs are being deposited and during the incubation period, there is a loss caused by predators such as trout and birds. Meteorological conditions during the incubation period affect the success or failure of a brood year. Floods, dry spells, or freezing weather may affect the eggs adversely. After hatching, the fry work their way out of the gravels of the spawning beds and, if in the tributaries, migrate downstream to the lake. Until the young fish distribute themselves along the lake shores and seek shelter among the rocks and boulders on the bottom, they are preyed upon by trout. During the next 2 or 3 years they are subject to diseases and parasites, and many are devoured by fish-eating birds such as mergansers and terns. Thus, there is a constant decimation of the population, until less than 1 percent of the possible number of progeny have survived to migrate to the ocean.

Of the fraction of 1 percent of possible progeny which have survived to the seaward migrant stage, 79 percent perish while in the ocean due to disease and natural enemies, leaving only 21 percent of the seaward migrants (between 0.1 and 0.2 percent of the possible number of progeny) to return as mature fish.

SUMMARY AND CONCLUSIONS

1. There has been a marked reduction in the abundance of Karluk River red salmon since the inception of intensive commercial fishing in 1888. The average yearly catch for the period 1888 to 1894, inclusive, was more than 1,000,000 fish greater than the average yearly total run (catch plus escapement) for the period 1921 to 1936.

2. Karluk red salmon migrate to the ocean in their first to fifth year counting from the time the eggs are deposited in the gravel of the spawning beds, the majority migrating in their third or fourth year.

3. From a few months to 4 years are spent in the ocean, after which the fish return as adults to spawn.

4. While the fish range from 3 to 8 years of age at maturity, the 5-year age group is usually dominant, followed in importance by the 6-year age group.

5. The number of fish in the spawning escapements during the period 1921 to 1936 has ranged from 400,000 to 2,533,402 and averaged 1,113,594.

6. The runs of red salmon at Karluk are bimodal, and it is considered that there are actually two distinct runs, spring and fall.

7. The fluctuations in the ratio of return to escapement have been considerable, and no correlation has been found between escapement and return. This is due in part to unfavorable environmental conditions on the spawning grounds in certain years.

8. A negative correlation exists between escapement and surplus which might indicate that most of the escapements have been too large. This suggestion is believed to be untrue. The negative correlation is related to adverse factors influencing the survival value.

9. While the affluents of Karluk Lake contained appreciable amounts of phosphorus and silica, during the summer months, less than a measurable quantity of these inorganic salts were present in the lake water, indicating that they are limiting factors in the production of phytoplankton and indirectly of the zooplankton of Karluk Lake. As the lack of these inorganic salts indirectly affects the production of zooplankton it is probable that it also indirectly affects the growth and survival of young red salmon which depend, to a large extent, on the zooplankton as a source of food.

10. Little change, if any, is taking place in the relationship between the percentage of fish of a certain ocean history in the escapement and the percentage of fish of the same ocean history in the return. However, a marked change is occurring in the percentage of fish of a particular fresh-water history in the escapement in relation to the percentage of fish of the same fresh-water history in the return. This relationship is quite unusual, and though evidently existent during most of the period of time under consideration could not possibly have existed for any great length of time in the past. Unless the relationship changes, the majority of the fish in the Karluk runs will be four-fresh-water fish, whereas formerly the three-fresh-water age group was dominant.

11. The change in the period of time spent in fresh water is considered to be due to unfavorable environmental conditions, which may also adversely affect the survival value of the population.

12. The seaward migration of Karluk red salmon takes place during the last week of May and the first 2 weeks of June.

13. The percentage of 4-year fingerlings decreases, and the percentage of 3-year fingerlings increases, during the period of the migration.

14. The time of seaward migration depends on the growth rate of the fingerlings, the fastest growing individuals migrating first.

15. Among the seaward migrants the males and females are equally represented.

16. Among the adult fish there is a greater proportion of females than males.

17. There is a decrease in the percentage of males among the adult fish, with increased ocean residence.

18. Among the fish of a single ocean history, there is usually a decrease in the percentage of males with increased total age.

19. The returns from the marking experiments at Karluk have been consistently greater than returns from similar experiments in other areas. This is probably true because the Karluk seaward migrants were larger at the time of marking and migration than the fish in similar experiments in other areas.

20. A greater return, or survival, was found among the older and larger 4-year migrants than among the 3-year migrants.

21. Although the ocean survival is greatest for fish that have had the longest lake residence, these fish suffer a greater mortality in fresh water due to the longer residence in the lake.

22. Removal of the adipose and right, left, or both ventral fins is considered preferable in marking fish rather than the removal of adipose and dorsal, or adipose and one pectoral fin.

23. The adipose and dorsal mark compared equally well with the adipose and right ventral mark in the returns. However, the removal of the dorsal fin left a large wound on the back of the young fish which may cause a high rate of mortality.

24. The right and left pectoral marks are definitely inferior to the others, due probably to the need of these fins by the fish for maintaining their equilibrium when eluding their enemies.

25. The total calculated returns from those experiments wherein either the adipose and left ventral, adipose and right ventral, or adipose and both ventral fins were amputated were 20.8 (incomplete), 22.3, 21.0, 23.6, 20.5, and 20.5 percent for the experiments of 1926, 1929, 1930, 1931, 1932, and 1933, respectively.

26. The average return from the marking of 3-year seaward migrants was 17.4 percent and for the 4-year seaward migrants 25.7 percent.

27. While a slight differential mortality probably exists between the marked and the unmarked fish, it is not considered to be great in the case of the fish marked by the amputation of either the left, right, or both ventral fins, as the survival of the marked fish during their stay in the ocean is relatively high, averaging 21.45 percent.

28. The mortality of Karluk River red salmon during the fresh-water stage of their life history is usually over 99 percent.

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UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

FISH AND WILDLIFE SERVICE
Ira N. Gabrielson, Director

Fishery Bulletin 40

THE WHITEFISH FISHERY OF LAKES HURON AND MICHIGAN WITH SPECIAL REFERENCE TO THE DEEP-TRAP-NET FISHERY

By John Van Oosten, Ralph Hile, and Frank W. Jobes

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ABSTRACT

This study of the whitefish fishery of Lakes Huron and Michigan includes: (1) a review of the available statistics of production, 1879-1942; (2) a detailed analysis of the annual fluctuations in the production and abundance of whitefish and in the intensity of the whitefish fishery in the State of Michigan waters of the lakes, 1929-1942, with special reference to the effects of fishing with deep trap nets; (3) an account of the bathymetric distribution and vertical movements of whitefish and certain other species; and (4) a report of field observations made in 1931 and 1932, as related particularly to the destruction of undersized whitefish by pound nets and deep trap nets. The main body of the manuscript and appendices A, B, and C, completed in March 1942, contain statistics through the year 1939. Since that time, records for the years 1940–1942 have become available. Because these additional data did not alter any of the conclusions of the manuscript but actually strengthened them, it was not deemed justifiable to expend the considerable amount of time and money that would be required to revise the study. The 1940-1942 records are therefore presented in appendix D.

From a relatively high production in the earlier years of the period, 1879 to 1942, the yield of whitefish declined to a lower level about which the catch fluctuated until the late 1920's and early 1930's when a general increase in production occurred. This recent increase was higher and the subsequent decline more severe in the Michigan waters of Lake Huron than in other areas.

THE WHITEFISH FISHERY OF LAKES HURON AND MICHIGAN WITH SPECIAL REFERENCE TO THE DEEP-TRAP-NET FISHERY[1]

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[1] Approved for publication September 5, 1944. Fishery Bulletin 40.

GENERAL INTRODUCTION

The great economic value of the whitefish (*Coregonus clupeaformis*) and the widespread demand for it by the general public combine to make conservation of this species a matter of primary importance. Accordingly, conservation officials were gravely disturbed by the numerous reports and complaints of commercial fishermen in 1928, 1929, and 1930 concerning the operation of a new type of gear—the deep trap net—in the waters of Lake Huron off Alpena, Mich. These nets, the complainants contended, took whitefish literally by the tons, threatening the immediate extinction of the commercial stock. They held further that the deep trap net not only took legal-sized whitefish in unreasonable quantities but that it was also highly destructive to immature fish.

Gill-net fishermen stated that they were forced to suspend operations in areas in which deep trap nets were fished because of the thousands of rotting, undersized whitefish that drifted into their nets. These fish, they believed, had been destroyed in the deep-trap-net fishery. They charged specifically that young whitefish were killed by confinement in deep trap nets, by gilling in the trap-net meshes, by the rapid change of pressure when the nets were lifted, and by excessive and rough handling in the sorting of the catch. They charged further that deep-trap-net fishermen habitually dumped the dead, undersized whitefish overboard, and thus ruined the best whitefish grounds by polluting the bottom and driving away the fish.

Operators of both gill nets and pound nets objected to allegedly unfair tactics of deep-trap-net fishermen. Gill-netters stated that deep-trap-netters had usurped the traditional gill-net grounds and even had deliberately set deep trap nets across strings of gill nets. Pound-netters asserted that deep trap nets were set offshore in such positions as to block the passage of whitefish to the inshore pound-net grounds.

Both groups of fishermen complained that the high production by deep trap nets had glutted the market and depressed prices, making operations with other gears unprofitable.

The extent to which the many accusations leveled against deep trap nets and their operators were just could not be determined without extensive field observations. Preliminary inquiries, nevertheless, revealed that the deep trap net constituted an undeniably serious threat to the whitefish fishery. It was in recognition of this menace that the Michigan Department of Conservation and the United States Bureau of Fisheries (now the Fish and Wildlife Service) agreed to carry out cooperatively a program of field observation, in order first, to determine the effects of the deep trap net on the whitefish fishery, and second, to obtain information on which to base recommendations for sound regulation of the gear.

By 1931, the first year of the cooperative field investigations, the deep-trap-net fishery had expanded so rapidly that in a number of localities the net had become the dominant gear for the catching of whitefish. These nets were then being fished extensively in the State of Michigan waters of Lake Huron as far south as the "Middle Grounds" off the mouth of Saginaw Bay and had spread also into Lake Michigan where they were used in Green Bay and in northern Lake Michigan, out of Manistique and especially out of ports of the north channel area (region north of the Beaver Islands). In 1931 deep trap nets were fished also in the waters of Door County, Wisconsin. (For a condensed report of the brief survey of these waters in 1931 consult appendix C.)

The Michigan Department of Conservation's Patrol Boat No. 1 was placed at the service of the United States Bureau of Fisheries investigators from July 22 to 27, 1931, when a general survey of the deep-trap-net grounds of northern Lake Michigan and of Lake Huron was made. For the conduct of the later routine field observations, the Department of Conservation assigned one field assistant and paid the operating expenses of one automobile from August 1 to October 21, 1931, and during the month of May 1932. Beginning June 1, 1932, and extending into October, when the field work was discontinued, the Michigan Department of Conservation furnished three field assistants and paid the operating expenses of two automobiles. This increase of the staff made it possible to conduct the investigation simultaneously on both northern Lake Michigan and Lake Huron. The fishermen were practically all willing to cooperate by allowing

the investigators to go aboard their boats, by giving specific information requested, and by discussing frankly problems concerning the fishing industry on the Great Lakes.

The research staff of the U.S. Fisheries Vessel *Fulmar* obtained data in 1932 on some of the deep trap nets and pound nets fishing in Green Bay and around Gull Island in northern Lake Michigan.

The general procedure in the field investigation was to observe the lifting of the deep trap nets, to make counts of all fish in the net, and to take notes both from observation and interviews with the fishermen.

Certain data were, of necessity, obtained from the fishermen. They were: distance and direction from port or from some charted landmark; depth of water in which the net was set; size of mesh (as manufactured) in the lifting pot; depth of lead; and the dimensions of the net.

Other data were recorded as observed. These included: size of mesh (as found in use) in the lifting pot; preservative with which the twine was treated; numbers of legal- and illegal-sized fish, and of dead, bloated, and gilled fish of each species. Gilled whitefish were measured and weighed whenever possible. When it was impossible to measure or weigh the gilled fish, an estimate was made of the numbers that were of legal or illegal size. Lengths, weights, and scales were procured from samples of the catches of whitefish when possible. Few data could be obtained on the sex and maturity of the legal-sized whitefish because practically all were sold in the round.

The procedure for the study of pound nets was the same as that for the deep trap nets. As these two types of gear are of such similar construction, it has been possible in certain phases of the study to combine the data collected from both.

The data collected during the course of the 1931–1932 field investigations form the basis of parts III and IV of the present report.

Statistical investigations also have been made an integral part of the present study of the whitefish fishery of Lakes Huron and Michigan. In order to provide a better background for the understanding of conditions in the recent critical years, a compilation was made of all available statistics of production in the United States waters of the two lakes and of production in the Ontario waters of Lake Huron, beginning in 1879. These data are presented in part I.

Detailed statistical analyses have been made of local fluctuations in the production and abundance of whitefish and in the intensity of the whitefish fishery in the State of Michigan waters of Lakes Huron and Michigan over the period, 1929-1939 (part II). These analyses, which were based on commercial fishing reports supplied by the Michigan Department of Conservation, have contributed greatly to the understanding of the effects of extensive deep-trap-net operations on the general conditions of the fishery.

The deep trap net, with the effect of which on the course of the whitefish fishery this report is primarily concerned, was developed by the late John H. Howard at Cape Vincent, N.Y., and was first used by him in Lake Ontario in 1924. By experimentation Mr. Howard discovered that "the bigger the trap the bigger was the catch of fish taken."[2] Accordingly, he built larger trap nets, using his Lake Erie type of trap nets as a pattern, and increased their depth from about 12 feet to as much as 30 feet. This type of net soon was adopted by other fishermen in the vicinity of Cape Vincent, but apparently did not spread to other ports on Lake Ontario.

The deep trap net was introduced into Lake Huron July 12, 1928, when John H. Howard and his brother, D. C. Howard, set five nets in Thunder Bay off Alpena, Mich. Deep-trap-net operations were confined to the Alpena region in 1928 and 1929. In 1930, however, an expansion of the fishery got under way, that ultimately carried the deep trap net to all parts of the United States waters of Lake Huron and to most of the important whitefish grounds of Lakes Michigan and Superior.

In all three of these lakes the deep-trap-net fishery was confined to, or underwent its principal development in, the State of Michigan. Since deep trap nets were never permitted in the Province of Ontario or introduced into the Minnesota and Wisconsin

[2] We are indebted to the late John H. Howard and to J. P. Snyder, former Superintendent of the Federal Fish Hatchery, Cape Vincent, N. Y., for information on the deep trap net in Lake Ontario.

waters of Lake Superior, operations with the gear in Lakes Huron and Superior were limited to Michigan waters. Deep trap nets were fished in Lake Superior as far west as Ontonagon but were most abundant in Whitefish Bay at the eastern end of the lake. The use of deep trap nets became illegal in the Michigan waters of Lake Superior, July 1, 1936. The most extensive deep-trap-net fisheries of Lake Michigan were developed in the State of Michigan waters of Green Bay and of the northeastern section of the lake. Relatively limited operations were carried on also in Michigan waters off Grand Haven (chiefly in 1934), in the Wisconsin waters off Door County (1931-1935), and in Indiana (June 1935-July 1, 1936). The use of deep trap nets became illegal in the Michigan and Wisconsin waters of Lake Michigan after the 1935 season and in Indiana, effective July 1, 1936. This type of gear was never used in Illinois. The deep trap net may now be legally operated in the Great Lakes only in Lake Huron (Michigan waters) and Lake Ontario (New York waters).

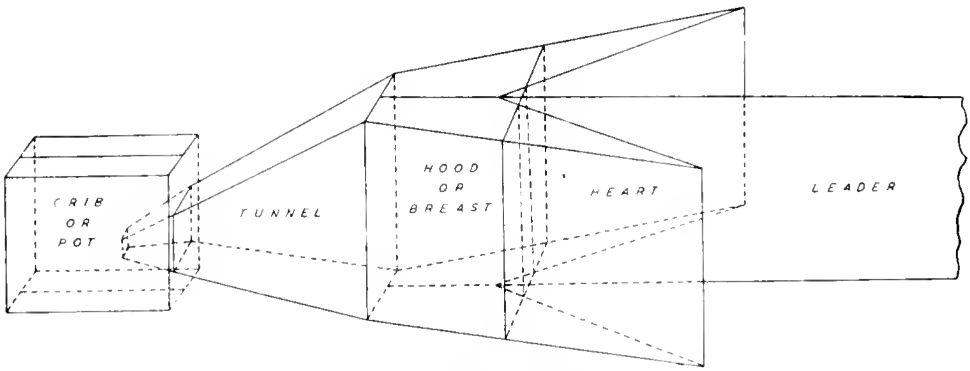


FIGURE 1.—The deep trap net.

The deep trap net (fig. 1) consists of the leader, hearts, hood or breast, tunnel, and lifting pot or crib.

The lifting pot or crib of the deep trap net is covered with webbing, whereas that of the pound net is open at the top. Deep trap nets are held in position by means of anchors and buoys while pound nets are generally held in position by stakes driven in the lake bottom. Aside from these two differences, deep trap nets and pound nets are of similar construction. In fact, during the earlier years of the deep-trap-net fishery the gear frequently was termed a "submarine pound net."

In the nets observed,[3] the anchors were 2-point hook anchors weighing about 35 pounds each except the "king" anchor which weighed about 60 pounds. The smaller anchors (usually numbering 12 to 16) were attached to lines that varied from 400 to 600 feet in length; the "king" line attached to the back of the crib was about 1,800 feet long. The leader was from 40 to 80 rods long, from 20 to 47½ feet deep, and had meshes of 7 to 9 inches. (All mesh sizes in this description are extension measure as manufactured.)

The hearts had the same depth as the leader. The size of mesh in the hearts was reported to have ranged from 5 to 7 inches. The hearts were about 45 feet long with a spread of approximately 100 feet between the tips. In some nets the outside walls of the hearts were extended forward about 24 feet as single thicknesses of netting known as wings. The hood or breast, which connects the hearts and the tunnel, varied from 24 to 27 feet in length.

The tunnel, the length of which varied from about 45 to 75 feet, tapered from a depth equal to that of the hearts to form a 3-foot square opening inside the pot. Meshes in the part of the tunnel outside the pot varied from 5 to 7 inches, but meshes as small as 2 inches were reported for the tunnel inside the pot. Variations reported in the length

[3] The dimensions given in this description were obtained from the fishermen and based on those nets observed in the field and possibly may not cover the full range of variation in the size of deep trap nets. It was, for example, reported to us that one fisherman operated a net that was 75 feet deep.

and depth of the lifting pot were: depth—18 to 47½ feet; length—30 to 40 feet. The lifting pot usually tapered from front to rear so that the width in a single net varied from about 24 to 20 feet. Mesh sizes in the pots ranged from 3½ to 5 inches as manufactured[4] except that the front side of the net (the side through which the tunnel enters) contained meshes measuring not more than 3½ inches. In some nets this small mesh was extended along the sides and bottom of the net, but for a distance of not more than one third the length of the pot.

The lifting methods employed varied considerably, the most general method being that in which the net was brought to the surface by means of a lifting line attached to the "king" anchor line 75 to 150 feet from the back of the pot. When the net was brought to the surface, the boat was pulled under the anchor line and worked forward until it was under the pot of the net. The fish were shoaled on the front or tunnel side of the net and removed through laced openings. After the fish were removed, the boat was worked back to the point where the lifting line was attached, the lines were allowed to slip into the water, and the net was permitted to settle to the bottom. The average time required to lift a deep trap net was approximately one hour. Numerous mechanical devices have been developed to reduce the amount of labor involved and several types of power lifting machines are now in use. Some fishermen released the tension on the back anchor line and handled the net alongside the boat in a way similar to that employed for lifting pound nets.

[4] The present minimum size of mesh permitted in the pots of deep trap nets operated in the Michigan waters of Lake Huron is 4½ inches as found in use; provision is made for a section of netting the meshes of which may not be more than 3½ inches on which the fish may be shoaled.

PART I

PRODUCTION OF WHITEFISH IN LAKES HURON AND MICHIGAN, 1879-1939

LAKE HURON

Because of defects in the data on the catch of whitefish in the United States (State of Michigan) waters of Lake Huron in certain of the earlier years, the graphical representation (fig. 2) of the production history of the lake (table 1) begins with the year

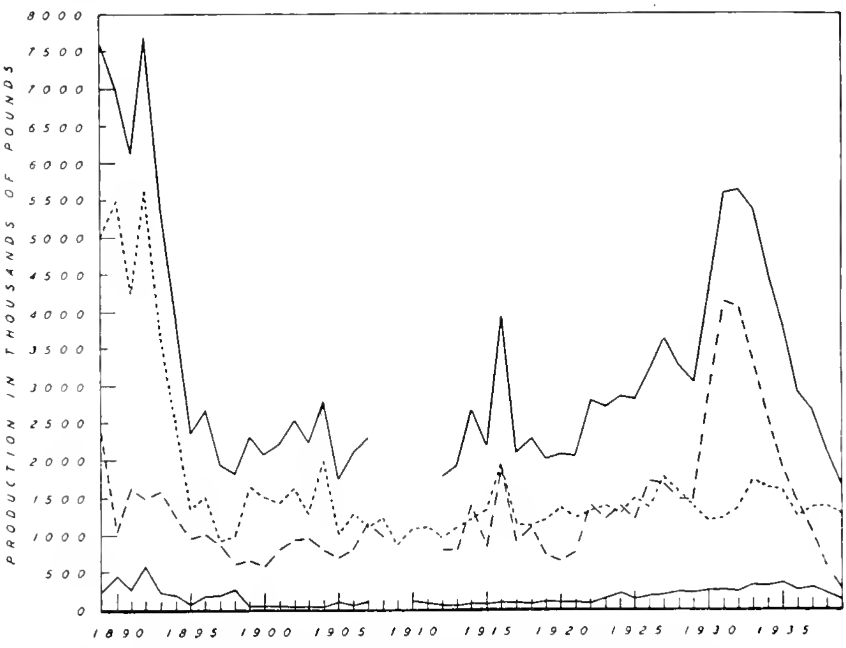


FIGURE 2.—Commercial production of whitefish in Lake Huron, 1889–1939. Lower solid line, Ontario waters of Huron proper; short dashes, North Channel and Georgian Bay; long dashes, State of Michigan waters; upper solid line, entire lake.

1889.[5] It is true that data are available for Ontario waters of Lake Huron for years prior to 1889. However, it is with the course of production in the State of Michigan waters that the present study is most concerned.

Despite the known inclusion of the catch of Menominee whitefish or pilots[6] in the data for 1879, 1885, and 1890, the recorded production of whitefish in the State of Michigan waters of Lake Huron exceeded 2 million pounds in only 2 of the 4 earliest years for which records are available (1879 and 1889) and was less than 1½ million pounds in 1885 and 1890 (only slightly above a million in the latter year).

The production of whitefish in the State of Michigan waters of Lake Huron was well over 2 million pounds in 1889, the first year for which acceptable data are available. In 1891, the second year for which presumably usable statistics are available, this yield was somewhat above 1½ million pounds. The next several years saw an irregular but distinct downward trend. The average production for the years, 1889

[5] See appendix A for a listing of the sources of the statistical data of table 1 and statements concerning their limitations in certain years. Also see appendix D for the 1940–1942 records.

[6] Although there can be no certainty concerning the production of Menominee whitefish in the early years of the fishery, it is not believed that catches of that species made up a great part of the reported production of whitefish in years earlier than 1891. Consequently, the catch for 1890 was graphed in figure 2 although the yield for that year was excluded from the computation of averages. The catch of Menominee whitefish in the State of Michigan waters of Lake Huron exceeded 100,000 pounds only 6 times in the 32 years for which data are available within the period, 1893–1939, and frequently was less than 50,000 pounds.

and 1891–1896 (1896 was the last of the earlier years in which the catch exceeded a million pounds), was 1,464,000 pounds. (In the discussion of this section, yields will be given to the nearest thousand pounds.) The period, 1897–1921, was one of rather consistently low output, the catch of whitefish exceeding a million pounds in only 4 isolated years of the 22 for which there are records. The average annual yield for this period was 885,000 pounds.

TABLE 1.—*Production of whitefish in pounds in Lakes Michigan and Huron, 1879–1939*

[See appendix A for list of sources of the data]

Year	Lake Michigan			Lake Huron			
	Wisconsin	Michigan	Entire lake[1]	Michigan	Ontario Huron proper	Ontario Georgian Bay	Entire lake
1879	...	...	[2]12,030,400	[3]2,700,778	726,600	864,800	[3]4,292,178
1880	...	...	...	...	762,800	1,540,400	...
1881	...	...	...	...	907,000	2,178,523	...
1882	...	...	...	...	836,500	1,838,485	...
1883	...	...	...	...	620,000	1,668,392	...
1884	...	...	...	...	701,750	1,640,946	...
1885	[2]1,733,675	[2]6,672,225	[2]8,652,986	[3]1,425,380	757,100	1,421,160	[3]3,603,640
1886	...	...	...	...	557,000	1,823,849	...
1887	...	...	...	...	325,600	2,664,406	...
1888	...	...	...	...	236,550	4,946,788	...
1889	481,955	5,004,641	5,523,971	2,391,503	210,219	5,003,259	7,604,981
1890	187,442	[2]4,281,921	4,056,841	[3]1,033,158	442,020	5,498,800	[3]6,973,978
1891	...	2,404,571	...	1,624,860	267,900	4,236,880	6,129,640
1892	334,080	2,522,402	2,856,482	1,486,183	578,050	5,630,106	7,694,339
1893	470,325	1,975,800	2,446,125	1,577,600	226,000	3,645,800	5,449,400
1894	417,100	1,295,805	1,712,905	1,218,250	187,600	2,509,436	3,915,286
1895	520,325	1,022,740	1,543,065	945,867	58,230	1,355,275	2,359,372
1896	553,000	1,447,300	2,000,300	1,005,735	168,520	1,498,180	2,672,435
1897	886,358	2,418,953	3,345,071	865,960	172,570	910,466	1,948,996
1898	...	2,320,100	...	592,750	249,340	968,590	1,810,680
1899	125,355	1,633,880	1,769,793	645,580	28,074	1,651,086	2,324,740
1900	...	1,625,600	...	555,420	26,154	1,503,101	2,084,675
1901	...	2,079,550	...	788,245	23,606	1,413,239	2,225,090
1902	...	2,723,350	...	913,530	17,018	1,621,540	2,552,088
1903	116,764	2,284,600	2,404,269	937,460	19,630	1,279,060	2,236,150
1904	...	2,501,700	...	787,360	16,500	2,002,870	2,806,730
1905	...	2,570,100	...	674,860	78,980	994,050	1,747,890
1906	...	2,820,700	...	791,720	45,300	1,273,850	2,110,870
1907	...	3,273,800	...	1,132,972	82,020	1,095,220	2,310,212
1908	116,900	3,106,095	3,287,995	973,905	[4]875,292	1,211,251	3,060,448
1909	133,253	...	...	...	[4]354,405	861,721	...
1910	77,561	...	...	...	92,332	1,072,665	...
1911	124,519	1,305,447	1,429,966	...	70,352	1,104,336	...
1912	180,283	1,157,510	1,337,793	781,739	38,738	955,821	1,776,298
1913	117,925	1,202,299	1,320,224	787,101	39,017	1,105,683	1,931,801
1914	40,665	1,331,364	1,372,029	1,393,139	69,608	1,211,499	2,674,246
1915	120,916	1,358,838	1,479,754	812,286	56,859	1,335,484	2,204,629
1916	108,221	1,521,107	1,629,328	1,919,369	77,160	1,944,109	3,940,638
1917	126,933	2,458,084	2,622,767	888,977	76,535	1,144,620	2,110,132
1918	254,079	2,092,334	2,346,413	1,101,948	65,668	1,123,608	2,291,224
1919	202,119	1,286,601	1,488,720	727,194	97,419	1,200,842	2,025,455
1920	131,433	805,558	936,991	646,696	83,094	1,354,506	2,084,296
1921	362,415	958,709	1,321,124	757,616	76,493	1,222,676	2,056,785
1922	163,201	1,151,250	1,335,251	1,401,347	68,111	1,323,390	2,792,848
1923	442,923	1,061,701	1,504,624	1,198,971	128,909	1,390,021	2,717,901
1924	247,104	1,149,683	1,396,787	1,381,694	193,122	1,282,569	2,857,385
1925	242,379	1,405,028	1,652,000	1,203,149	121,524	1,495,881	2,820,554
1926	325,420	1,537,554	1,875,068	1,722,757	155,351	1,365,055	3,243,163
1927	314,232	2,254,623	2,591,291	1,676,875	191,494	1,773,983	3,642,093
1928	554,067	2,956,146	3,525,667	1,468,801	224,262	1,568,267	3,261,330
1929	644,489	4,287,869	4,968,733	1,456,368	204,761	1,385,316	3,046,445
1930	559,028	4,812,825	5,382,548	2,879,440	246,551	1,186,319	4,312,310
1931	841,539	3,823,983	4,675,277	4,139,772	245,157	1,214,918	5,599,847
1932	491,606	3,332,284	3,836,340	4,050,334	219,227	1,362,809	5,632,370
1933	332,000	2,235,840	2,574,440	3,333,901	309,519	1,733,056	5,376,476
1934	246,000	1,932,178	2,182,778	2,568,233	308,939	1,635,832	4,513,004
1935	263,900	1,431,724	1,697,124	1,894,807	340,327	1,596,312	3,831,446
1936	142,600	876,411	1,025,511	1,442,169	235,304	1,244,030	2,921,503
1937	122,300	946,867	1,072,967	1,018,681	286,981	1,377,130	2,682,792
1938	141,800	1,117,079	1,258,879	557,969	205,230	1,381,841	2,145,040
1939	110,700	839,856	950,556	•255,183	115,061	1,275,255	1,645,499

[1] See appendix A for list of years in which the Lake Michigan total includes the catches in the waters of Illinois and Indiana.
[2] Includes blackfins, longjaws, and pilots (Menominee whitefish); the total for the lake in 1890 does not include the catch of these three species
[3] Includes pilots; the totals for the lake include only the pilots from the State of Michigan waters.
[4] Accuracy considered questionable; see p. 381.

The production of whitefish in the State of Michigan waters of Lake Huron rose to a higher level in 1922 and was consistently between 1 and 2 million pounds through the period, 1922–1929. The average catch for the 8 years was 1,439,000 pounds, practically the same as that for 1889 and 1891–1896.

In 1930, the whitefish fishery entered a period of chaotic change. The production of 2,879,000 pounds in this year was nearly double that of 1929 and was greater than that of any previous year. A further increase carried the yield of whitefish to an all-time high of 4,140,000 pounds in 1931. The 1932 output (4,050,000 pounds) was only a little below the record catch. In the years following 1932, whitefish production declined rapidly. This decline culminated in a 1939 yield of only 255,000 pounds, less than half the lowest production recorded for any previous year (555,000 in 1900). Detailed treatment of the violent fluctuations in the catch of whitefish in the State of Michigan waters of Lake Huron over the period, 1930–1939, is given on pp. 317–333. There evidence is presented that the high production in the earlier years of the period was made possible in large measure by the use of deep trap nets, and that this excessive yield in turn brought about a depletion of the stock that was responsible for the great severity of the subsequent decline.

The history of production of whitefish in the State of Michigan waters of Lake Huron may be summarized as follows. An early period of relatively high but decreasing yield (1889–1896) was followed by a long period (1897–1921) over which the catch was fairly stable at a rather low level. Production was stable in the years, 1922–1929, also, but the level of the take was considerably higher than that of the period, 1897–1921. The most recent period of the fishery (1930–1939) was one of violent fluctuations. Production rose suddenly to an all-time peak in 1931 of more than 4 million pounds only to decline to an all-time low in 1939 of ¼ million pounds. The normal annual take may be estimated as 1,114,000 pounds, the average catch per year for the period, 1889–1929.

The early yield of whitefish was high in the Ontario waters of Lake Huron proper;[7] the average was 759,000 pounds for the 7 years, 1879–1885. The annual catch varied erratically but averaged much lower (283,000 pounds) in the period, 1886–1898. The year 1899 was the first in a long period of low production. With the exception of 1908 and 1909, for which years the accuracy of the statistics is open to question (appendix A), the take of whitefish did not exceed 100,000 pounds at any time in the years, 1899–1922 (average, 57,000 pounds). These years of low output nearly coincided with a similar period in Michigan (1897–1921). The increase to a higher level of production in 1923 in Ontario resembles the increase that occurred in the State of Michigan waters of the lake a year earlier, in 1922. The significance of the increase in 1923 is made questionable by the fact that additional waters were included under Huron proper in 1922 and later years (see footnote 7). It should be pointed out, however, that this extension of Huron proper was not accompanied by an increase in the recorded catch in 1922. Furthermore, comparisons may be made among the years, 1922–1939. Within this period the yield increased irregularly through 1935 and thereafter dropped rapidly. The take exceeded 300,000 pounds in each of the years, 1933–1935. The relatively high yields of these years were still considerably less than those of the early period (1879–1886) even though the recent figures covered more territory. Although production declined in the Ontario waters of Lake Huron proper after 1935, it was still above 100,000 pounds in 1939.

The catch of whitefish in Georgian Bay[8] increased from an average of 1,622,000 pounds per year in 1879–1886 to an average of 4,267,000 pounds in 1887–1894. The decrease that began toward the close of the latter period brought the production of whitefish in 1895 approximately to the level about which the yield fluctuated during the 45 years, 1895–1939. The relative stability of the take in 1895–1939 is brought out by the fact that production exceeded 2 million pounds only once (1904) and fell below

[7] Production listed in table 1 under this heading for the years, 1879–1921, is for the shore of Lake Huron from Cape Hurd at the tip of the Saugeen Peninsula to the extreme southern end of the lake. Beginning in 1922, however, more northerly localities (islands of the open lake and the westerly shore of Manitoulin Island) were included in "Huron proper."

[8] Production listed in table 1 under this heading includes the catches from the entire North Channel and Manitoulin Island regions except in 1922 and later years. (See footnote 7.)

one million pounds only 5 times (1897, 1898, 1905, 1909, and 1912) during the 45 years. The average annual production of 1895–1939 was 1,333,000 pounds. This average may be accepted as an estimate of normal production in Georgian Bay. The relatively good yields of 1933–1935 suggest an increase comparable (but less pronounced) to that which took place in the same years in the Ontario waters of Lake Huron proper. Again it may be observed that the change in the territory covered by the statistics collected after 1921 showed no effect on the figures of yield.

It may be noted here that the periods of decline and of increase in the production of whitefish in the Michigan waters were followed a year or two later by similar periods in the Ontario waters of Lake Huron. This correspondence suggests that the annual fluctuations in ecological conditions on the two sides of the lake may be similar. The changes in take in the Georgian Bay waters, however, showed no similarity with those in Lake Huron proper.

The totals for the entire lake indicate that the earlier years of the fishery were the years of the heaviest yields. Especially noteworthy was the high production in the period, 1889–1894, when the average annual catch was 6,295,000 pounds.[9] Subsequent to 1894 the production of whitefish was relatively stable over a long period. The catch rose above 3 million pounds only once (1916) in the period, 1895–1925,[10] and dropped below 2 million pounds only 5 times (1897, 1898, 1905, 1912, and 1913). The average production in this period (with the catch for 1908 omitted) was 2,351,000 pounds, which yield may be accepted as the normal for the entire lake. Good catches in both Canadian and United States waters made possible yields that were consistently above 3 million pounds in the years, 1926–1929 (average, 3,298,000 pounds). It was in the period, 1930–1934, however, that the production of the modern fishery reached its greatest heights. The take was greater than 4 million pounds in all 5 years and exceeded 5 million pounds in 3 years. The average was 5,087,000 pounds. The most recent of the earlier years with comparable production was 1893. It is to be noted that Canadian waters were largely responsible for the high production of the early years (1893 and earlier), whereas in 1930–1934 United States waters accounted for the bulk of the catch. In fact, the Canadian production exceeded that of the United States in every year except 1914, 1922, 1926, and the years, 1930–1934. By reason of a continuous decrease in production the average yield for 1935–1939 was only 2,645,000 pounds. The catch of 1,645,000 pounds in 1939 was the lowest for which there is a record. The small yield in that year can be attributed in large measure to the collapse of the fishery in United States waters.

LAKE MICHIGAN

The first acceptable records of the production of whitefish in Lake Michigan (table 1), as in the United States waters of Lake Huron, begin with the year 1889. (The 1890 record for the State of Michigan includes species other than whitefish.)[11] Attention will be given first to the production in the State of Michigan waters, the area with which the present report is most concerned. It is true also that the data are more complete for the State of Michigan waters than for other regions of the lake and that the production in these waters dominates the catch in the entire lake.

The production of whitefish in the State of Michigan waters of Lake Michigan was between 2 and 3 million pounds in 10 of the 19 years, 1889 and 1891-1908. (See fig. 3.) The catch was less than 2 million pounds in 6 years (less than 1½ million pounds in the 3 years, 1894-1896) and was more than 3 million pounds in only 3 years (1889, 1907, and 1908). The 1889 yield of 5,005,000 pounds was the highest for which there is a dependable record. The average for the period was 2,370,000 pounds. Production tended to decrease in the earlier span of years but to increase in the later part of the period.

[9] It is unlikely that the inclusion of the catch of pilots in the production figures of whitefish in State of Michigan waters in 1890 affected this average materially.

[10] No data for 1909–1911; the production of 3,060,000 pounds in 1908 may be discounted because of the questionable accuracy of the data for the Ontario waters of Huron proper in that year (p. 381).

[11] See appendix A for a discussion of the defects in the statistics for 1879 and 1885 and for the State of Michigan waters in 1890 and appendix D for the 1940–1942 records.

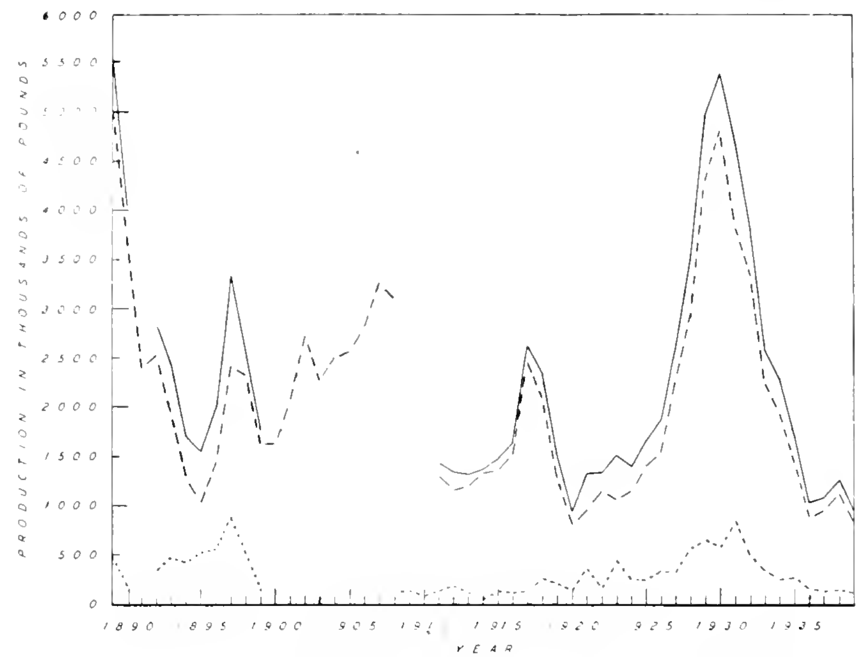


FIGURE 3.—Commercial production of whitefish in Lake Michigan, 1890–1939. Short dashes, State of Wisconsin waters; long dashes, State of Michigan waters; solid line, entire lake.

The general level of the yield was lower over the period, 1911-1926, than in 1889 and 1891-1908; the 1911-1926 average was only 1,361,000 pounds. The catch was between 1 and 1½ million pounds in 10 of the 16 years. Four years (1916, 1917, 1918, and 1926) had productions of more than 1½ million pounds (more than 2 million pounds in 1917 and 1918) and two years (1920 and 1921) had yields of less than a million pounds.

An increase in production that got under way as early as 1924 and proceeded slowly in the years, 1924-1926, became sufficiently rapid in 1927 to raise the catch above 2 million pounds. The catch continued to increase rapidly until a maximum of 4,813,000 pounds was reached in 1930. The subsequent decline did not carry the take of whitefish below 2 million pounds until 1934. The average yield for the 7 years, 1927-1933, was 3,386,000 pounds. This average was greater than the largest yield reported for any single year earlier than 1929 with the exception of 1889 and possibly of some other years prior to 1891—years for which accurate statistics are lacking.

The average production of whitefish in the most recent period, 1934-1939, was 1,191,000 pounds. The yield exceeded 1½ million pounds in only one year (1934), and in two years (1936 and 1939) it was not far above the lowest catch recorded for any previous year (806,000 pounds in 1920).

The history of the production of whitefish in the State of Michigan waters of Lake Michigan may be summarized as follows. The catch fluctuated about a level of somewhat more than 2⅓ million pounds during the earliest period (1889 and 1891-1908) for which reliable statistics are available; the annual yields tended to be below average and to decrease in the earlier years and to be above average and to increase in the later years of this period. The level of production was relatively low in the years, 1911-1926, with the catch exceeding 1½ million pounds in only 4 of the 16 years. The grand average of 1,909,000 pounds covering both periods (1889-1926) may perhaps be accepted as the normal yield in these Michigan waters. The years, 1927-1939, constituted a period of wide fluctuations in production that resembled the variations that took place in the State of Michigan waters of Lake Huron at about the same time (1930–1939). Further considerations of these more recent fluctuations will be found in the next section.

The take of whitefish was relatively high in the Wisconsin waters of Lake Michigan[12] in most of the earlier years for which records are available. The catch averaged 481,000 pounds for the years, 1889-1897, and was less than 300,000 pounds in only 1 of 8 years (1890). The yield of 886,000 pounds in 1897 was the highest for which there is a record. (The statistics for 1885 include species other than whitefish.)

Statistics of the production of whitefish in the Wisconsin waters of Lake Michigan are available for only 2 of the 10 years, 1898-1907. The catches of both 1899 and 1903 were a little above 100,000 pounds and at approximately the level of production for 1908-1917. The average annual take for 12 years within the 20-year period, 1898–1917 was 116,000 pounds. In these 12 years the production exceeded 150,000 pounds only once (1912) and was less than 100,000 pounds twice (1910 and 1914).

An increase occurred in 1918 in the general level of production. The average catch of the 8 years, 1918-1925, was 256,000 pounds. Production within the period was variable and ranged from 131,000 pounds in 1920 to 443,000 pounds in 1923.

The year 1926 was the first in an 8-year period during which the output of whitefish in the Wisconsin waters of Lake Michigan did not fall below 300,000 pounds. The average 1926-1933 yield was 508,000 pounds, the maximum of 842,000 pounds in 1931 constituting the highest production since 1897. The increased catch in Wisconsin waters of Lake Michigan in 1926-1933 corresponds to the high production in the State of Michigan waters of Lakes Michigan and Huron in approximately the same general period.

The peak Wisconsin yield of 1931 was followed by a rapid if irregular decrease. The average annual production of the most recent 6-year period, 1934-1939, was 171,000 pounds. The catch of 111,000 pounds in 1939 was the lowest since 1916. Production was below the 1939 level in only 3 years (1910, 1914, and 1916) of the 42 years for which there are records in the period, 1889–1939. Probably the best estimate of the normal take of whitefish for these Wisconsin waters is the grand average for all years (1889–1939), namely, 295,000 pounds.

Despite defects (inclusion of the catches of blackfins, longjaws, and Menominee whitefish) in the whitefish statistics for the whole of Lake Michigan in 1879 and 1885 (in 1890 a separation of the catches of whitefish and of blackfins, longjaws, and pilots was possible for the entire lake but not for Michigan waters; Wisconsin data were taken from State sources) the data provide evidence, nevertheless, that the level of production of whitefish in the earlier years was considerably higher than in later years. The only information on the extent to which the whitefish statistics for Lake Michigan may have been distorted by the inclusion of the catches of blackfins, longjaws, and Menominee whitefish is provided by the data for 1890. In that year, according to the Report of the United States Commissioner of Fisheries, the catch of these three species made up 1,398,238 pounds of the reported whitefish take of 5,455,079 pounds in the entire lake. (Data were not given on the production of the species named, in the waters of the individual States.) The catch of whitefish alone (4,056,841 pounds), therefore, made up 74.4 percent of the combined output of whitefish, blackfins, longjaws, and Menominee whitefish.

If it is assumed that whitefish made up the same percentage of the reported catch in Lake Michigan in 1879 and 1885 as in 1890, the following estimates of production in these years are obtained: 1879, 8,951,000 pounds; 1885, 6,438,000 pounds. To be sure, the use of the percentage derived from statistical data for 1890 for the estimation of the catch of whitefish in earlier years is open to severe criticism. Undoubtedly, the relative abundance of whitefish and of blackfins, longjaws, and Menominee whitefish in the catch varied from year to year. Nevertheless, the preceding estimates, inexact as they may be, together with records for 1889 and 1890 provide strong evidence in support of the belief that production of whitefish in the

[12] For a discussion of Wisconsin's whitefish production in Green Bay and Lake Michigan proper separately, see appendix C.

earlier years of the fishery was greater than in 1891 and subsequent years. The normal annual output of these earlier years most probably exceeded 5 million pounds.

The description of the fluctuations in the production of whitefish in the entire lake before 1911 is made difficult by the lack of complete information in a number of years.[13] Records of the total yield are available for only 11 years of the period, 1889-1910. These catches exhibited considerable variation. The production was less than 2 million pounds in 3 years (1894, 1895, and 1899), ranged between 2 and 3 million pounds in 4 years (1892, 1893, 1896, and 1903), fell between 3 and 4 million pounds in 2 years (1897 and 1908), and exceeded 4 million pounds in 1889 and 1890, the earliest years of the period. The average for the 11 years was 2,813,000 pounds.

The level of whitefish production for the entire lake was considerably lower in the years, 1911-1926. The catch was greater than 2 million pounds in only 2 years (1917 and 1918) of the 16, and in 10 years production was below 1½ million pounds. The 16-year average was 1,566,000 pounds.

Improved catches in both Wisconsin and Michigan waters were responsible for an uninterrupted period of 8 years, 1927–1934, in which the total catch of whitefish in Lake Michigan did not fall below 2 million pounds. The production was more than 3 million pounds in 5 of these years (1928-1932), was above 4 million pounds in 3 years (1929-1931), and exceeded 5 million pounds in 1930. The average for the 8-year period was 3,717,000 pounds. The production in each of the 3 years, 1929-1931, was greater than that recorded for any year of the period, 1890-1928, although a higher yield was recorded for 1889 and there is evidence that the catch of whitefish in certain years prior to 1889 may have been even greater.

The average annual production of whitefish in Lake Michigan in the most recent 5-year period, 1935-1939, was 1,201,000 pounds. The catches in 1936, 1937, and 1939 were all below the smallest yield recorded for any year prior to 1936 except 1920; the 1939 record provides the second report of a total whitefish catch in Lake Michigan of less than a million pounds.

The grand average of 2,074,000 pounds for the years, 1889-1926, may perhaps be accepted as the normal yield of whitefish for the entire lake.

RECENT LARGE INCREASE IN THE PRODUCTION OF WHITEFISH IN GREAT LAKES WATERS

The preceding pages were devoted exclusively to a description of fluctuations in the production of whitefish in the various waters of Lakes Huron and Michigan. A discussion of these fluctuations in terms of variations in the abundance of whitefish has been avoided deliberately because of the many disturbing factors that render such interpretations exceedingly unreliable.

A fundamental difficulty in the use of the statistical data of the type given in table 1 for estimations of fluctuations in the abundance of fish lies in the lack of adequate information on the intensity of the fishery. It is known that in general the fishing intensity of the early fishery was far less than that of the modern fishery—that with the passage of the years the number of men and boats engaged in commercial operations increased greatly. It is known too that certain technical developments such as the invention of power lifters, improvements in the efficiency of nets, and the construction of faster and more cheaply operated craft, permitted an expansion of fishing activity out of proportion to the mere increase in men and boats. Because of the known increase in fishing intensity a given annual catch in the earlier years of the fishery may be held to indicate a greater abundance of fish than an equally large production a number of years later.

Changes in fishery regulations also may affect production significantly. Increases or decreases in the minimum legal mesh size, the imposition of a closed season, the establishment or abandonment of a fishery for spawn, the closure of grounds or the restriction of operations in certain areas, changes in the size limit of fish—all these

[13] Totals were omitted for all years in which records were lacking for either the State of Michigan or the State of Wisconsin waters. Certain of the totals listed for Lake Michigan in table 1 do not include the production in Illinois and Indiana waters, but the omission of these catches most probably had little effect on the values of the totals. (See appendix A.)

and other changes in fishery regulations can have a profound if undeterminable effect on total yields.

Production may vary according to general economic conditions. In periods of depression low prices may render operations unprofitable and thus bring about a curtailment of fishing activities. On the other hand, an economic depression has been observed in at least one industrial district to have the reverse effect of stimulating fishing intensity. Here numbers of unemployed turned to small-scale fishing as an emergency source of income—meager, to be sure, but preferable to none at all.

Other factors, such as weather conditions, might be listed which cause fluctuations in production that are independent of the level of abundance of the stock. However, those mentioned are sufficient to bring out the difficulties inherent in the use of catch statistics for the estimation of changes in the abundance of fish, particularly over long periods of time.

Despite the limitations just outlined, there is good reason to believe that under normal conditions (without disruption in the methods or regulations of the fishery), over limited areas, and for short periods of years, large increases or decreases of production may serve as reliable indicators of increases or decreases in the abundance of fish on the grounds. The changes in annual yields do not measure the changes in abundance, but merely indicate their occurrence. This view concerning the general relationship between the production and abundance of fish has grown from the careful examination of records that have been maintained, beginning in 1929, of the annual fluctuations in the catch and abundance of fish on the grounds and in the intensity of the fishery for all commercially important species in 21 fishing areas of the State of Michigan waters of the Great Lakes.

Ordinarily fluctuations in production exceed those in abundance; that is, the increases in the catch tend to be relatively greater than the increases in abundance when the latter rises above the average, and conversely, the decreases in the yields tend to be greater than the decreases in abundance when the latter falls below the average. As a result the curves of production often are "exaggerations" of the curves of abundance. This general relationship between abundance and catch has its origin in the circumstance that fishing intensity tends to be above average when abundance is above average and below when abundance is below. Of course, exceptions occur in the relationships outlined above but these exceptions do not affect the general validity of the statements.[14]

Among the increases in production that safely may be held to reflect (but not measure) a greater abundance of fish on the grounds are those that occurred in the catch of whitefish in Great Lakes waters near the beginning of the 1930's. Although the actual years of high yields varied somewhat in the different waters, an increase occurred in every important center of production. The increase in the catch was relatively greater in the State of Michigan waters of Lake Huron than in other areas.

The extent to which the recent increase in production was relatively greater in the State of Michigan waters of Lake Huron than in other areas may be brought out by comparisons of the take in the 2 or 3 recent years of greatest yield with the average catch over a period of earlier years. The average production in the peak years, 1931 and 1932, was 3.67 times the average for the years 1889 and 1891-1929. This value is considerably higher than the ratios for other areas as the following tabulation shows:

Area	Years of early period	Years of recent period	Ratio of recent to early production
Huron (State of Michigan)	1889, 1891–1929	1931–1932	3.67
Huron (Province of Ontario-Huron proper)	1893–1932	1933–1935	2.86
Huron (Province of Ontario-Georgian Bay, North Channel)	1895–1932	1933–1935	1.26
Michigan (State of Michigan)	1889, 1891–1926	1929–1930	2.38
Michigan (State of Wisconsin)	1889–1927	1929–1931	2.58
Superior (State of Michigan)	1911–1930	1931–1933	1.97
Erie (entire lake)	1921–1927	1929–1931	1.68

[14] See part II for a discussion of the relationships among the fluctuations in the production and abundance of whitefish and in the intensity of the whitefish fishery in Lakes Huron and Michigan.

Although the selections of the periods for the preceding comparisons, based on the examination of the statistical data, were to a certain extent arbitrary, reasonable changes in the years included in these periods would not affect the validity of the general conclusion that the increase in the production of whitefish was greater in the State of Michigan waters of Lake Huron than in other Great Lakes areas.

Despite the known risks involved in the estimation of changes in abundance from changes in production, the ratios of the preceding paragraph would suggest the possibility that the recent increase in the abundance of whitefish may have been somewhat higher in the Michigan waters of Lake Huron than in other Great Lakes areas. Information from other sources, however, proves that such an assumption would be utterly invalid. The higher production in the Michigan waters of Lake Huron (as compared to other waters) was made possible by the introduction of a new and marvelously efficient gear, the deep trap net. The use of this net made possible a tremendous increase in fishing intensity. No doubt an increase in catch would have taken place without the use of deep trap nets; however, it was deep-trap-net operations that accounted for the relatively greater heights of production attained in the Michigan waters of Lake Huron.

The description of the annual fluctuations in the yields and abundance of whitefish and in the intensity of the whitefish fishery in the Michigan waters of Lakes Huron and Michigan, 1929–1939, presented in part II, is concerned largely with the effects of deep-trap-net operations on the fishery. It is shown that the widespread use of deep trap nets in Lake Huron (the gear was fished much less extensively in Lake Michigan) led to a multiplication of fishing intensity that raised production far beyond a reasonable level and was responsible for the subsequent collapse of the fishery.

PART II

FLUCTUATIONS IN THE PRODUCTION AND ABUNDANCE OF WHITEFISH AND IN THE INTENSITY OF THE WHITEFISH FISHERY IN THE STATE OF MICHIGAN WATERS OF LAKES HURON AND MICHIGAN, 1929-1939

INTRODUCTION

In the proper administration of commercial fisheries it is of primary importance to have at hand statistical data that afford a reliable indication of changes in the abundance of the commercially available stocks of the leading species. These data must include a record not only of the quantity of fish taken, but also of the extent of the fishing operations that led to the reported catch. Obviously, a decrease in production cannot be held with certainty to represent a depletion of the stock unless it can be demonstrated that this lowered yield has not resulted from a reduction of fishing intensity. On the other hand, an increase in catch with its suggested danger of possible overfishing may not be the result of an expansion of fishing activities but may originate in an increase in the abundance of fish on the grounds. Nor can it be said that a sustained production over a period of years demonstrates a corresponding stability of abundance, for abundance may decline or increase greatly while compensating fluctuations of fishing intensity hold the total catch at a nearly constant level. The true condition of the fisheries, therefore, cannot be measured accurately by statistics of catch alone, but should be expressed in terms of production in relation to fishing intensity, that is, catch per unit of fishing effort.

It was with a view toward obtaining complete and reliable information on the fisheries of the Great Lakes waters under the jurisdiction of the State of Michigan that the senior author devised and recommended to the Michigan Department of Conservation the monthly report system now in effect. Under this system all licensed commercial fishermen must submit each month a complete record of their daily fishing activities. The required data on each day's fishing include: fishing locality; kind and amount of gear fished; the length of time (number of nights out) stationary gear fished before it was lifted; and the catch in pounds of each species taken. From these data it is possible to determine both the yield and the intensity of the fishery.

The law requiring the submission of monthly reports became effective in September 1927. The early returns were incomplete and the individual reports were often faulty. By the beginning of 1929, however, the fishermen had obtained sufficient experience in making out their reports so that almost all returns contained the complete data necessary for statistical analysis. These records for the 11-year period, 1929–1939, comprise the basic materials on which part II of this paper is founded.

METHODS OF ANALYSIS

Methods proposed for the analysis of Great Lakes fishery statistics were described by Hile and Duden (1933).[15] In general, the procedure outlined in this publication has proved satisfactory, although subsequent experience has shown certain simplifications of the original methods to be valid. (See discussion under "Units of Fishing Effort" in this section.) As an addition to the original procedure, methods have been devised for a more precise statement of changes in abundance and fishing intensity.

STATISTICAL DISTRICTS

Statistical tabulations and analyses have been made separately for six areas in Lake Huron and eight in Lake Michigan. (The boundaries of the different districts are indicated in the accompanying chart, fig. 4.) It was attempted to make these dis-

[15] Hile, Ralph and William R. Duden. Methods for the Investigation of the Statistics of the Commercial Fisheries of the Great Lakes. Trans. Am. Fish. Soc., vol. 63, 1933, pp. 292–305.

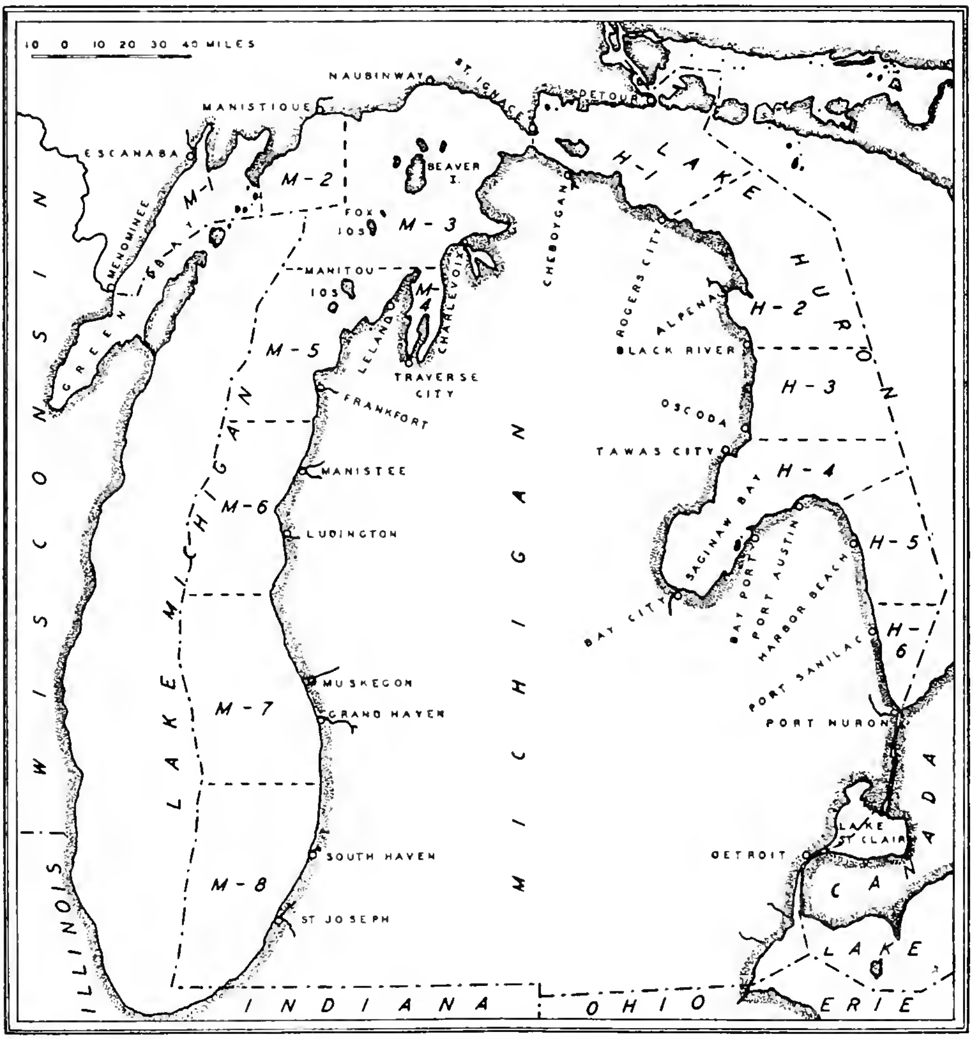


Figure 4.—Map showing the statistical districts of the State of Michigan waters of Lakes Huron and Michigan.

tricts natural divisions from the standpoint of both fishing grounds and fishing operations.[16] For some purposes the data for the separate districts have been combined to provide more general information for different regions of the lakes and for the entire lakes. For convenience, the districts will be designated in later discussions by the initial letter of the lake and the number of the district. For example, the third district of Lake Huron will be termed H-3, the fifth district of Lake Michigan, M-5,***.

PRODUCTION

The production was tabulated according to gear for each month. The only important gears used for the taking of whitefish are the large-mesh gill net ($4\frac{1}{2}$ inches or larger, stretched measure), the deep trap net, and the pound net. The discussion in this paper will be concerned chiefly with annual totals of the catch of the different gears and of all of them combined. Data on monthly yields will be confined to the discussion

[16] Hile and Dudeo (*loc. cit.*) stated that Lake Michigan had been divided into 11 statistical districts. Experience revealed, however, that certain of the original tentative divisions were not practical. Changes of boundaries and combinations of areas have reduced the number of statistical districts in Lake Michigan to eight. The six statistical districts of Lake Huron all proved satisfactory as originally defined.

of the effects of the deep trap net on the seasonal trend of production in Lake Huron (p. 332).

UNITS OF FISHING EFFORT

The units of fishing effort employed in this paper are:

Gill nets.—The lift of 10,000 linear feet of net (10,000 foot-lifts).[17]

Impounding nets (deep trap nets and pound nets).—The lift of one net (1 net-lift).

Fishing effort may be expressed as total effort and as effective effort (with respect to a given species). In large-mesh gill nets, for example, the total effort for a given area over a certain interval of time is the total number of units of 1,000 feet (see footnote 17) of net lifted. The effective effort with respect to whitefish is the number of units of gill net lifted that actually took this species. Corresponding definitions of total and effective effort apply to the pound net. A distinction between total and effective effort is necessary because both large-mesh gill nets and pound nets are fished for other species on grounds where whitefish do not occur. In the deep trap net, which was designed and operated primarily for the capture of whitefish, the total fishing effort and the effective effort with respect to this species may be considered identical. All tabulations of catch per lift in this paper are based on effective fishing effort.

In addition to the above "units of effort," the methods proposed by Hile and Duden defined "units of intensity" which included a consideration of fishing time (nights out). The intensity unit for gill nets was defined as the fishing effort of 1,000 feet of gill net over a period of one day, and for impounding nets as the fishing effort of one net over a period of one day. The basis for these definitions of intensity units was the assumption that the amount of fishing done by stationary gear varies directly with the time out. This assumption holds, for example, that a net which is out three nights may be expected to take three times as many fish as the same net in one night.

Subsequent detailed analyses of hundreds of fishermen's reports made by Hile and described briefly by him in 1935[18] and by Van Oosten (1935)[19] have proved this preliminary assumption to be erroneous. Although the catches of both gill nets and impounding nets, on the average, become larger with increase in fishing time, the improvement in the catch is far less than might be expected on theoretical grounds. A summary of the data on the actual relationship between fishing time and the average size of the lift in the gears most important in the whitefish fishery appears in table 2. In this table all catches are expressed as percentages of the catch of nets one night out. Although the data for the three gears disagree somewhat as to the relationship between the actual size of the catch and the number of nights out, these small discrepancies lose significance in the face of the large deviations that all the actual catches show with respect to the theoretical catches. For example, the largest increase in nets 2 nights out over nets 1 night out (pound nets) was only 16 percent of the expected increment of 100. Similarly, the largest increase in the catch of nets 5 nights out over 1 night out (54 in pound nets) was only 13.5 percent of the expected increment of 400. It is obvious, therefore, that only small increases in the catch can be expected as the time between lifts is increased. Consequently, the use of the catch per net per night as a measure of abundance is not valid. The strictly valid unit for the measure of abundance is neither the catch per lift nor the catch per night, but is rather the catch per lift, corrected for fishing time (from empirical data of the type contained in table 2).

The necessity for considering fishing time in the computation of annual fluctuations in abundance depends, of course, on the existence of annual variations in the average number of nights out. Annual variations in fishing time occur in all areas and for all stationary gears, but for a single area and a single type of gear these variations have a limited and characteristic range. The limited range of variation in the average number of nights out, together with the fact that a change in fishing time affects the

[17] The unit of effort was defined originally as the lift of 1,000 feet of gill nets. In the present study, however, the catch of gill nets has been recorded in terms of the yield per 10,000 foot-lifts (tables 11 and 17) in order to obtain values more nearly comparable with the catch per unit of effort of pound nets and deep trap nets.

[18] The Fisherman, vol. 4, no. 12, pp. 1 and 2, 1935.

[19] Van Oosten, John. Logically Justified Deductions Concerning the Great Lakes Fisheries Exploded by Scientific Research. Trans. Am. Fish. Soc., vol. 65, 1935, pp. 71–75.

TABLE 2.—*Relationship between fishing time and the average size of the lift*

[In order that the data for the different gears may be comparable, the catch per lift at one night out is set at 100 and all other catches expressed as percentages of this value. In parentheses, the number of fishermen's reports upon which determination was based]

Item		Number of nights out				
		1	2	3	4	5
Theoretical catch		100	200	300	400	500
Actual catch	Large-mesh gill nets	100	111 (304)	120 (430)	133 (403)	150 (278)
	Deep trap nets	100	115 (157)	116 (228)	128 (272)	[1]126 (197)
	Pound nets	100	116 (353)	138 (458)	141 (306)	154 (177)

[1]Less than preceding catch.

size of the catch only slightly, suggested the possibility that abundance curves calculated from the average catch per lift without reference to time might differ only slightly from curves calculated from the average catch per lift, corrected for time. To test this possibility a series of abundance curves for the period, 1929–1934, was computed by each of the two methods, covering all types of stationary gear and a variety of species and fishing areas. For each gear particular care was taken to select the statistical district with the widest annual variation in the average fishing time. Despite this selection, in each example the two curves resembled each other so closely that the same conclusions concerning the annual changes in abundance would have been drawn from either of them. As the neglect of the time element does not affect the results materially, all computations of abundance have been based on the catch per lift, without reference to time.

ESTIMATION OF ABUNDANCE AND FISHING INTENSITY

The method employed for the estimation of the abundance of species of fish in the State of Michigan waters of the Great Lakes in different calendar years was outlined by Hile (1937).[20] The definition of fishing intensity was given by Hile and Jobes (1941).[21] The steps in the determination of the general abundance of a species within a fishing area (statistical district) in a particular calendar year are:

(1) The "expected catch" of each important gear is determined as the product of known fishing intensity (number of impounding nets or thousands of feet of gill nets, that took the species, lifted within the district during the entire 12 months) and the average catch of that species per unit of fishing effort over a period of years.

(2) The expected catches as determined individually for the important gears are added to obtain the "total expected catch."

(3) The "general abundance" is the actual catch of the important gears expressed as a percentage of the total expected catch of the same gears.

As the average catch per unit of effort is constant in all of the computations of expected catch for a single type of gear, annual fluctuations in the expected catch by each gear and hence for all gears combined depend only on the amount of gear lifted. Consequently, the total expected catch of any single year, expressed as a percentage of the average total expected catch over a period of years, provides a measure of the relative intensity of the fishery in that particular year.

The above procedures make it possible to combine the data for all gears important for the capture of a particular species in such a way as to obtain estimates of the "general" abundance and of the total fishing intensity.

Originally all estimates of abundance and fishing intensity were made with reference to average conditions over the 6-year period, 1929–1934. Later, the percentages were adjusted to describe deviations about the mean for the 11 years, 1929–1939.

[20] Hile, Ralph. The Increase in the Abundance of the Yellow Pike-Perch, *Stizostedion vitreum* (Mitchill), in Lakes Huron and Michigan, in Relation to the Artificial Propagation of the Species. Trans. Am. Fish. Soc., vol. 66, (1936) 1937, pp. 143–159.

[21] Hile, Ralph and Frank W. Jobes. Age, Growth, and Production of the Yellow Perch, *Perca flavescens* (Mitchill), of Saginaw Bay. Trans. Am. Fish. Soc., vol. 70, (1940) 1941, pp. 102–122.

GENERAL REMARKS

It does not come within the province of this paper to undertake a detailed criticism of the statistical methods employed here, to discuss at length possible sources of systematic errors, to attempt to estimate the degree of reliability of certain necessary approximations, or to explain the basis for the selection of methods followed over possible alternative procedures. It can be said only that the methods employed for the analysis of the statistics of the commercial fisheries of the Great Lakes have been developed gradually from a careful study of extensive data covering all the commercially more important species over a period of years and in a large number of different localities. These methods have been adapted specifically to conditions in the Great Lakes. An outstanding feature of the Great Lakes fisheries is that most species are taken in quantity by several types of gear and that most types of gear take several species (usually simultaneously). These circumstances add greatly to the complexity of the problem of analysis.

No claims are advanced for the indexes of abundance and fishing intensity as "precision measures" of the changes that occurred in the fishery. On the other hand, we believe them to be sufficiently sensitive to bring out all changes of significant magnitude. This belief is supported by the consistency with which conclusions based entirely on our statistical data have been corroborated by reliable evidence gained independently from other sources (interviews with fishermen; observations of field workers).

Although, as stated previously, a general criticism of our methods of analysis will not be undertaken, it does appear desirable to call attention to certain difficulties of interpretation peculiar to the statistics of the whitefish fishery.

It is indeed unfortunate that the statistical data on the commercial fishery for whitefish are less satisfactory than those for any other important commercial species. The invention and rapid expansion in the use of that tremendously efficient gear, the deep trap net, brought about, particularly in Lake Huron, an almost immediate threat of depletion or commercial extinction to the whitefish stocks of the areas in which the net was fished. In this critical situation the need for dependable statistical measures of abundance was most pressing. However, the very circumstances that made the need for adequate statistical data so urgent also made the interpretation of these data difficult. The chief obstacles to appraising the statistical data on the whitefish over the period, 1929–1939, are: lack of information concerning normal conditions, inaccurate data on the deep-trap-net fishery, and the difficulty of bridging the transition to a fishery dominated by this gear.

As stated earlier (p. 314), in the statistical study of the important commercial species in the State of Michigan waters of the Great Lakes, the average conditions of production, abundance, and fishing intensity during the 6-year period, 1929–1934, were employed tentatively as the point of reference for the study of fluctuations. The fisheries for most species appeared to be approximately normal (with reference to modern conditions) during this period; consequently the 6-year averages may be expected to provide a fairly reliable basis for estimating changes in the condition of the fisheries, not only in that period but in subsequent years as well.

The whitefish fishery, however, was not normal in the years, 1929–1934, nor can the average conditions in the longer period, 1929–1939, be held to provide a satisfactory point of reference. It is recognized generally that whitefish were abnormally abundant at the beginning of these periods. The peak of abundance probably was reached in Lake Michigan in 1929 and in Lake Huron a year or so later. The high abundance in turn stimulated fishing intensity. As a result, production, abundance, and fishing intensity were all doubtless far above normal in the earlier years of the period for which detailed statistics are available. It should then be kept in mind throughout the discussion of the following sections that all fluctuations are described with reference to averages the relationship of which to the normal is not known.

The interpretation of the Lake Huron data is made even more difficult by the disturbing effects of the use of the deep trap net. This gear, which became the dominant one for the capture of whitefish as early as 1931, raised production to excessive heights and disrupted completely the ordinary course of return to normal conditions.

The fact that in all districts but H-2 the deep trap net was not fished throughout the entire "period of reference" (1929–1934) introduced certain difficulties into the estimation of abundance. For example, the deep trap net was operated in H-1 during only 5 years (1930–1934) of this 6-year period. The average catch of whitefish per lift of deep trap nets in the years, 1930–1934, was 111.08 pounds. However, the data for large-mesh gill nets and pound nets indicated that the 1930–1934 abundance averaged only 99.12 percent of the 1929–1934 mean. Consequently, the average catch per lift of deep trap nets would have been higher had the gear been fished in 1929 also. It was necessary, therefore, to base the computations of the expected catch (p. 314) of deep trap nets on the "corrected" catch per lift, 111.08/0.9912=112.07 pounds.

Although this method of "correcting" the average catch per lift of deep trap nets (in some districts the data for pound nets had to be treated similarly) is sound logically, the actual reliability of the results is open to question in some districts in which the rise of the deep-trap-net fishery was accompanied by the practical extinction of the gill-net and pound-net fisheries (for whitefish). The correction was based, for example, on the data for only 3 years in H-3 and H-5 and for 2 years in H-6. The difficulties involved in following annual changes in abundance in areas in which the deep trap net replaced other types of gears completely or nearly completely will be mentioned again on page 328.

The deep trap net was important also in Green Bay and northern Lake Michigan, but the disturbance of the fishery was not as severe as in Lake Huron.

Although the greatest need for dependable statistical data existed with respect to those districts in which the deep trap net became almost the only gear that produced whitefish, it was for precisely these areas that the original data were least trustworthy. This lack of dependability had its origin in the extensive inaccuracies and misstatements of fact known to have occurred in the reports of numerous deep-trap-net fishermen. This observation is not intended as an indictment of any fisherman or group of fishermen. Nevertheless, the fact that these inaccuracies existed cannot well be ignored. To discuss changes in abundance computed from deep-trap-net data without giving some idea as to their degree of dependability would be misleading. Misstatements were found in the reports of deep-trap-net fishermen as to the type of gear fished, the numbers of nets lifted, and the size of the catch.

Numerous deep-trap-net reports were indicated erroneously to be reports of pound-net operations. Most of the errors of this type were made by operators in the Saginaw Bay region in 1931 and in both the Saginaw Bay and Harbor Beach regions in 1932. In other years and in other districts the designation of deep trap nets as pound nets was much less frequent. Without naming sources of information or explaining the procedure followed, it may be stated that we are certain that we have detected and corrected practically all, if not all, of the misstatements as to the type of gear. Consequently, this originally serious source of error does not affect materially the data of this paper.

It has not been possible to correct the inaccuracies of data as to the number of nets lifted and the size of the catch, nor is there any basis for a good estimate of the extent of these inaccuracies. Where there was opportunity of comparing actual and reported data the discrepancies were sometimes appalling. Some fishermen not only reported incorrectly the number of nets lifted but gave dates of lifting that did not coincide with the dates on which they actually left port. The reported catches were often understatements. The extreme in this type of misrepresentation is offered by the report of an operator who is known to have taken more fish in a single day than he reported for the entire month. It must be considered highly probable that the actual total production of whitefish in deep trap nets was far above that recorded in this study.

In calling attention to the defects in the deep-trap-net data it is not intended to imply that all operators of deep trap nets submitted erroneous and carelessly prepared reports. There is good evidence that many of them prepared scrupulously accurate accounts of operation and of catch. Although the number of inaccurate reports may be sufficient to invalidate the deep-trap-net data as descriptive of details, these data still serve satisfactorily to indicate the trends of the fisheries in the different districts. This view finds support in the fact that for the whitefish as well as for other species there was good agreement between conclusions as to the course of the fishery based on statistical data and on the testimony of the fishermen themselves.

WHITEFISH FISHERY OF LAKE HURON, 1929-1939

In part I attention was called to the general increase in the abundance and production of whitefish that occurred in the waters of the Great Lakes in the late 1920's and early 1930's. Emphasis was placed on the fact that the increase in yield in Michigan waters of Lake Huron was relatively much higher than in other waters. The average Michigan catch in Lake Huron in the two peak years, 1931 and 1932, was 3.67 times the average annual production over a period of earlier years, and the years 1930, 1933, 1934, and 1935 had yields well above normal, whereas in other waters the average annual productions during the recent maximum were only 1.26 to 2.86 times the earlier averages (p. 309). The excessive catch in Lake Huron was attributed to the widespread use of the deep trap net in that lake. The detailed data that will be presented for the six statistical districts in the State of Michigan waters of Lake Huron fully support this earlier position. In fact, the origin and expansion of the deep-trap-net fishery dominate the recent history of Michigan's whitefish fishery of Lake Huron so completely that a summary of the 1929–1939 statistics constitutes in reality little more than a study of the effects of this new gear.

The deep trap net was introduced into Lake Huron off Alpena, Mich., in district H–2 in July 1928, and continued to be fished in the same area in 1929. The rapid expansion of the deep-trap-net fishery got under way in 1930. In this year the net was fished extensively not only in the neighborhood of Alpena but also in H-1 (especially in Hammond Bay) and in H–3 (mostly from Au Sable-Oscoda); a few deep trap nets were used also in 1930 on the "Middle Grounds" off Saginaw Bay (H-4). No new statistical districts were added to the deep-trap-net grounds until 1932, in the latter part of which season the net was introduced into the waters of southern Lake Huron off Harbor Beach (H-5). The expansion into H-6 in 1933 completed the coverage of the Michigan waters of the lake. This sequence makes the history of the deep-trap-net fishery, in a sense, discontinuous as the major "scene of action" shifted from year to year.

FLUCTUATIONS IN THE PRODUCTION OF WHITEFISH IN LAKE HURON

The production of whitefish in Lake Huron[22] increased phenomenally in 1930 and 1931 (table 3). The catch of 2,879,000 pounds in 1930 was nearly twice the 1929 yield of 1,456,000 pounds, and the 1931 production of 4,140,000 pounds represented an additional increase of 1,260,000 pounds above the 1930 level. The decline from the 1931 yield was relatively insignificant in 1932 (decrease of 89,000 pounds). The reduction in the catch was large, however, in the succeeding years, averaging 719,000 pounds per year for the 3 years, 1933–1935, 446,000 pounds for the 3 years, 1936–1938, and 303,000 pounds in 1939. Despite these large decreases the catch did not return to an approximately normal level until 1936. The subsequent declines carried the production far below normal. The 1938 yield of 558,000 pounds was only a little above the lowest catch recorded for any previous year (555,000 pounds in 1900), and the 1939 production of only 255,000 pounds was less than half the previous all-time low. The 11-year period (1929–1939) saw, therefore, a remarkable cycle in the yield of whitefish in Lake Huron. From a nearly normal level in 1929 the catch increased suddenly to the unprecedented height of more than 4 million pounds in 1931 and 1932 only to decline rapidly to an unprecedented low yield in 1939.

Much of the increase to the 1931–1932 peak and of the high production in 1933–1935 can be traced to the new gear, the deep trap net. The catch by this gear jumped from 87,000 pounds in 1929 to 871,000 pounds in 1930 (a ten-fold increase), 2,080,000 pounds in 1931, and 2,764,000 pounds (the peak production for the gear) in 1932. The catch of deep trap nets did not fall below 2 million pounds in the 4 years, 1931-1934.

[22] In this and the following section the terms, "Lake Huron" and "the entire lake," refer to the State of Michigan waters only.

TABLE 3.—*Production of whitefish in pounds according to gear in the State of Michigan waters of Lake Huron, 1929–1939*

[Percentages of annual yield in parentheses]

Year	Production in gear				Total annual production	Increase or decrease
	Large-mesh gill net	Deep trap net	Pound net	Other		
1929	489,961 (33.6)	87,121 (6.0)	823,696 (56.6)	55,590 (3.8)	1,456,368	−12,433
1930	613,752 (21.3)	871,321 (30.3)	1,302,586 (45.2)	91,781 (3.2)	2,879,440	1,423,072
1931	619,515 (15.0)	2,079,596 (50.2)	910,940 (22.0)	[1]529,721 (12.8)	4,139,772	1,260,332
1932	385,566 (9.5)	2,764,317 (68.2)	569,698 (14.1)	[1]330,753 (8.2)	4,050,334	−89,438
1933	269,271 (8.1)	2,704,576 (81.1)	305,229 (9.2)	54,825 (1.6)	3,333,901	−716,433
1934	189,701 (7.4)	2,061,483 (80.3)	258,207 (10.0)	58,842 (2.3)	2,568,233	−765,668
1935	132,789 (7.0)	1,487,342 (78.5)	172,280 (9.1)	102,396 (5.4)	1,894,807	−673,426
1936	88,951 (6.2)	1,166,707 (80.9)	127,100 (8.8)	59,411 (4.1)	1,442,169	−452,638
1937	49,937 (4.9)	834,164 (81.9)	107,221 (10.5)	27,359 (2.7)	1,018,681	−423,488
1938	55,677 (10.0)	423,073 (75.8)	58,813 (10.5)	20,406 (3.7)	557,969	−460,712
1939	41,072 (16.1)	178,517 (70.0)	28,911 (11.3)	6,683 (2.6)	255,183	−302,786
Average	266,927 (12.4)	1,332,565 (62.1)	424,062 (19.8)	121,615 (5.7)	2,145,169	

[1] A considerable portion of this catch, entered in the original records under the heading, "Gear unknown," was taken by deep trap nets.

It cannot be concluded that all of the production of deep trap nets represented additional demands on the whitefish stock of Lake Huron or that an increase in yield would not have taken place after 1929 without the operation of this gear. Substantial increases occurred in the production of whitefish by both gill nets and pound nets in 1930, and the 1931 catch in these gears was above the 1929 level. Unquestionably the output of gill nets and pound nets would have been even higher in 1930 and 1931 and the subsequent decline in production in those two gears would have been less rapid had not considerable numbers of fishermen abandoned the use of gill nets and pound nets in favor of the much more efficient deep trap net. On the other hand, the fact that deep trap nets produced more whitefish in every year of the 5-year period, 1931–1935, than did all gears combined in 1929, and did so, as will be shown later (p. 330) in the face of a rapid decline in abundance after 1931, suggests that this gear possesses capabilities for the capture of whitefish far greater than can be attributed to either gill nets or pound nets. (Superiority of deep trap nets over pound nets is due largely to the greater range of fishing depths of the former. See pp. 331 and 332.) Although the deep trap net cannot be held to be solely responsible for the increase in production that took place after 1929, the conclusion is justified, nevertheless, that the increase would have been much smaller had this gear not been fished.

The superiority of the deep trap net for the capture of whitefish is indicated strongly by the speed with which it replaced other gears. In 1929 deep trap nets accounted for only 6.0 percent of the total yield of whitefish in Lake Huron. Two years later in 1931 they took more than half the total and by 1933 were responsible for more than 80 percent of the catch. Deep-trap-net production as a percentage of the total yield fluctuated about the 80-percent level for 5 years (1933–1937) and declined only with the virtual collapse of the fishery in 1938 and 1939.

The deep trap net became at some time the dominant gear for the capture of whitefish in every statistical district of Lake Huron (table 4 and appendix B). With the increase in the use of deep trap nets the operations with pound nets and gill nets declined in most districts to the point of insignificance. Only in H–1 did the deep trap net fail to become established as the overwhelmingly dominant gear. The percentage of the total production of whitefish taken by deep trap nets was not greater than 38 percent in that district before 1935, and exceeded 50 percent in only 3 years (1936, 1937, and 1939). In other districts the deep trap net accounted for more than 50 percent of the total catch of whitefish in the first or second year of operation (possible exception in H–4 where considerable quantities of whitefish taken by deep trap nets in 1931 are included in the catches for which the records of gear were not available) and maintained a dominant position with great consistency throughout the later years. This statement is true especially for southern Lake Huron (H–5 and H–6 combined) where the deep trap net was responsible for more than 90 percent of the total yield in every year after 1932 and for more than 95 percent in every year after 1935.

TABLE 4.—*Production of whitefish in pounds in deep trap nets in Lake Huron, 1929–1939*

[In parentheses, the deep-trap-net production expressed as a percentage of the total whitefish production]

District or area	Production of whitefish in deep trap nets in year											Total
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	
H-1	....	286,453 (37.9)	375,122 (38.0)	170,313 (27.3)	64,251 (17.6)	104,696 (27.7)	163,465 (43.8)	346,821 (64.1)	236,196 (73.2)	73,184 (40.6)	73,406 (52.0)	1,893,910 (37.2)
H-2	87,121 (31.7)	358,872 (60.4)	376,887 (78.7)	94,527 (80.5)	28,540 (50.3)	44,153 (47.4)	94,584 (80.0)	46,602 (83.8)	14,009 (67.3)	34,315 (83.0)	41,980 (99.3)	1,221,590 (64.5)
Northern Lake Huron (H-1 and H-2)	87,121 (13.4)	645,325 (47.8)	752,009 (51.3)	264,840 (35.7)	92,791 (22.0)	148,852 (31.6)	258,049 (52.5)	393,423 (65.9)	250,205 (63.4)	107,499 (48.5)	115,386 (62.9)	3,115,500 (44.6)
H-3	....	157,248 (63.5)	395,230 (84.0)	85,236 (62.0)	9,912 (70.1)	12,558 (87.2)	7,964 (89.4)	7,567 (94.5)	1,934 (69.1)	8,910 (97.2)	277 (49.7)	686,836 (67.9)
H-4	....	68,748 (6.6)	[1]932,357 (47.9)	[1]1,934,325 (78.5)	620,125 (81.4)	116,849 (59.9)	138,446 (65.1)	75,438 (58.6)	121,796 (78.5)	38,224 (68.4)	18,785 (72.4)	4,065,093 (53.8)
Central Lake Huron (H-3 and H-4)	....	225,996 (17.5)	1,327,587 (54.9)	2,019,561 (77.7)	630,037 (81.2)	129,407 (61.8)	146,410 (66.1)	83,005 (60.7)	123,730 (78.4)	47,134 (72.5)	19,062 (71.9)	4,751,929 (55.4)
H-5	....	....	....	479,916 (93.5)	1,658,753 (98.9)	783,606 (99.9)	272,746 (99.8)	119,103 (100.0)	66,688 (99.8)	41,832 (99.8)	12,247 (100.0)	3,434,891 (92.4)
H-6	....	....	....	....	322,995 (70.3)	999,618 (90.6)	810,137 (89.1)	571,176 (96.9)	393,541 (98.5)	226,608 (98.7)	31,822 (96.1)	3,355,897 (77.7)
Southern Lake Huron (H-5 and H-6)	....	....	....	479,916 (67.7)	1,981,748 (92.8)	1,783,224 (94.5)	1,082,883 (91.6)	690,279 (97.4)	460,229 (98.7)	268,440 (98.9)	44,069 (97.2)	6,790,788 (84.5)
Lake Huron (all 6 districts)	87,121 (6.0)	871,321 (30.3)	2,079,596 (50.2)	2,764,317 (68.2)	2,704,576 (81.1)	2,061,483 (80.3)	1,487,342 (78.5)	1,166,707 (80.9)	834,164 (81.9)	423,073 (75.8)	178,517 (70.0)	14,658,217 (62.1)

[1] Pounds and the corresponding percentage are too low; the total production in H-4 in 1931 and 1932 included considerable quantities of whitefish for which records of the gear of capture were lacking, but a large part of which came from deep trap nets. Other totals and percentages in the computation of which these figures were involved were affected relatively less severely.

A peculiar feature of the production of whitefish in Lake Huron, 1930-1935, lay in the circumstance that a high level of yield was maintained by a successive rather than a simultaneous exploitation of the stocks in the various portions of the lake (table 5 and appendix B). In each area the catch of whitefish followed a typical cycle after the introduction of the deep trap net. Production was raised to tremendous heights for about 2 years, only to fall away sharply. Since the use of the deep trap net spread gradually throughout the lake, first one area and then another bore the burden of heavy fishing.

Although the deep trap net was fished in H–2 in 1929 (in 1928 also), it did not produce large quantities of fish until 1930. In this same year the net was employed extensively in H–1 and H–3 also and was introduced into H–4. In 1931 high yields were obtained in each of these first four districts. Thus it was possible for the production of whitefish in Lake Huron to increase phenomenally in 1930 and attain an

TABLE 5.—*Total annual production of whitefish in pounds in the different districts and areas of the State of Michigan waters of Lake Huron, 1929–1939*

[Each total is expressed also as the percentage (in parentheses) of the production of the entire lake]

District or area	Total whitefish production in year											Average
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	
H-1	375,577 (25.8)	[1,2]755,362 (26.2)	[2]987,466 (23.8)	623,670 (15.4)	364,683 (11.0)	378,105 (14.7)	372,874 (19.7)	541,392 (37.5)	373,755 (36.7)	180,127 (32.3)	141,051 (55.3)	463,187 (21.6)
H-2	[1]274,640 (18.9)	[2]594,526 (20.7)	[2]478,969 (11.6)	117,432 (2.9)	56,745 (1.7)	93,116 (3.6)	118,287 (6.2)	55,606 (3.9)	20,813 (2.0)	41,363 (7.4)	42,285 (16.5)	172,162 (8.0)
Northern Lake Huron (H-1 and H-2)	650,217 (44.7)	1,349,888 (46.9)	1,466,435 (35.4)	741,102 (18.3)	422,428 (12.7)	471,221 (18.3)	491,161 (25.9)	596,998 (41.4)	394,568 (38.7)	221,490 (39.7)	183,336 (71.8)	635,349 (29.6)
H-3	98,818 (6.8)	[1,2]247,572 (8.6)	[2]470,423 (11.4)	137,463 (3.4)	14,130 (0.4)	14,399 (0.6)	8,907 (0.5)	8,006 (0.6)	2,798 (0.3)	9,163 (1.7)	557 (0.2)	92,021 (4.3)
H-4	571,605 (39.2)	[1]1,043,395 (36.2)	[2]1,948,085 (47.0)	[2]2,462,958 (60.8)	761,562 (22.8)	194,945 (7.6)	212,513 (11.2)	128,717 (8.9)	155,091 (15.2)	55,885 (10.0)	25,945 (10.2)	687,337 (32.0)
Central Lake Huron (H-3 and H-4)	670,423 (46.0)	1,290,967 (44.8)	2,418,508 (58.4)	2,600,421 (64.2)	775,692 (23.2)	209,344 (8.2)	221,420 (11.7)	136,723 (9.5)	157,889 (15.5)	65,048 (11.7)	26,502 (10.4)	779,358 (36.3)
H-5	62,987 (4.3)	91,493 (3.2)	74,038 (1.8)	[1]513,409 (12.7)	[2]1,676,432 (50.3)	784,215 (30.5)	273,421 (14.4)	119,140 (8.3)	66,825 (6.6)	41,915 (7.5)	12,247 (4.8)	337,830 (15.8)
H-6	72,741 (5.0)	147,092 (5.1)	180,791 (4.4)	195,402 (4.8)	[1]459,349 (13.8)	[2]1,103,453 (43.0)	[2]908,805 (48.0)	589,308 (40.8)	399,399 (39.2)	229,516 (41.1)	33,098 (13.0)	392,632 (18.3)
Southern Lake Huron (H-5 and H-6)	135,728 (9.3)	238,585 (8.3)	254,829 (6.2)	708,811 (17.5)	2,135,781 (64.1)	1,887,668 (73.5)	1,182,226 (62.4)	708,448 (49.1)	466,224 (45.8)	271,431 (48.6)	45,345 (17.8)	730,462 (34.1)
Lake Huron (all 6 districts)	1,456,368	2,879,440	4,139,772	4,050,334	3,333,901	2,568,233	1,894,807	1,442,169	1,018,681	557,969	255,183	2,145,169
Percentage of average	68	134	193	189	155	120	88	67	48	26	12	....

[1] Year of introduction of deep trap net.
[2] Years of heaviest production of whitefish in deep trap nets.

all-time high in 1931 without the benefit of a really significant contribution from the southern region of the lake (H–5 and H–6) where the increase from 1929 to 1931 amounted to only 119,000 pounds.

In 1932 the first three districts, H–1, H–2, and H–3, after 2 peak years, suffered a severe decline in production. The combined decrease amounted to more than a million pounds. This reduction was compensated to a large extent by further increases in H–4, the center of the deep-trap-net fishery in 1932, and by the phenomenal rise in output in H–5, into which district deep trap nets were introduced for the first time. As a result, the total catch for the lake fell only slightly from the 1931 maximum.

After 2 years of extremely high production the catch of whitefish in H–4 decreased 1,701,000 pounds in 1933. The yield in the first four districts combined dropped from 3,342,000 pounds in 1932 to 1,198,000 pounds in 1933, a decrease of 2,144,000 pounds. It was hardly to be expected that this large decline in the first four districts could be compensated fully by a rise in production in southern Lake Huron, a region that produced only 136,000 pounds of whitefish in 1929. The increase in catch in southern Lake Huron was nevertheless enormous—1,163,000 pounds in H–5, 264,000 pounds in H–6, and 1,427,000 pounds in the two districts combined. In H–5 the 1933 production was 26.6 times the yield in 1929; for H–5 and H–6 combined the 1933 catch was 15.7 times that of 1929. The production in the entire lake, however, decreased in 1933 by 716,000 pounds.

The output of whitefish increased markedly in H–6 in 1934 (increase of 644,000 pounds), but the larger decrease of 892,000 pounds in H–5 led to a drop of 248,000 pounds in southern Lake Huron. Increases ranging from an insignificant recovery in H–3 to a sharp rise in H–2 occurred in the first three districts. In H–4, however, the catch dropped 567,000 pounds (from 762,000 pounds in 1933 to 195,000 pounds in 1934). The decrease for all six districts was 766,000 pounds.

The increases in the catch of whitefish in H–2 and H–4 in 1935 exceeded the decreases in H–1 and H–3; consequently, the totals increased slightly in both northern and central Lake Huron. However, the large decreases in H–5 and H–6 (705,000 pounds for the two districts) caused the yield of the entire lake to decline 673,000 pounds.

With the onset of the decline in production in H–6 in 1935 the cycle of exploitation of the stocks of Lake Huron whitefish by means of the deep trap net was approaching its final stages. As the fishery failed in other areas deep-trap-net fishermen had moved on to new grounds. H–6, however, had provided the last unexploited fishing area available. The lack of new grounds may account for the fact that large numbers of deep-trap-net fishermen remained longer in H–6 than they had in any other district. H–6, despite a continued decline in the catch, maintained first rank among the districts in the production of whitefish during the 5-year period, 1934–1938, relinquishing this position only with the almost complete collapse of the fishery in 1939.

It is true that in some districts the general decline during the later years of the fishery was interrupted by temporary increases as fishermen returned to glean a scant harvest from their former grounds. The most noteworthy recovery occurred in H–1, where in 1936 the production of whitefish rose above a half million pounds. However, the deep-trap-net operations in H–1 in 1936 were not centered in the southeastern part of the district (especially in Hammond Bay) as in earlier years but were carried on chiefly in the northwestern end (Cheboygan-St. Ignace) in an area that formerly had been exploited only moderately. These temporary increases in certain districts were insufficient by far to halt the general downward trend of the catch in the lake as a whole.

An outstanding feature of the statistical data discussed in the preceding pages was the shift from year to year in the center of production of whitefish. The output fluctuated over a wide range in all districts. Especially striking, however, were the increases in southern Lake Huron which accounted for only 9.3 percent of the 1929 production but yielded more than 60 percent of the total for the lake in 1933, 1934, and 1935 (73.5 percent in 1934).

These violent fluctuations in production and shifts in the center of operations suggest distinctly abnormal conditions in the fishery. The belief that conditions were abnormal in the years following 1929 finds support in the data on the catch of whitefish in the various districts in the earlier period of the fishery, 1891–1908 (table 6). Although a certain amount of shifting did occur in the relative importance of the several districts for the production of whitefish, these changes were insignificant in comparison with the tremendous fluctuations that took place during the recent years, 1930–1939 (table 5). In the earlier period, for example, H–1 and H–4 held first or second rank in every year except 1891 when the second highest yield was made in H–2 (H–1 in first position and H–4 in the third). Third and fourth rankings usually were held by H–2 and H–3 (characteristically in that order) while H–6 commonly ranked fifth and H–5 was normally sixth (only one exception). The limited extent of the fluctuations in the rankings of the districts with respect to the production of whitefish in 1891–1908 is brought out by the following tabulation (left half) which shows the number of years each position was held by each district. The right half of the tabulation brings out the sharp contrast in yield with that for the period of the deep-trap-net fishery, 1930–1939:

District	Rank (1891–1908)						District	Rank (1930–1939)					
	1	2	3	4	5	6		1	2	3	4	5	6
H-1	12	6	--	--	--	--	H-1	1	7	1	1		--
H-2	--	1	12	3	2	--	H-2	--	1	2	--	6	1
H-3	--	--	4	12	2	--	H-3	--	--	--	2	1	7
H-4	6	11	1	--	--	--	H-4	3	1	3	3	--	
H-5	--	--	--	--	1	17	H-5	1	1	2	3	1	2
H-6	--	--	1	3	13	1	H-6	5	--	2	1	2	--

The range of rank was the greater in the more recent period in each district except H–3, a region in which the whitefish fishery was unimportant after 1932. The greatest increase in range occurred in H–5 which held every position from first to sixth although this area had ranked sixth 17 times (fifth in the remaining year) in the period, 1891–1908, and had not yielded more than 7,500 pounds in any one of the 18 years.

It should be noted further that with only one exception (the rank of 5) each of the rankings from 1 to 6 occurred in more districts in 1930–1939 than in 1891–1908. For example, first position was held in four districts (all but H–2 and H–3) in the more recent period as compared with only two (H–1 and H–4) in the earlier years, second rank was held by four districts in 1930–1939 as compared with three in 1891–1908,***.

The actual figures of catch of tables 5 and 6 support the observations based on the rankings, for the yields of the individual districts were in general far less variable in the early than in the recent period.

TABLE 6.—*Production of whitefish in pounds in Lake Huron according to statistical districts, 1891–1908*

Year	Statistical district						Total
	H-1	H-2	H-3	H-4	H-5	H-6	
1891	1,304,220	133,000	58,500	91,540	6,000	31,600	1,624,860
1892	1,150,933	94,000	29,200	160,450	3,500	48,100	1,486,183
1893	1,204,400	12,000	131,500	199,900	2,000	27,800	1,577,600
1894	939,250	91,600	61,500	116,550	1,000	8,350	1,218,250
1895	614,830	75,550	39,500	203,687	1,500	10,800	945,867
1896	440,600	118,616	167,300	264,119	500	14,600	1,005,735
1897	392,100	141,555	38,300	285,200	4,000	4,805	865,960
1898	239,800	59,500	38,500	249,050	1,500	4,400	592,750
1899	201,600	96,000	36,100	306,560	1,800	3,520	645,580
1900	152,400	104,000	99,500	191,520	4,500	3,500	555,420
1901	219,025	137,000	154,300	263,720	5,000	9,200	788,245
1902	307,000	137,500	122,000	331,930	600	14,500	913,530
1903	312,700	106,100	70,700	436,360	400	11,200	937,460
1904	328,000	54,000	85,000	303,860	1,000	15,500	787,360
1905	381,200	30,300	29,800	208,260	3,500	21,800	674,860
1906	492,300	38,500	25,600	198,220	5,000	32,100	791,720
1907	658,500	45,000	64,600	282,772	3,300	78,800	1,132,972
1908	578,915	48,963	41,666	270,832	7,500	26,029	973,905
Average	550,987	84,621	71,865	242,474	2,922	20,367	973,236
Percentage	56.6	8.7	7.4	24.9	0.3	2.1	

The records of yield for the years, 1891–1908, indicate also that the percentages of the total catch of whitefish in the different districts were approximately normal in 1929, the only recent year (with data for each district separately) in which the statistics were not seriously distorted by the deep-trap-net fishery. It is true, the percentage distribution of the catch of whitefish in Lake Huron in 1929 (table 5) differed somewhat from that for the average for 1891–1908. It will be noticed, for example, that in 1929 the greatest production (39.2 percent) was from H–4 with H–1 in second position (25.8 percent) whereas in 1891–1908 the greatest average yield came from H–1 (56.6 percent) with H–4 in second position (24.9 percent). Among the remaining districts the percentages were higher in 1929 in H–2 (in part because of the catch in deep trap nets), H–5, and H–6, and possibly lower in H–3,[23] but the rankings of the districts were the same.

The differences in the values of these percentages are not large enough, however, to warrant the conclusion that the relative capacities of the various districts for the production of whitefish in 1929 were changed greatly from those of 1891–1908. Although the high percentage of the total yield of whitefish in H–4 in 1929 is in disagreement

[23] The division of the statistics for the earlier years was based on the location of the home port and not necessarily on the grounds actually fished. It is known that, in more recent years at least, some fishermen from Au Sable-Oscoda (H-3) have operated with gill nets in H-4 on the "Middle Grounds" off Saginaw Bay. In 1929 and 1930 these fishermen accounted for about 14 percent of the total whitefish catch of H-4. If this same percentage held for the earlier years the average production in H-3 and H-4 should have been 32,392 pounds and 281,947 pounds, respectively, instead of 71,865 pounds and 242,474 pounds as recorded in table 6; the percentages should have been 3.3 and 29.0 instead of 7.4 and 24.9. There is no reason to believe that the data for other districts were affected significantly by the division of the catch according to port.

with average conditions in 1891–1908, evidence that the 1929 percentage for the district did not represent an abnormal condition may be seen in the fact that the catch in H–4 exceeded that in H–1 in 6 successive years (1898–1903) of the 18 in the early period. The percentage of the Lake Huron catch produced in H–4 in 1929 apparently was somewhat above the average for the modern as well as the early period, as in the 9 years, 1920–1928, the percentage of whitefish taken in Saginaw Bay (in H–4) did not exceed 31.3 percent and averaged only 23.5 percent. (This statement is based on statistics published for Saginaw Bay and Huron proper by the Michigan Department of Conservation.)

The evidence that the percentages of the 1929 yield of whitefish taken in the several districts were within the normal range of variation lends further support to the belief that the deep-trap-net fishery brought about abnormal conditions in 1930–1939.

CHANGES IN PRODUCTION IN LAKE HURON AS RELATED TO FLUCTUATIONS IN THE ABUNDANCE OF WHITEFISH AND IN THE INTENSITY OF THE FISHERY

Up to this point the discussion has been concerned only with the fluctuations in the catch of whitefish, because it was believed that this, the more obvious phase of the fishery, should be outlined clearly before the changes in production were analyzed in relation to concurrent fluctuations in the abundance of whitefish and the intensity of the whitefish fishery. The fundamental problem in the analysis of the statistical data relative to the whitefish fishery of Lake Huron is the determination of the probable effects of deep-trap-net operations on the abundance of marketable whitefish. As pointed out previously (p. 315) this problem is complicated greatly by the circumstance that whitefish are known to have been abnormally abundant during the years in which the deep-trap-net fishery was undergoing its most rapid expansion. The abundance of whitefish in Lake Huron was possibly above normal in 1929; certainly it was well above normal in 1930 and 1931 (table 10). A decline from this abnormally high abundance would have occurred even if deep trap nets had not been operated in the lake. It is only logical to believe also that the high abundance following 1929 would have stimulated fishing intensity even had deep trap nets not been fished. The general problem resolves itself, therefore, into the estimation of the degree to which the increased fishing intensity and the heightened production made possible by the use of deep trap nets affected the rate of the decline in abundance and its ultimate extent.

That the deep trap net accounted for the bulk of the extremely high yields of whitefish over the period, 1930–1935, was brought out in the preceding section. It will now be demonstrated that the high production resulted from an unreasonably great fishing intensity and that this overfishing in turn accelerated the decline in the abundance of whitefish. In the four southernmost districts in which the deep trap net was fished most extensively the whitefish fishery reached a state of collapse. Abundance and catch were reduced in the other two districts in which the deep-trap-net operations were less extensive but the decline was far less pronounced than in the four districts.

A comparison of the extent of the changes in production, abundance, and fishing intensity in the several districts may be found in table 7. In this one table the year 1929 rather than the 11-year period (1929–1939) has been taken as the point of reference. To be sure, there is no certainty that 1929 was a "normal" year. However, the catch in 1929 was at approximately the typical level for 1922–1929, and there is no evidence of any unusual conditions in the fishery in that year. Certainly, 1929 is the most nearly normal year for which detailed statistical data are available.

The data of table 7 do not provide a complete history of the deep-trap-net fishery. They do serve, however, to show the variation among the districts in the maxima of yields and fishing intensity that followed the introduction of the deep trap net, and the apparent relationship between these maxima and conditions in 1939. The increases in catch were by no means as great in H–1 and H–2 as in the remaining districts. In these two northern districts the maximum productions were 263 and 317 percent, respectively, of the 1929 yield. In central Lake Huron the maxima were 476 percent in H–3 and 431 percent in H–4. It was in southern Lake Huron, however, that the greatest relative increases in production occurred. The maximum yield was more than 26 times the 1929 catch in H–5 and more than 15 times the 1929 production in H–6.

The differences in the relative maximum yields attained in the several districts are to be attributed primarily to differences in the relative increases in fishing intensity. The maximum intensity in H–1 and H–2 was a little more than twice that of 1929. It was roughly 5 times the 1929 level of intensity in H–3 and 4 times in H–4. In H–5 and H–6, however, the maximum fishing intensities were, respectively, 42 and 27 times the 1929 intensity.

The relative maximum abundance attained in the various districts exhibited remarkable agreement. In four of the six districts (H–1, H–4, H–5, and H–6) the maximum abundance was between 140 and 150 percent of the abundance in 1929, and in a fifth (H–2) the maximum was a little less than 140 percent (136 percent) of the 1929 level. In H–3 the greatest estimated abundance occurred in 1929 in which year the pound nets were particularly successful (table 11). The abundance in H–3 fell in 1930 but increased in 1931; peculiarly enough the abundance in 1931 was 143 percent of that in 1930 (*cf.* increases in other districts over 1929 abundance).

Production and abundance in 1939 were below the 1929 level in every district, and the fishing intensity was less than that of 1929 in all but the two southernmost districts. Of especial significance is the fact that the abundance in 1939 was relatively much higher in H–1 and H–2, the two districts in which production and intensity had reached the relatively lowest maxima. In the remainder of the lake the whitefish had almost disappeared. So great was the depletion that in H–5 and H–6

TABLE 7.—*Maximum and 1939 production and abundance of whitefish and maximum and 1939 fishing intensity for whitefish expressed as percentages of the 1929 values in each statistical district of Lake Huron*

District	Year of maximum production	Production		Year of maximum intensity	Intensity		Year of maximum abundance	Abundance	
		Maximum	1939		Maximum	1939		Maximum	1939
H-1	1931	263	38	1931	233	89	1930	140	41
H-2[1]	1930	317	23	1930	228	50	1930	136	43
H-3	1931	476	1	1931	528	5	1929	100	6
H-4	1932	431	5	1932	377	60	1931	149	7
H-5	1933	2,662	19	1933	4,211	433	1931	142	5
H-6	1934	1,517	46	1935	2,678	489	1932	148	10

[1] The deep-trap-net fishery of 1929 was excluded in the computations of these percentages of production and fishing intensity for H-2.

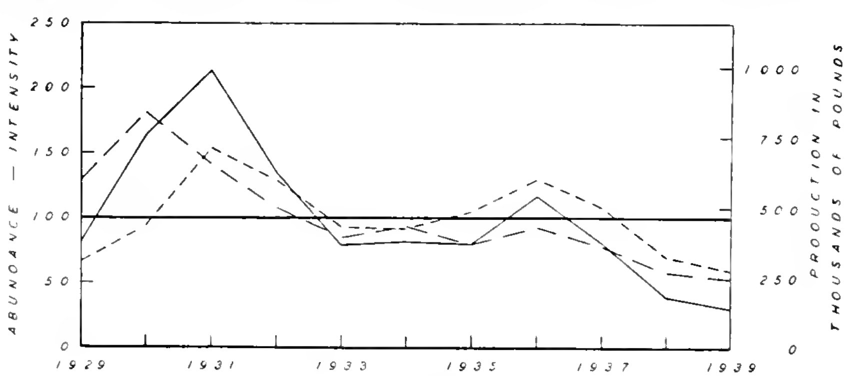


FIGURE 5.—First district, H-1.

Figures 5 to 10 show the annual fluctuations in the production (solid lines) and abundance (long dashes) of whitefish and in the intensity of the whitefish fishery (short dashes) over the period, 1929–1939, in each of the six statistical districts of Lake Huron (see fig. 4). In each figure the central horizontal line represents the average conditions for the 11 years, 1929–1939.

fishing intensities between 4 and 5 times those of 1929 yielded productions amounting to only 19 and 46 percent, respectively, of the 1929 catch. For practical purposes it can be said that there was no whitefish fishery in H–3 in 1939, and that the fishery in H–4 was insignificant.

The data of table 7 have brought out the fact that a disastrous depletion of the

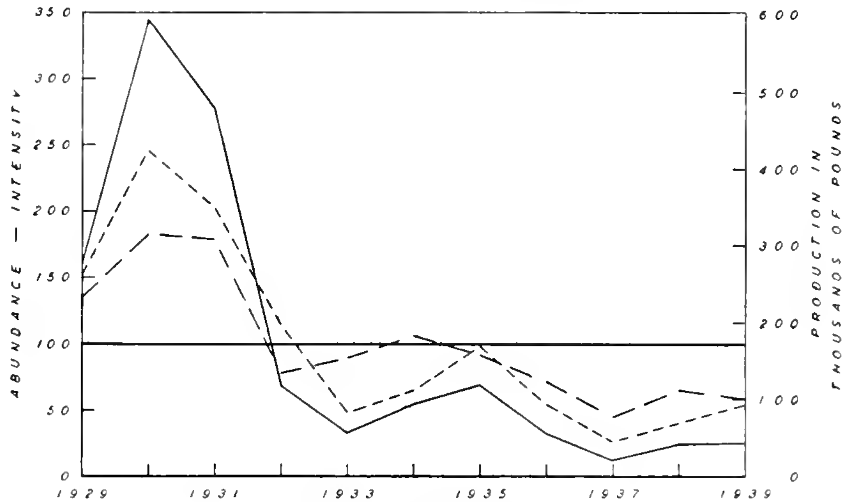


FIGURE 6.—Second district, H-2.

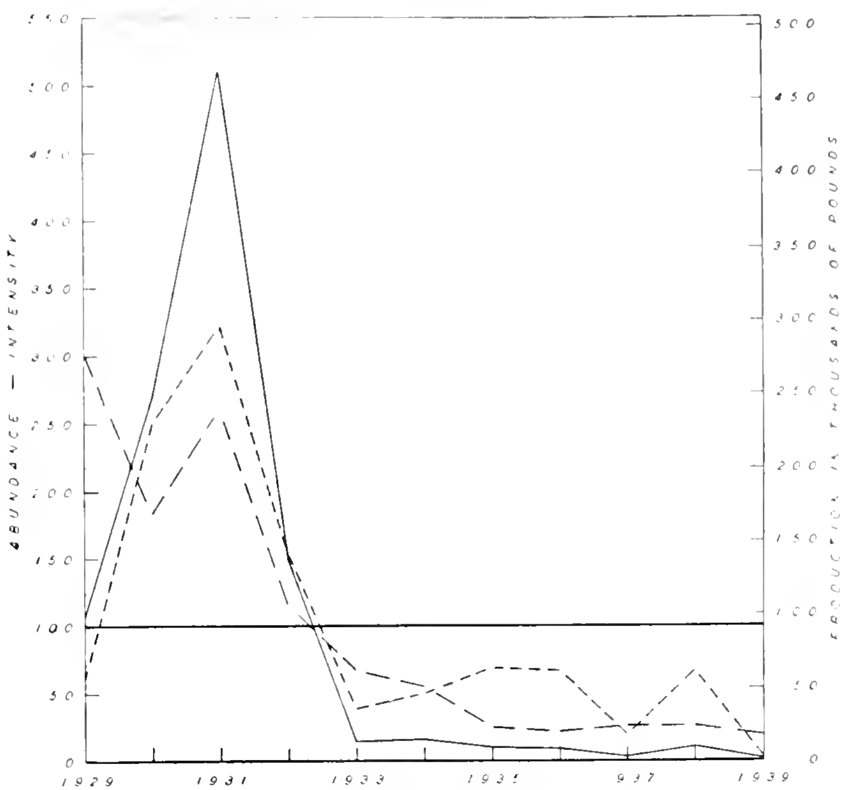


FIGURE 7.—Third district, H-3.

whitefish occurred in the four districts in which the use of the deep trap net led to an excessive multiplication of fishing intensity and catch. The decline in the abundance of whitefish was much less severe in the two districts in which the exploitation of the stock was more moderate. Further evidence on the harmful effects of deep-trap-net operations will be brought out by a more detailed consideration of the annual changes in production, fishing intensity, and abundance in the various districts with reference to the 1929–1939 averages.

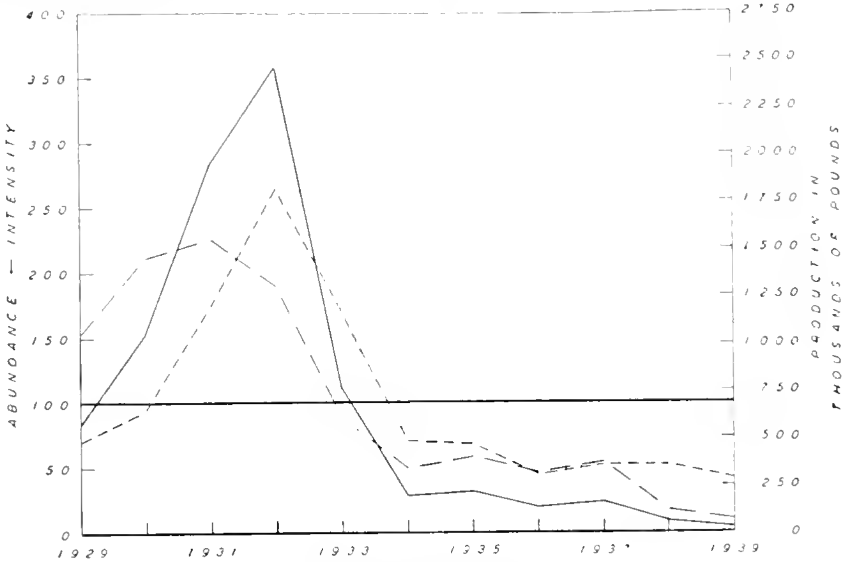


FIGURE 8.—Fourth district, H-4.

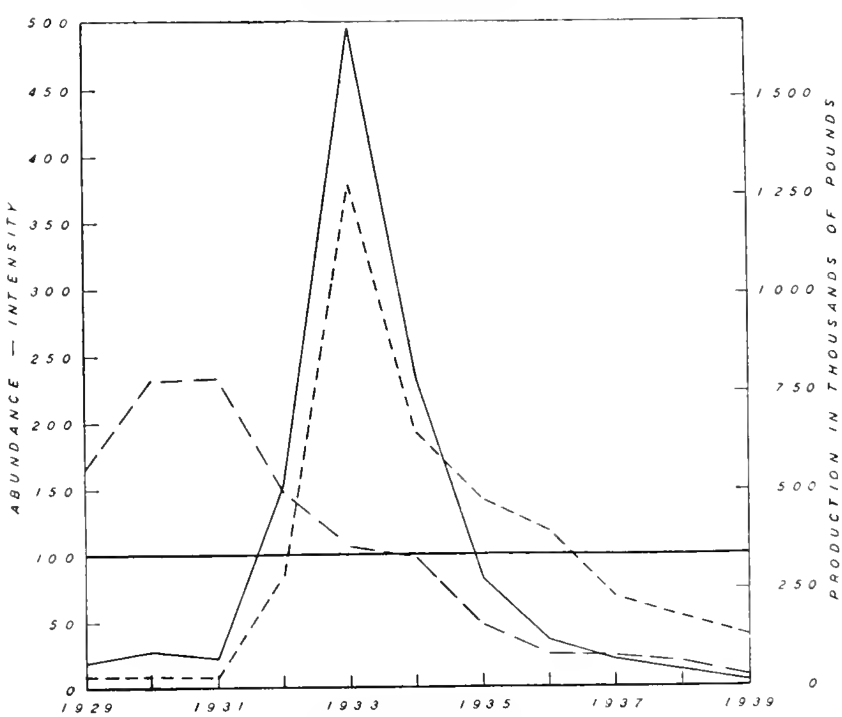


FIGURE 9.—Fifth district, H-5.

In the previous section attention was called to the existence of a typical deep-trap-net cycle of production (p. 319) in which the catch "was raised to tremendous heights for about 2 years, only to fall away sharply." It is equally valid to speak of "typical deep-trap-net cycles" of fishing intensity and in the abundance of whitefish. (For graphical representations of the annual fluctuations in the catch and abundance of whitefish and in the intensity of the whitefish fishery in the several districts, see figs. 5 to 10.) The tremendous increases in yields were accompanied by

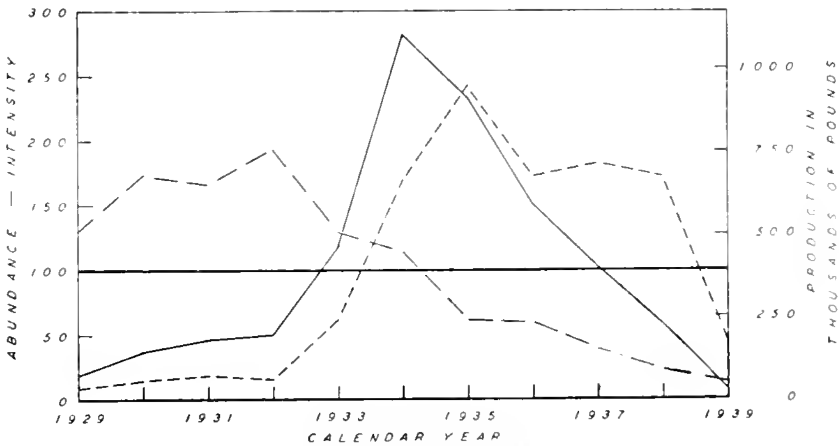


FIGURE 10.—Sixth district, H-6.

great increases in fishing intensity (table 8). To a large extent these increases in intensity represented deep-trap-net operations (table 9). In about 2 years, however, the fishing intensity declined in a district as the fishermen moved on to more productive grounds. An exception to this cycle of intensity is to be found in H-6 where an extremely intensive fishery was carried on for 5 years (1934–1938) despite a rapid decrease in the returns. Operators of deep trap nets remained longer in H-6 because the more northerly grounds had been exploited thoroughly in previous years (p. 321). H-1 and H-2 showed limited secondary increases in fishing intensity (about 1935–1937 in H-1 and 1934–1935 in H-2) as some fishermen returned from the depleted grounds in the south.

Without exception the abundance of whitefish fell sharply after a period (usually 2 years) of intensive deep-trap-net operations. This fact is brought out clearly by the data of table 10 in which the years of greatest production of deep trap nets have been designated. (The comparison of tables 4 and 9 will reveal that the years of greatest yields of deep trap nets and the years of greatest intensity of the deep-trap-net fishery were not always the same.) The nature of the changes in abundance that followed heavy removals of whitefish may be summarized for the districts as follows:

H-1. Abundance began to decline in 1931, the second year of heavy production by deep trap nets. This decline continued through 1933.

TABLE 8.—*Annual fluctuations in the intensity of the fishery for whitefish in each district of Lake Huron*

[Expressed as percentages of the average 1929–1939 intensity in the district]

District	Fishing intensity as percentage of average in year										
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
H-1	66	94	154	129	93	92	105	130	108	70	59
H-2	152	246	203	114	48	65	98	54	26	40	54
H-3	61	250	322	153	39	50	69	67	19	67	3
H-4	70	94	174	264	170	70	68	44	52	52	42
H-5	9	9	8	84	379	192	141	118	68	53	39
H-6	9	15	19	16	62	168	241	172	182	172	44

H–2. Abundance was high in 1930 and 1931, the years of high yields; in 1932 abundance declined to less than half that of 1931.

H–3. Abundance increased in 1931, the second year of heavy production, but was less than half as great in 1932 as in 1931.

H–4. Abundance decreased somewhat in 1932, the second year of high production; the abundance in 1933 was less than half that of 1932.

TABLE 9.—*Annual fluctuations in the intensity of the whitefish fishery for all six districts of Lake Huron combined (third row from bottom of table) and distribution of each year's fishing intensity among the districts*

[The average annual intensity for the entire lake, 1929–1939, is 100.0. In parentheses are the intensity values of the deep-trap-net fishery. The value of one unit is 1/1,100 of the total expected catch (p. 314) of all districts, 1929–1939]

District or area	Fishing intensity in year											Total	Percentage of intensity represented by deep trap nets
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939		
H-1	13.8	19.9 (7.5)	32.4 (13.0)	27.0 (8.1)	19.6 (4.5)	19.3 (4.2)	22.0 (7.3)	27.3 (16.0)	22.7 (13.5)	14.7 (7.4)	12.6 (6.2)	231.3 (87.7)	37.9
H-2	9.7 (2.8)	15.5 (9.5)	12.8 (10.1)	7.2 (5.7)	3.1 (1.5)	4.1 (2.2)	6.2 (4.7)	3.4 (3.1)	1.7 (1.3)	2.5 (2.4)	3.4 (3.4)	69.6 (46.7)	67.1
Northern Lake Huron (H-1 and H-2)	23.5 (2.8)	35.4 (17.0)	45.2 (23.1)	34.2 (13.8)	22.7 (6.0)	23.4 (6.4)	28.2 (12.0)	30.7 (19.1)	24.4 (14.8)	17.2 (9.8)	16.0 (9.6)	300.9 (134.4)	44.7
H-3	1.6	6.3 (4.6)	8.2 (7.0)	3.9 (3.5)	1.0 (0.7)	1.2 (1.0)	1.7 (1.6)	1.7 (1.6)	0.5 (0.4)	1.7 (1.6)	0.1 (0.1)	27.9 (22.1)	79.2
H-4	16.4	21.8 (4.5)	40.2 [1](16.6)	61.2 [1](47.4)	39.4 (30.8)	16.2 (11.2)	15.6 (10.7)	10.1 (7.2)	12.0 (9.2)	12.1 (10.7)	9.7 (8.6)	254.7 (156.9)	61.6
Central Lake Huron (H-3 and H-4)	18.0	28.1 (9.1)	48.4 (23.6)	65.1 (50.9)	40.4 (31.5)	17.4 (12.2)	17.3 (12.3)	11.8 (8.8)	12.5 (9.6)	13.8 (12.3)	9.8 (8.7)	282.6 (179.0)	63.3
H-5	1.8	1.9	1.5	16.6 (15.7)	75.3 (74.5)	38.2 (38.1)	27.9 (27.7)	23.4 (23.4)	13.6 (13.5)	10.6 (10.5)	7.7 (7.7)	218.5 (211.1)	96.6
H-6	2.5	4.0	5.1	4.4	16.9 (12.6)	45.4 (42.2)	65.3 (62.9)	46.5 (45.5)	49.2 (48.5)	46.6 (46.4)	12.1 (12.0)	298.0 (270.1)	90.6
Southern Lake Huron (H-5 and H-6)	4.3	5.9	6.6	21.0 (15.7)	92.2 (87.1)	83.6 (80.3)	93.2 (90.6)	69.9 (68.9)	62.8 (62.0)	57.2 (56.9)	19.8 (19.7)	516.5 (481.2)	93.2
Lake Huron (all 6 districts)	45.8 (2.8)	69.4 (26.1)	100.2 (46.7)	120.3 (80.4)	155.3 (124.6)	124.4 (98.9)	138.7 (114.9)	112.4 (96.8)	99.7 (86.4)	88.2 (79.0)	45.6 (38.0)	1,100.0 (794.6)	72.2
Percentage of intensity represented by deep trap nets	6.2	37.6	46.6	66.8	80.2	79.5	82.8	86.1	86.7	89.6	83.3	72.2	......

[1] Value too low; the estimate of the total intensity for H-4 in 1931 and 1932 included consideration of large catches for which gear records were lacking, but a large part of which was taken by deep trap nets. Other totals and percentages in the computation of which these figures were involved were affected, but relatively less severely than those indicated by the footnote.

H–5. Abundance decreased considerably in 1933, the first of the two years of heaviest production, and declined slightly in 1934, the second of these years. In 1935 after the two years of heaviest production the abundance fell to less than half the 1934 level.[24]

H–6. Abundance declined somewhat in 1934, the first year of heaviest production, and fell sharply in 1935, the second year. (See footnote 24.) The decline was small in 1936 but a rapid rate of decrease was resumed in 1937.

Comment was omitted deliberately on the recorded decreases in abundance from 1931 to 1932 in H–5 and from 1932 to 1933 in H–6. Because of the difficulty of bridging the gap between a fishery dominated by gill nets and pound nets to one dominated by deep trap nets (p. 316) there is some question as to the accuracy of the comparison between the two years involved in each district. However, comparisons are valid within each of the periods, 1929–1931 and 1932–1939 in H–5, and 1929–1932 and 1933–1939 in H–6. Consequently the observations on the change in abundance that followed the extensive use of deep trap nets in these two districts also are valid. Furthermore,

[24] Part of the decline from 1933 to 1934 and 1934 to 1935 may be attributed to the fact that effective August 1, 1934, deep trap nets were restricted in Lake Huron to water with depths of 80 feet or less.

TABLE 10.—*Annual fluctuations in the abundance percentages for whitefish in the various districts and areas of Lake Huron, 1929–1939*

[Expressed as percentages of average 1929-1939 abundance. In the computation of percentages for areas of more than one district and for the entire lake, the abundance percentage for each district was weighted according to the percentage of the total 1929 production contributed by that district]

District or area	Abundance percentage in year										
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
H-1	129	[1,2]181	[2]141	108	85	94	80	93	78	58	53
H-2	[1]135	[2]183	[2]179	78	89	106	91	71	45	65	58
Northern Lake Huron (H-1 and H-2)	131	182	157	95	87	99	85	84	64	61	55
H-3	301	[1,2]183	[2]261	115	67	55	25	22	26	26	19
H-4	152	[1]211	[2]226	[2]189	88	49	58	46	54	17	10
Central Lake Huron (H-3 and H-4)	174	207	231	178	85	50	53	43	50	18	11
H-5	164	231	233	[1]147	[2]106	98	47	24	23	19	8
H-6	130	173	166	193	[1]129	[2]114	[2]61	59	39	23	13
Southern Lake Huron (H-5 and H-6)	146	200	197	172	117	107	54	43	32	21	11
Lake Huron (all 6 districts)	152	195	195	140	89	77	67	61	55	38	31

[1] Year of introduction of the deep trap net.
[2] Years of greatest production by deep trap nets.

TABLE 11.—*Annual fluctuation in the catch of whitefish per unit of fishing effort of gill nets, deep trap nets, and pound nets in the various districts of Lake Huron, 1929–1939*

District	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	Average
	Pounds of whitefish per 10,000-foot-lift of gill nets											
H-1	109.4	115.9	99.4	65.3	67.8	70.2	56.8	57.8	56.7	91.1	44.1	75.9
H-2	29.4	61.8	48.8	10.8	16.6	21.8	15.0	15.3	6.1	....	2.0	22.8
H-3	62.5	60.6	48.7	24.7	16.7	11.5	8.4	6.1	9.0	3.8	4.6	33.3
H-4	72.1	81.5	69.3	63.7	13.7	40.5	4.1	....	5.6	4.2	6.4	36.1
H-5	131.2	187.5	186.0	137.4	87.3	14.1	6.4	....	8.7	3.4	....	84.7
H-6	88.8	115.8	107.9	134.4	106.6	83.0	33.6	18.5	24.0	14.2	....	72.7
	Pounds of whitefish per lift of one deep trap net											
H-1	....	167.7	125.6	91.7	61.8	108.5	97.3	94.5	76.2	43.3	51.3	91.8
H-2	115.2	141.9	139.1	62.2	73.0	76.3	75.8	56.6	40.4	52.8	45.7	79.9
H-3	....	282.4	476.1	206.1	115.3	99.1	41.5	39.2	41.7	45.9	....	149.7
H-4	....	127.3	470.4	340.7	168.3	87.5	108.2	87.1	110.8	30.0	18.2	154.9
H-5	....	....	....	404.3	295.9	272.9	130.8	67.5	65.2	52.8	21.3	163.8
H-6	....	....	....	....	402.5	372.3	202.2	197.2	127.3	76.8	41.9	202.9
	Pounds of whitefish per lift of one pound net											
H-1	65.2	120.5	93.7	78.4	54.6	50.7	35.8	47.1	42.8	29.2	24.2	58.4
H-2	70.2	94.6	97.1	43.1	49.1	65.8	39.6	34.1	....	5.2	....	55.4
H-3	98.3	68.5	53.1	12.2	....	....	4.5	....	....	3.2	....	47.3
H-4	33.1	57.5	40.0	35.1	13.8	9.8	11.3	8.1	5.0	4.5	2.5	20.1
H-5	46.1	60.2	78.5	100.3	26.2	12.3	101.2	3.1	....	....		53.5
H-6	30.0	42.0	51.7	38.8	25.1	18.7	9.9	11.7	5.3	12.3	6.6	22.9

these same decreases are apparent in the records of the actual catch per lift of deep trap nets in these same districts (table 11).

The history of the annual fluctuations in the abundance of whitefish in the years subsequent to the decline that followed immediately upon the extensive use of the deep trap net varied widely among the districts.

In H–1, where the use of deep trap nets may be described as "moderate," the abundance percentage for whitefish dropped to 85 in 1933, fluctuated irregularly in 1933–1937, and declined to a level of less than 60 percent in 1938 and 1939. Abundance did not fall significantly below 80 before 1938. In H–2, the other district in which the maxima of production and fishing intensity were relatively low, the sudden decline to

78 percent in 1932 was followed by recoveries in 1933 and 1934 (89 and 106 percent, respectively) and relatively high abundance in 1935 (91 percent). The decreases in 1935–1937 that led to the minimum of 45 in 1937 were followed by a recovery in 1938 and a slight decline in 1939. In both H–1 and H–2 the secondary declines in abundance were preceded by secondary increases in fishing intensity—increases traceable to revivals of deep-trap-net operations.

The remaining districts experienced greater ultimate declines than did H–1 and H–2. Furthermore, these districts failed to show recoveries comparable to those that occurred in H–1 and H–2. In H–3 the decline in abundance continued through 1935; abundance remained rather stable at about 25 in the years, 1935–1938, and declined to 19 in 1939. The abundance in H–4 declined through 1934, was at approximately 50 percent in 1934–1937, and dropped to an extremely low level in 1938 and 1939. In both H–5 and H–6 the decline in abundance that followed the introduction of the deep trap net proceeded without interruption (albeit at an irregular rate) through 1939. In that year whitefish were extremely scarce in both districts.

The data that have been discussed in the preceding pages support the general conclusion that the deep trap net was in large measure responsible for a disastrous depletion of the whitefish in the four southernmost districts of Lake Huron. This depletion was the result of the unreasonable increases in fishing intensity and hence in production in these districts. In the northern portion of the lake where the net was used more moderately the decline in the abundance of whitefish was severe but it did not reach such extremes as were found in the central and southern regions of the lake.

Largely for the sake of completeness the annual fluctuations of production, abundance, and fishing intensity for all six districts combined have been presented graphically in figure 11 (data from tables 5, 9, and 10). To some extent the data for the entire

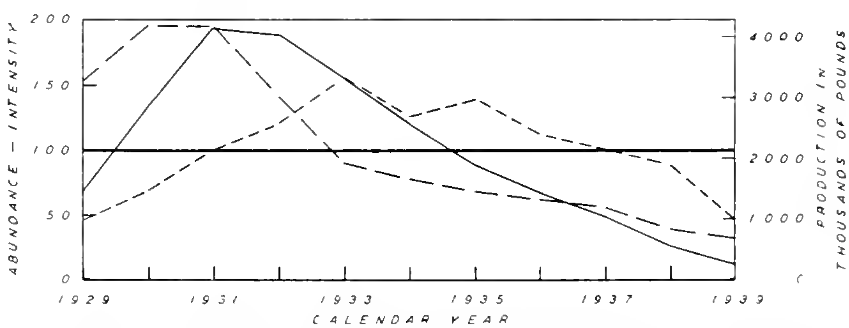


FIGURE 11.—Annual fluctuations in the production (solid line) and abundance (long dashes) of whitefish and in the intensity of the whitefish fishery (short dashes) in Lake Huron (all six districts combined), 1929–1939.

lake lack significance as the combination of the data for all districts obscures the extreme nature of the fluctuations that took place within the individual districts. The data serve chiefly to show that a relatively great abundance of whitefish contributed materially to the high production in 1930–1932 (especially in 1930 and 1931), and that the decline in catch subsequent to 1932 would have been much more rapid had not the intensity of the fishery been so great. Although the decline in abundance began in 1932 the intensity of the fishery increased rapidly until 1933. Beyond 1932 the abundance of whitefish was below the 11-year average and decreasing in every year. Fishing intensity, however, did not return to the 11-year average before 1937 or to the 1929 level before 1939.

The question now arises, "What characteristics made the deep trap net so deadly effective?" The tremendous production of deep trap nets was possible chiefly because: (1) they can be set in deeper water, and hence in areas with greater concentrations of whitefish, than can the pound nets; and (2) they are much more efficient in taking whitefish than are gill nets fished on the same grounds. Attention will be given first to the advantages of the deep trap net over the pound net.

In size and construction the pound net and deep trap net resemble each other so closely that the latter gear was known in some localities as the "submarine pound net" (p. 300). If the two gears are fished in the same depth of water neither has an important advantage over the other.[25] However, pound nets which are held in place by stakes driven into the bottom of the lake, and have cribs or pots extending from the bottom to above the surface, ordinarily cannot be fished successfully at depths greater than 80 feet. Most pound nets are operated in much shallower water. Deep trap nets, on the other hand, have covered cribs and are held in position by means of lines attached to anchors and by buoys. Consequently, they can be employed at all depths frequented by whitefish. The use of stakes also limits pound nets to areas with a soft bottom into which stakes can be driven. Deep trap nets do not suffer from this limitation.

A further advantage of the deep trap net lies in its greater mobility. Pound nets are fished in the same locality throughout the season (and usually year after year) but deep trap nets can be moved much more easily and consequently can be fished in the exact locations at which whitefish are found to be concentrated.

The vertical distribution of the whitefish will be treated in part III. It may be stated at this time, however, that usually whitefish are readily available to pound nets

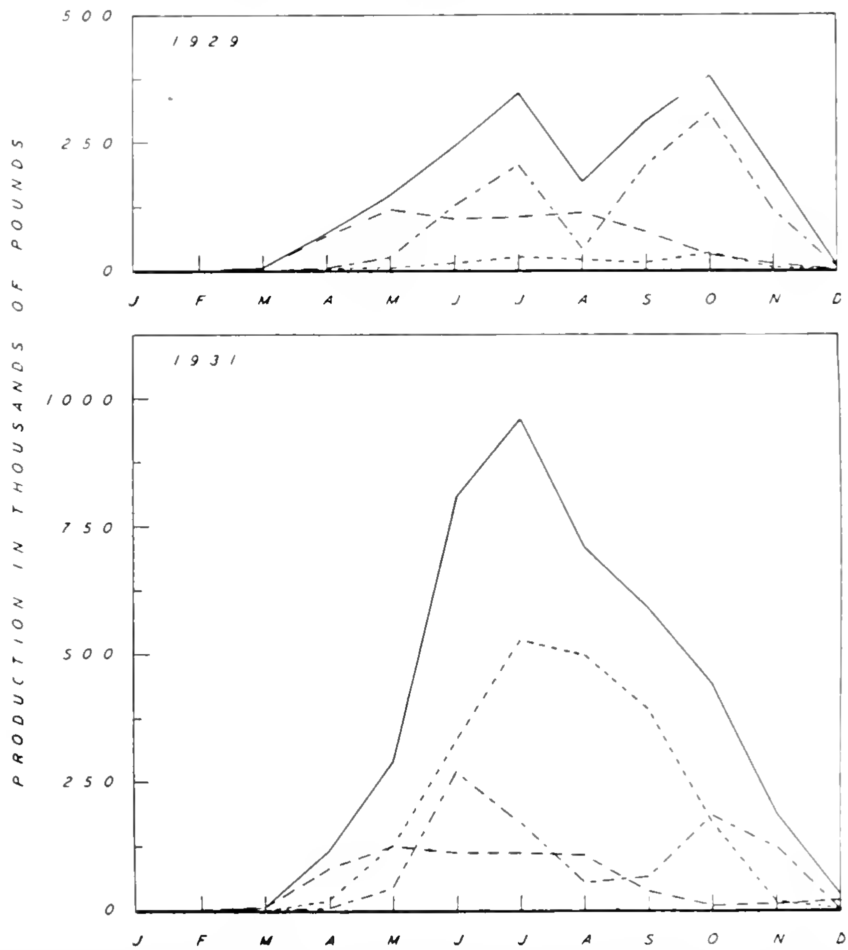


FIGURE 12.—Comparison of the monthly production of whitefish in the Michigan waters of Lake Huron in 1929 and 1931, to bring out the effects of the deep-trap-net fishery on the seasonal distribution of the catch. Gill nets, long dashes; deep trap nets, short dashes; pound nets, short and long dashes; total production, solid line.

[25] Field observations in northern Lake Michigan indicated that pound nets may take slightly more fish than deep trap nets fished at the same depth. This relationship is not surprising since the pound net is a "lighter" net (that is, the open top permits the free penetration of light) and would, therefore, be entered by fish more readily than the "darker" deep trap net. Also see table 51, appendix C.

TABLE 12.—*Monthly production of whitefish in Lake Huron, 1929 and 1931, in gill nets, deep trap nets, pound nets, and all gears combined*

[Percentages are in parentheses]

Gear	Production of whitefish in pounds in month												Total
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1929													
Gill net	180 (0.0)	580 (0.1)	2,465 (0.5)	52,029 (10.6)	94,066 (19.2)	79,724 (16.3)	82,332 (16.8)	88,890 (18.2)	58,534 (12.0)	21,744 (4.4)	8,848 (1.8)	569 (0.1)	489,961 (100.0)
Deep trap net	------	------	------	1,239 (1.4)	1,774 (2.0)	10,867 (12.5)	20,535 (23.6)	15,068 (17.3)	9,809 (11.3)	24,061 (27.6)	3,768 (4.3)	------	87,121 (100.0)
Pound net	------	------	------	1,278 (0.2)	19,582 (2.4)	101,424 (12.3)	165,066 (20.0)	33,145 (4.0)	163,763 (19.9)	244,055 (29.6)	91,878 (11.2)	2,505 (0.4)	823,696 (100.0)
All gears	180 (0.0)	580 (0.0)	2,468 (0.2)	57,764 (4.0)	117,463 (8.1)	193,906 (13.3)	276,917 (19.0)	137,161 (9.4)	233,074 (16.0)	302,087 (20.7)	130,694 (9.0)	4,074 (0.3)	1,456,368 (100.0)
1931													
Gill net	390 (0.1)	317 (0.1)	4,663 (0.7)	82,423 (13.3)	124,071 (20.0)	112,776 (18.2)	113,365 (18.3)	107,329 (17.3)	36,492 (5.9)	7,752 (1.2)	9,001 (1.5)	20,936 (3.4)	619,515 (100.0)
Deep trap net	------	------	------	19,220 (0.9)	115,241 (5.6)	334,943 (16.1)	528,609 (25.4)	498,984 (24.0)	391,921 (18.8)	172,701 (8.3)	15,757 (0.8)	2,220 (0.1)	2,079,596 (100.0)
Pound net	------	2 (0.0)	55 (0.0)	3,340 (0.4)	41,882 (4.6)	269,224 (29.5)	169,001 (18.5)	53,513 (5.9)	65,801 (7.2)	184,552 (20.3)	121,774 (13.4)	1,796 (0.2)	910,940 (100.0)
All gears	390 (0.0)	319 (0.0)	4,785 (0.1)	116,754 (2.8)	289,342 (7.0)	808,065 (19.5)	961,095 (23.2)	709,469 (17.2)	591,894 (14.3)	441,501 (10.7)	186,997 (4.5)	29,161 (0.7)	4,139,772 (100.0)

only during limited periods, one in late spring and early summer and another in mid-autumn. Many fishermen discontinue pound-net operations at other seasons. It is true also that even in periods of active operation the greatest concentrations of whitefish may be at depths beyond the reach of pound nets.

The offshore movement that leads to a concentration in relatively deep water in the summer and early autumn exposes the whitefish to the inroads of the deep trap net at the time it is most vulnerable. Formerly, the only toll on the whitefish in its summer concentration was that levied by gill nets, and in the modern fishery of Lake Huron this type of gear has not proved generally effective for the large-scale catching of whitefish. The gill net is so ineffective for the capture of whitefish under modern conditions that gill-net fisheries are supported by this species alone only in very limited areas or over extremely short periods of time (chiefly during the spawning season).[26] The large-mesh gill-net fishery is now conducted ordinarily for the capture of both trout and whitefish or of trout alone, but very seldom exclusively for the taking of whitefish.[27] The comparative ineffectiveness of gill nets made the time of summer concentration of the whitefish a "semi-closed" season during which the species was in large measure immune to capture. The introduction of the deep trap net made this same period the season of maximum production.

The effect of the deep-trap-net fishery on the monthly distribution of the whitefish catch and the high production this gear made possible in the summer months may be illustrated by the data of table 12 and figure 12. The gill-net season extended through the months, May-August, in both 1929 and 1931. (September was a fairly good month in 1929.) No distinct peaks occurred in either year. The pound-net catch, on the contrary, was divided into two distinct seasons, each with a sharp peak. The early-season maximum occurred in July in 1929 and in June in 1931. Both of the autumn maxima were in October. The 1931 data which show the more pronounced summer depression provide the better description of the monthly distribution of pound-net production because the 1929 early-summer peak was later and the September catch was relatively higher than usual. The data for both years, however, have a distinct late-summer minimum—August in 1929 and August-September in 1931.

The curve of total catch in 1929 has a minimum in August corresponding to the August depression in the pound-net data. A similar minimum would have existed in

[26] When gill nets were fished on the spawning grounds the catches were sometimes enormous—thousands of pounds in a single lift.
[27] This statement holds true even in Lake Michigan where the gill net is normally the dominant gear for the production of whitefish.

the curve of total production in 1931 if only gill nets and pound nets had been in operation. The deep-trap-net catch, however, changed the form of the curve completely. This gear not only deprived the whitefish of its former temporary respite during the period of habitation in deep waters, but actually exposed the fish to a far more severe exploitation in late summer than it had previously suffered at any season. From these facts it is obvious that effective regulation of the deep trap net must include the reduction of its catches on the deep-water grounds on which whitefish congregate during late summer.

The summer assemblings of whitefish that made possible the great effectiveness of the deep trap net seemingly were not as dense in northern Lake Huron as in the central and southern regions of the lake. In each of the four southerly districts the average catch per lift of deep trap nets exceeded 400 pounds in one year and was more than 200 pounds per lift in 2 or 3 years (table 11). In the northern districts the greatest average catch per lift of deep trap nets was 168 pounds in H–1 and 142 pounds per lift in H–2 (in 1930 in both districts). The relatively poor success of deep trap nets is the more remarkable in H–1 because that area under normal conditions had been an important and in many, if not the majority of years, the leading center of whitefish production in the lake. At any rate these small catches per lift account for the more moderate use of deep trap nets in H–1 and H–2.

A final point that deserves consideration is the possibility that mass migrations of whitefish may have played a role in the shift from year to year in the center of the deep-trap-net fishery. The failure of the grounds on which the deep trap nets first were fished and the resultant necessity for opening up new areas gave an early indication of the disastrous results to be expected from the unrestricted operation of this gear. Deep-trap-net fishermen denied most vigorously, however, that their activity had caused any depletion on the grounds. They contended that the fish had not been caught but that they merely had migrated to another area. They held further that in changing the center of the fishery they were only following the movements of the whitefish population. In support of their contention they stressed the argument that only mass migrations could make possible such high production in southern Lake Huron (H–5 and H–6), an area in which the catch of whitefish had always been small.

The assumption of a mass migration of whitefish proceeding in the same direction year after year runs counter to all known facts concerning the habits of the species. Nevertheless, the possibility cannot be denied that extraordinary conditions might bring about unusual reactions on the part of the fish. The strongest argument against the theory of mass migration lies in the fact that such an assumption is altogether unnecessary. The heavy yield in southern Lake Huron in 1932 and later years was not made possible, as fishermen contended, by the influx of whitefish from more northerly grounds. The records of the catch of gill nets per unit of effort (table 11) prove that dense concentrations of whitefish had been present on the offshore grounds of H–5 and H–6 for years before the deep trap net was introduced. In fact, the catch of whitefish per unit of effort of gill nets in H–5 exceeded that in every other district during the four years, 1929–1932. The catch per unit of effort of gill nets in H–6 was greater than that in any other district in 1933 and was second only to the catch per lift in H–5 in 1931 and 1932.

The large production of deep trap nets in H–5 and H–6 was made at the expense of the reserve stock rather than of a population of recent migrants. The generally low output of whitefish in southern Lake Huron prior to the introduction of the deep trap net can be attributed to a low fishing intensity. Gill nets, comparatively ineffective gear for the capture of whitefish, accounted for the bulk of the catch (appendix B). Apparently the relatively few pound nets were fished either at the wrong localities or depths to produce large quantities of whitefish. Actually, suitable localities for whitefish pound nets are scarce in southern Lake Huron.

WHITEFISH FISHERY OF LAKE MICHIGAN, 1929-1939

The most important difference between the histories of the whitefish fisheries of Lakes Michigan and Huron, 1929–1939, lies in the relatively limited development of the deep-trap-net fishery in the former lake. With the exception of the deep-trap-net fishery out of Grand Haven, Mich., in 1934 (the deep trap net was the dominant gear for the production of whitefish in M–7 in that year), significant operations with this gear were confined to the extreme northern portion of the lake (M–1, M–2, and M–3). Deep trap nets were introduced into M–1 and M–3 in 1930 and into M–2 in 1931. Even in these northern districts the place of the deep trap net in the fishery resembled that which it occupied in northern Lake Huron rather than in central and southern Lake Huron. At no time did the deep trap net become the dominant gear for the capture of whitefish in the Green Bay area (M–1). In M–2 and M–3 deep trap nets led other gears in the production of whitefish in only two years (1932 and 1933 in both districts). The use of deep trap nets in the Michigan waters of Lake Michigan became illegal after 1935.[28]

The fact that the deep trap net did not disturb the whitefish fishery as seriously in Lake Michigan as in Lake Huron makes it possible to follow a more or less natural course of events subsequent to an abnormal increase in abundance. Comparisons with the data on the whitefish fishery of Lake Huron should prove particularly instructive.

FLUCTUATIONS IN THE PRODUCTION OF WHITEFISH IN LAKE MICHIGAN

The increase in the catch of whitefish that characterized the late 1920's and early 1930's in the various waters of the Great Lakes got under way early in Lake Michigan.[29] Production exceeded 2 million pounds in 1927 and was nearly 3 million pounds in 1928.

TABLE 13.—*Production of whitefish in pounds according to gear in the State of Michigan waters of Lake Michigan, 1929–1939*

[Percentages of annual yield in parentheses]

Year	Production in gear				Total annual production	Increase or decrease
	Large-mesh gill net	Deep trap net	Pound net	Other		
1929	2,244,093 (52.3)		2,032,083 (47.4)	11,693 (0.3)	4,287,869	+1,331,723
1930	2,339,162 (48.6)	135,634 (2.8)	2,328,326 (48.4)	9,703 (0.2)	4,812,825	+524,956
1931	1,986,579 (51.9)	408,209 (10.7)	1,421,576 (37.2)	7,619 (0.2)	3,823,983	−988,842
1932	1,564,505 (46.9)	856,804 (25.7)	890,667 (26.7)	20,308 (0.6)	3,332,284	−491,699
1933	1,307,943 (58.4)	440,090 (19.7)	485,187 (21.7)	2,620 (0.1)	2,235,840	−1,096,444
1934	1,001,074 (51.8)	398,635 (20.6)	531,070 (27.5)	1,399 (0.1)	1,932,178	−303,662
1935	911,079 (63.6)	211,246 (14.8)	301,367 (21.0)	8,032 (0.6)	1,431,724	−500,454
1936	635,284 (72.5)		240,508 (27.4)	619 (0.1)	876,411	−555,313
1937	709,515 (74.9)		236,527 (25.0)	825 (0.1)	946,867	+70,456
1938	765,416 (68.5)		351,447 (31.5)	216 (0.0)	1,117,079	+170,212
1939	482,801 (57.5)		356,488 (42.4)	567 (0.1)	839,856	−277,223
Average	1,267,950 (54.4)	222,784 (9.6)	834,113 (35.8)	5,782 (0.2)	2,330,629	

28 Limited operations have been carried on in the northern Michigan waters since 1935, with a modified deep trap net in which the crib or pot extends to the surface of the water and is open at the top. This arrangement has qualified the nets for legal definition as pound nets with which gear they have been grouped in the preparation of this report.

29 In this section the terms, "Lake Michigan" and "the entire lake," refer to the State of Michigan waters only.

In 1929, the first year for which detailed statistics are available, the catch of whitefish (4,288,000 pounds) was greater than that of any previous year, except 1889, for which there are usable records (table 1). The increase over the take for 1928 was 1,332,000 pounds (table 13). A further rise of 525,000 pounds in 1930 brought the yield of whitefish in Lake Michigan to the peak of 4,813,000 pounds.

Whitefish production declined continually throughout the next 6 years. The decreases were large (average of 656,000 pounds per year). In two years (1931 and 1933) the drop in catch amounted to roughly a million pounds. In three years (1932, 1935, and 1936) the decreases were approximately a half million pounds. The smallest drop in production (304,000 pounds) in the 6-year period occurred in 1934.

The 1931–1936 decline in catch was followed by increases in 1937 (70,000 pounds) and 1938 (170,000 pounds). A new drop of 277,000 pounds in 1939 carried the yield to a level that was only a little above the lowest recorded for any previous year (806,000 in 1920).

Great as the decline in production was in Lake Michigan, the yield in 1939 amounted to 17.5 percent of the 1930 maximum as compared with a 1939 catch in Lake Huron that was only 6.2 percent of the 1931 peak in that lake.

The records of the production of whitefish in deep trap nets (tables 13 and 14) confirm the earlier statement that the gear failed by far to become as important in Lake Michigan as in Lake Huron. In Lake Michigan the deep trap net accounted for only 25.7 percent of the total catch in 1932, the year of its greatest success. This percentage was less than that of pound nets (26.7 percent) and was far below the percentage for gill nets (46.9 percent). In fact, the total quantity of whitefish taken by deep trap nets in Lake Michigan in their 6 years of operation (1930–1935) was less than the amount taken by the same gear in Lake Huron in each of the single years, 1932 and 1933. The gill net was the most important gear for the capture of whitefish throughout the 11-year period and accounted for more than 50 percent of the total yield in 9 years (average of 54.4 percent for 1929–1939). With equal consistency the pound net held second rank, and accounted for 35.8 percent of the 1929–1939 take.

TABLE 14.—*Production of whitefish in pounds in deep trap nets in Lake Michigan, 1930–1935 (use of deep trap nets illegal after July 1, 1935)*

[In parentheses, the deep-trap-net production expressed as a percentage of the total whitefish production]

District or area	Production in deep trap nets in year						Total
	1930	1931	1932	1933	1934	1935	
M-1	37,655 (3.5)	111,523 (9.3)	191,979 (21.1)	77,161 (32.4)	56,918 (21.6)	22,783	498,019
M-2		13,645 (16.7)	59,303 (61.0)	30,753 (72.7)	11,580 (43.1)	3,621	118,902
M-3	97,454 (4.0)	273,282 (19.8)	596,246 (40.0)	318,260 (35.7)	251,012 (32.9)	177,374	1,713,628
M-4		174 (0.2)	1,218 (1.5)	1,569 (3.1)	249 (0.5)	4,389	7,599
Northern Lake Michigan (M-1, M-2, M-3, and M-4)	135,109 (3.6)	398,624 (14.5)	848,746 (33.0)	427,743 (35.0)	319,759 (29.1)	208,167	2,338,148
Central Lake Michigan (M-5)			3,797 (0.7)	3,482 (0.7)			7,279
M-6	525 (0.2)	8,877 (3.5)	173 (0.2)	2,625 (6.0)	3,920 (10.5)		16,120
M-7		347 (0.3)	3,819 (8.0)	6,240 (4.0)	74,956 (39.3)	3,079	88,441
M-8		361 (0.3)	269 (0.4)				630
Southern Lake Michigan (M-6, M-7, and M-8)	525 (0.1)	9,585 (1.9)	4,261 (2.2)	8,865 (1.8)	78,876 (14.8)	3,079	105,191
Lake Michigan (all 8 districts)	135,634 (2.8)	408,209 (10.7)	856,804 (25.7)	440,090 (19.7)	398,635 (20.6)	211,246	2,450,618

The deep trap net became the dominant gear for the taking of whitefish in only three (M–2, M–3, and M–7) of the eight districts of Lake Michigan (table 14 and appendix B), and maintained that position in the first two districts only 2 years (1932 and 1933) and in M–7 only 1 year (1934). With the exception of the fishery in M–7 in 1934, deep trap nets were operated only sporadically in waters south of M–3.

Although the actual yield of whitefish in each district and the percentage distribution among the several districts of the total for the lake both varied rather widely in Lake Michigan during the period, 1929–1939 (table 15), there is no evidence of a shifting of the center of production comparable to that which took place in Lake Huron. For example, M–3 did not relinquish once its position as the most productive district of the lake; neither did northern Lake Michigan (M–1, M–2, M–3, and M–4) fail in any year to account for more than 50 percent of the catch of the entire lake.

TABLE 15.—*Total annual production of whitefish in pounds in the different districts and areas of the State of Michigan waters of Lake Michigan, 1929–1939*

[Each total is expressed also as the percentage (in parentheses) of the production of the entire lake]

District or area	Total whitefish production in year											Average
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	
M-1	1,139,628 (26.6)	1,075,748 (22.4)	1,194,969 (31.3)	910,106 (27.3)	238,169 (10.7)	263,005 (13.6)	174,637 (12.2)	90,293 (10.3)	104,889 (11.1)	354,235 (31.7)	237,509 (28.3)	525,736 (22.6)
M-2	90,019 (2.1)	100,625 (2.1)	81,618 (2.1)	97,248 (2.9)	42,277 (1.9)	26,858 (1.4)	46,264 (3.2)	46,465 (5.3)	31,497 (3.3)	24,221 (2.2)	15,402 (1.8)	54,772 (2.3)
M-3	2,202,064 (51.3)	2,460,656 (51.1)	1,380,450 (36.1)	1,489,472 (44.7)	890,899 (39.8)	761,831 (39.4)	749,666 (52.4)	445,967 (50.9)	450,619 (47.6)	497,776 (44.6)	425,495 (50.7)	1,068,627 (45.9)
M-4	72,629 (1.7)	84,119 (1.7)	84,253 (2.2)	78,771 (2.4)	51,010 (2.3)	48,369 (2.5)	47,978 (3.3)	56,234 (6.4)	43,866 (4.6)	29,249 (2.6)	31,767 (3.8)	57,113 (2.4)
Northern Lake Michigan (M-1, M-2, M-3, & M-4)	3,504,340 (81.7)	3,721,148 (77.3)	2,741,290 (71.7)	2,575,597 (77.3)	1,222,355 (54.7)	1,100,063 (56.9)	1,018,545 (71.1)	638,869 (72.9)	630,867 (66.6)	905,481 (81.1)	710,173 (84.6)	1,706,248 (73.2)
Central Lake Michigan (M-5)	284,620 (6.6)	280,701 (5.8)	580,536 (15.2)	558,573 (16.8)	529,697 (23.7)	298,497 (15.5)	208,807 (14.6)	198,801 (22.7)	267,385 (28.3)	189,658 (17.0)	97,268 (11.6)	317,686 (13.6)
M-6	103,397 (2.4)	222,148 (4.6)	252,015 (6.6)	85,080 (2.5)	43,181 (1.9)	37,450 (1.9)	24,861 (1.7)	14,063 (1.6)	11,100 (1.2)	6,787 (0.6)	4,653 (0.5)	73,158 (3.2)
M-7	139,690 (3.3)	447,760 (9.4)	107,206 (2.8)	47,934 (1.4)	157,699 (7.1)	190,582 (9.9)	30,506 (2.2)	5,212 (0.6)	8,017 (0.8)	1,137 (0.1)	1,537 (0.2)	103,389 (4.4)
M-8	255,822 (6.0)	141,068 (2.9)	142,936 (3.7)	65,100 (2.0)	282,908 (12.6)	305,586 (15,8)	149,005 (10.4)	19,466 (2.2)	23,498 (3.1)	14,016 (1.2)	26,225 (3.1)	130,148 (5.6)
outhern Lake Michigan (M-6, M-7, and M-8)	498,909 (11.6)	810,976 (16.9)	502,157 (13.1)	198,114 (5.9)	483,788 (21.6)	533,618 (27.6)	204,372 (14.3)	38,741 (4.4)	48,615 (5.1)	21,940 (1.9)	32,415 (3.8)	306,695 (13.2)
Lake Michigan (all 8 districts)	4,287,869	4,812,825	3,823,983	3,332,284	2,235,840	1,932,178	1,431,724	876,411	946,867	1,117,079	839,856	2,330,629
Percentage of average	184	206	164	143	96	83	61	38	41	48	36	....

Nevertheless, the relative importance of the districts varied considerably. M–3 produced as little as 36.1 percent (1931) and as much as 52.4 percent (1935) of the total catch of whitefish in the lake. In M–1, the district that ranked second in average yield, the percentages ranged from 10.3 (1936) to 31.7 (1938). The district that ranked third in average production (M–5) yielded from 5.8 percent (1930) to 28.3 percent (1937) of the total for the lake.

The percentage contributions of the less important districts varied relatively more widely than did those for the more productive areas. The greatest relative variation occurred in M–7 which produced 9.9 percent of the 1934 total but only 0.1 percent of the 1938 catch. However, among the five districts that each accounted for less than 10 percent of the 1929–1939 average only one (M–8) produced more than 10 percent of the total for the lake in any single year (percentages of 12.6, 15.8, and 10.4 in 1933, 1934, and 1935, respectively).

Comparison of later and earlier production of whitefish in the various districts of Lake Michigan (tables 15 and 16) reveals that M-3 contributed an even higher percentage of the total for the lake in 1891–1908 (59.5 percent) than in 1929–1939 (45.9 percent). M-2 and M-4 also accounted for higher percentages of the total in the earlier period (7.4 and 7.3 percent, respectively, as compared with 2.3 and 2.4 percent). However, the percentages for these two districts may be too high for the years, 1891–1908. As stated in footnote 23, the division of the catches for the early period was based on the home ports of the fishermen, not necessarily on the actual location of their fishing grounds. In recent years, at least, numbers of fishermen who operate from ports of M-2 and M-4 have done part of their fishing in other districts (chiefly in M-3). It is believed that the data for the remaining districts were not affected greatly by the separation of the catch of the earlier years according to the port from which the fishermen operated.

TABLE 16.—*Production of whitefish in pounds in Lake Michigan according to statistical districts, 1891–1908*

Year	Statistical district								Total
	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	
1891	78,140	237,000	1,521,101	214,580	290,100	41,050	17,100	5,500	2,404,571
1892	148,600	325,650	1,477,412	168,725	329,300	41,100	11,000	20,615	2,522,402
1893	123,150	83,000	1,326,900	137,050	233,600	19,500	27,500	25,100	1,975,800
1894	89,050	41,100	801,750	146,500	147,300	8,730	31,450	29,925	1,295,805
1895	71,850	18,500	631,550	109,990	138,000	7,400	21,150	24,300	1,022,740
1896	88,600	148,000	863,400	86,600	210,750	10,000	13,350	26,600	1,447,300
1897	83,570	180,000	1,762,900	84,300	261,700	13,700	6,053	26,730	2,418,953
1898	85,050	302,100	1,504,900	84,200	303,000	16,700	6,550	17,600	2,320,100
1899	111,560	104,100	1,040,870	87,500	249,600	12,350	2,800	25,100	1,633,880
1900	83,350	140,500	961,800	104,000	292,000	16,100	3,100	24,750	1,625,600
1901	97,700	146,100	1,372,600	148,700	278,200	8,700	8,900	18,650	2,079,550
1902	140,150	177,500	1,739,800	200,500	429,000	10,000	3,400	23,000	2,723,350
1903	228,200	166,000	1,369,400	148,500	319,500	17,100	6,200	29,700	2,284,600
1904	283,000	158,000	1,337,000	282,500	338,000	33,000	19,100	51,100	2,501,700
1905	348,000	184,000	1,246,800	218,000	338,500	62,600	73,500	98,700	2,570,100
1906	291,800	89,500	1,387,700	322,300	322,500	77,300	170,300	159,300	2,820,700
1907	291,700	179,000	1,689,500	214,100	330,000	139,300	265,500	134,700	3,273,800
1908	222,500	289,400	1,793,155	118,424	337,116	83,700	83,800	142,000	3,106,095
Average	159,221	164,963	1,323,808	163,137	286,009	34,352	43,153	49,076	2,223,725
Percentage	7.2	7.4	59.5	7.3	12.9	1.6	1.9	2.2	...

M-1, M-5, M-6, M-7, and M-8 yielded smaller percentages of the total catch of whitefish in 1891–1908 than in 1929–1939. Especially noteworthy are the comparative yields for M-1 which accounted for only 7.2 percent of the early total catch as against 22.6 percent of the recent production. The change was not large in M-5 (12.9 percent in the early period; 13.6 percent in the recent). The percentages were considerably lower in 1891–1908 than in 1929–1939 for all three districts (M-6, M-7, and M-8) of southern Lake Michigan (1.6, 1.9, and 2.2 percent as compared with 3.2, 4.4, and 5.6 percent).

Despite the changes just described in the percentage distribution of the catch of whitefish according to district, the most productive areas of the earlier years seem to be in general the best areas of recent years. This conclusion is supported by the following comparison of regions of the lake:

Area	Percentage of total whitefish production	
	1891–1908	*1929–1939*
Northern Lake Michigan (M-1, M-2, M-3, M-4)	81.4	73.2
Central Lake Michigan (M-5)	12.9	13.6
Southern Lake Michigan (M-6, M-7, M-8)	5.7	13.2

CHANGES IN PRODUCTION IN LAKE MICHIGAN AS RELATED TO FLUCTUATIONS IN THE ABUNDANCE OF WHITEFISH AND IN THE INTENSITY OF THE FISHERY

In Lake Michigan as in Lake Huron the abundance of whitefish was abnormally high near the beginning of the 1929–1939 period. The peak of abundance occurred a year or two earlier in the more productive areas of Lake Michigan than in Lake Huron. The abundance of whitefish was greater in 1929 than in any other of the 11 years in each of the four districts of northern Lake Michigan, a region that accounted for 73.2 percent of the 1929–1939 production. The maximum abundance occurred in 1929 in M–8 also. The large increase in catch in 1929 (table 1) suggests strongly that the abundance in this year was greater than that in 1928 and hence constituted the maximum for the modern fishery. (Certainty on this point is not possible as the intensity of the fishery in 1928 is unknown.) The maximum abundance of the 1929–1939 interval occurred later in the remaining districts (1930 in M–6 and M–7, 1931 in M–5). However, these districts were relatively far less important in the fishery of the entire lake than were those in which 1929 was the year of peak abundance. Lake Michigan resembles Lake Huron again in that a decline from the high level of abundance that existed early in the period was to be expected.

These resemblances between the data for Lake Michigan and Lake Huron are fortunate, as they make possible a comparison of the course of the decline in Lake Michigan, where the whitefish fishery was not disturbed violently by the use of deep trap nets, and in Lake Huron where the introduction and widespread use of that new and efficient gear brought about an utterly chaotic condition in the fishery. Accordingly, comparisons of data for Lakes Michigan and Huron are emphasized in the present section.

Several reasons may be advanced to account for the failure of the deep-trap-net fishery to develop as extensively in Lake Michigan as in Lake Huron: (1) no extensive or good whitefish grounds are found in Lake Michigan south of Frankfort; (2) pound-netters and gill-netters rather than trap-netters were dominant on Lake Michigan and opposed the use of deep trap nets (the Lake Huron deep-trap-netters who entered M–7 in 1934 were driven out by local fishermen; shortly thereafter the Lake

TABLE 17.—*Annual fluctuation in the catch of whitefish per unit of fishing effort of gill nets, deep trap nets, and pound nets in the various districts of Lake Michigan, 1929–1939*

District	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	Average
	Pounds of whitefish per 10,000-foot-lift of gill nets											
M-1	183.4	150.0	131.0	116.3	71.4	100.2	105.2	76.5	71.7	119.7	74.0	109.0
M-2	69.4	63.8	44.3	27.0	15.3	19.5	49.4	43.0	32.1	26.2	24.4	37.7
M-3	138.9	131.6	87.6	89.9	70.4	74.0	85.8	59.0	54.6	48.6	47.3	80.7
M-4	52.0	50.1	60.0	48.2	37.7	29.4	34.5	48.3	25.7	25.3	25.8	39.7
M-5	103.9	85.8	127.1	110.6	104.1	78.4	56.5	57.1	60.2	46.9	31.3	78.4
M-6	55.0	65.4	75.6	40.1	37.5	31.9	31.5	14.5	22.6	14.9	17.0	36.9
M-7	132.5	161.5	72.8	92.4	193.1	133.3	156.5	128.8	133.1	76.4	71.0	122.9
M-8	156.7	117.6	111.6	81.5	160.2	141.9	102.0	48.7	75.1	70.8	79.1	104.1
	Pounds of whitefish per lift of one deep trap net											
M-1	--------	131.7	100.2	118.0	54.6	74.6	91.1	--------	--------	--------	--------	95.0
M-2	--------	--------	184.4	257.5	120.6	68.1	43.1	--------	--------	--------	--------	134.8
M-3	--------	153.7	137.2	164.9	97.0	121.8	94.6	--------	--------	--------	--------	128.2
M-7	--------	--------	--------	--------	--------	118.2	--------	--------	--------	--------	--------	118.2
	Pounds of whitefish per lift of one pound net											
M-1	113.2	88.7	104.5	74.1	41.0	56.0	41.8	47.6	38.0	53.9	63.0	65.6
M-2	105.2	85.9	217.1	--------	--------	--------	--------	--------	--------	--------	--------	136.1
M-3	153.3	148.8	96.0	80.0	85.6	98.5	92.4	85.3	81.5	80.0	75.6	97.9
M-4	73.4	71.0	57.7	63.3	67.7	63.0	54.3	56.7	63.6	31.5	40.7	58.4
M-5	123.1	134.2	159.2	106.8	145.0	71.4	73.6	60.5	65.2	84.1	53.9	97.9
M-6	--------	261.7	126.9	55.2	26.6	41.2	34.2	84.7	--------	121.8	55.0	89.7
M-7	102.9	195.4	59.8	25.7	39.4	61.1	11.0	8.8	13.1	12.7	9.2	49.0
M-8	--------	243.1	146.0	--------	37.6	73.7	29.0	54.1	70.1	--------	13.4	83.4

Michigan fishermen were able to abolish the net from their waters by law); (3) the summer aggregation of whitefish occurs in shallower water in Lake Michigan than in Lake Huron and hence the Lake Michigan fish never moved beyond the reach of pound nets to the same degree as did those in Lake Huron; (4) the deep-water population of whitefish available to the deep trap nets was less dense in Lake Michigan than in Lake Huron, hence in contrast to the situation in Lake Huron the deep-trap-net lifts did not always average much larger than those of the pound nets. (See, for example, M–1 and M–2 for 1931, table 17.)

Although the deep trap net usually took more whitefish per lift than did the pound net in Lake Michigan, and from this point of view may be considered to have been very effective and successful, in no district of the lake did the catch per lift of deep trap nets approach the level that it attained in the four southerly districts of Lake Huron (tables 11 and 17). The average catch per lift of deep trap nets in Lake Michigan reached values of 257.5 pounds in M–2 in 1932 and 184.4 pounds in the same district in 1931. Operations were limited, however, in M–2. In M–1 and M–3, where deep-trap-net operations were more extensive, the greatest average catches per lift were 131.7 pounds (M–1 in 1930) and 164.9 pounds (M–3 in 1932). These values were far below the greatest averages in the districts of central and southern Lake Huron (402.5 to 476.1 pounds per lift), but compared favorably with the maxima in northern Lake Huron (167.7 pounds per lift in H–1 in 1930; 141.9 pounds per lift in H–2 in 1930). The deep trap net was relatively unsuccessful in southern Lake Michigan also, for the only significant operations with the gear (M–7 in 1934) yielded an average of 118.2 pounds of whitefish per lift.

To be sure, the deep trap net was introduced into northern Lake Michigan after the peak of abundance of the whitefish had passed. The examination of the abundance percentages of table 21 suggests that if this gear had been fished in 1929, the year of high abundance, the average catch per lift in that year most probably would have exceeded the highest yields listed in table 17 for deep trap nets in each of the northern districts. On the other hand, abundance percentages may not validly serve as an exact index to the average size of a lift since the fluctuations in the catch per lift of this gear did not always correspond with those in abundance subsequent to 1929. For example, the average catch per lift of deep trap nets in M–1 decreased in 1931 and increased in 1932 despite the fact that abundance remained practically unchanged in 1931 and fell in 1932. Again, the highest yield (257.5 pounds per lift) of the northern area occurred in a district (M–2) when abundance was normal (1932).

As the average deep-trap-net lifts were small in comparison with those of central and southern Lake Huron irrespective of how much abundance was above average, the conclusion appears valid that in northern Lake Michigan as in northern Lake Huron the deep trap net was far less successful than it was in central and southern Lake Huron.

The maximum and 1939 percentages of production, fishing intensity, and abundance in table 18 have been computed with respect to average conditions in 1929–1939. The corresponding estimates for Lake Huron (table 7) were made with reference to

TABLE 18.—*Maximum and 1939 production and abundance of whitefish and maximum and 1939 fishing intensity for whitefish*

[Expressed as percentages of the average 1929–1939 values in each statistical district of Lake Michigan]

District	Year of maximum production	Production		Year of maximum intensity	Intensity		Year of maximum abundance	Abundance	
		Maximum	1939		Maximum	1939		Maximum	1939
M-1	1931	227	45	1931	196	65	1929	170	81
M-2	1930	184	28	1932	180	41	1929	169	69
M-3	1930	230	40	1930	159	65	1929	166	67
M-4	1931	148	56	1931	127	88	1929	127	66
M-5	1931	183	31	1932	129	77	1931	162	41
M-6	1931	345	7	1931	242	16	1930	209	53
M-7	1930	433	1	1930	271	7	1930	222	33
M-8	1934	235	20	1934	215	34	1929	151	71

conditions in the single year, 1929. The figures for this year were taken as the most nearly "normal" data available (p. 323). The computation of the above percentages for Lake Michigan also with respect to 1929 conditions would not have been valid because production, abundance, and almost certainly fishing intensity, as well, were above normal in Lake Michigan in that year. On the other hand, the data for the period, 1929–1939, were not greatly, if at all, distorted by the deep-trap-net fishery in Lake Michigan. Furthermore, these 11 years included periods of high, moderate, and low production and apparently also periods of high, moderate, and low abundance and fishing intensity. Consequently, the 11-year averages have been taken as the most nearly normal bases available for the estimation of the maximum and 1939 percentages of production, fishing intensity, and abundance for the Lake Michigan whitefish. It is believed that this variation of procedure has made the data of tables 7 and 18 as nearly comparable as is possible.

In comparison with Lake Huron the maxima of yields in Lake Michigan were relatively small. The maximum exceeded 3 times the assumed normal in only two districts (433 percent in M–7 and 345 percent in M–6). Of the remaining six districts the maximum production was greater than twice the normal in three (M–1, M–3, and M–8), was between 1½ and 2 times the normal in two (M–2 and M–5), and was less than 1½ times the normal in one (M–4). In Lake Huron, on the contrary, the relatively lowest maximum yield was 263 percent of the 1929 catch (H–1) and the maxima in the remaining districts ranged from 317 in H–2 to as high as 2,662 in H–5. This comparison lends additional strong support to the belief that the use of the deep trap net brought about an excessive increase in yield in Lake Huron, especially in the four southern districts.

The maxima of fishing intensity were relatively lower in Lake Michigan than were the maxima of production. The peak fishing intensity was more than twice the normal only in southern Lake Michigan (M–6, M–7, and M–8). The five remaining percentages were all below 200, and two of them (M–4 and M–5) were less than 150. In Lake Huron the maximum percentage was more than twice the normal in every district; in the four southerly districts the maxima ranged from roughly 4 to 42 times the normal. Again the comparison of data for Lake Michigan and Lake Huron supports the earlier conclusion, namely, that the deep-trap-net operations led to an abnormally increased fishing intensity in Lake Huron with the increase greatest in the central and southern regions of the lake.

The maxima of abundance of whitefish were relatively higher in Lake Michigan than in Lake Huron. In two districts the percentages exceeded 200 (M–6 and M–7); of the remaining six districts the percentages were above 150 in five and below 150 in only one. The corresponding percentages for Lake Huron were all below 150. These low values of the maximum abundance of whitefish in Lake Huron suggest the possibility that abundance in 1929, the year taken as normal, may have been somewhat above normal as well as above the Lake Huron average for 1929–1939. An alternative explanation is offered by the possibility that, in some districts at least, a higher maximum abundance might have been attained if fishing intensity and production had been less.

The estimates of the 1939 conditions in Lakes Michigan and Huron in relation to the assumed "normals" for the lakes provide further striking comparisons. Production was at a low level in both lakes in 1939. In Lake Michigan, however, only two districts of eight had yields below 20 percent of normal, whereas in Lake Huron three of the six districts were below that level. Three of the Lake Michigan districts had percentages of 40 or above; in Lake Huron the only production greater than 40 percent of normal (46 in H–6) was made possible by reason of a fishing intensity that was more than 4 times the normal.

Fishing intensities in 1939 were generally relatively lower in Lake Michigan than in Lake Huron. In five of six districts of Lake Huron the intensity of the fishery for whitefish was 50 percent or more of the 1929 "normal"; in 2 districts (H–5 and H–6) the intensity in 1939 was more than 4 times the normal. The intensity of the whitefish fishery in Lake Michigan was above 50 percent of normal in only four of eight districts and was only 88 percent in M–4, the district with the most intensive fishery.

The comparison of the relative abundance of whitefish in Lakes Michigan and Huron in 1939 provides an explanation for the fact that the percentages for production were the higher in Lake Michigan in that year despite a relatively more intensive fishery in Lake Huron. The abundance of whitefish was below normal in 1939 in every district of Lake Michigan. However, the percentage was below 50 in only two of the eight districts (M–5 and M–7) and was below 60 in only three (M–5, M–6, and M–7). In Lake Huron, on the other hand, the abundance of whitefish was less than 50 percent of the 1929 "normal" in every district, and was so low as to suggest the virtual disappearance of the species from the four most southerly districts. Thus it seems that where the whitefish merely declined in abundance in Lake Michigan the species approached extermination in most of Lake Huron.

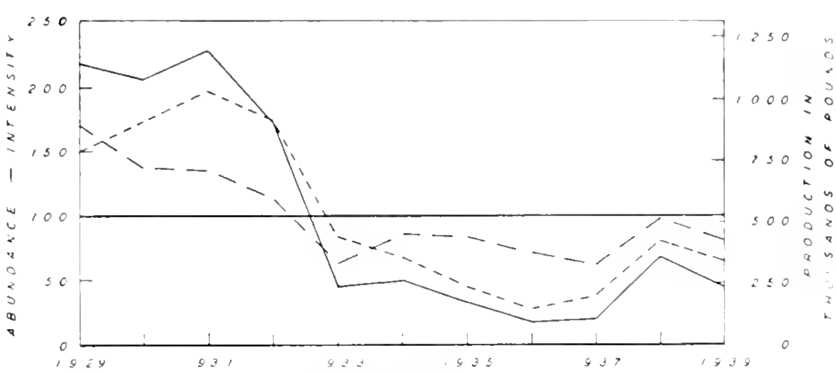
The possibility that abundance may have been above normal in 1929, the "normal" year of reference for Lake Huron, does not affect the validity of the preceding statement. If it is assumed, for example, that the abundance of whitefish in Lake Huron was 50 percent above normal in 1929, hence that the percentages for 1939 should be increased 50 percent, the following estimates are obtained of 1939 abundance as percentages of normal:

District	*Abundance*	*District*	*Abundance*
H–1	62	H–4	10
H–2	64	H–5	8
H–3	9	H–6	15

Even this increase leaves the percentages extremely low for the four southerly districts, although the percentages for H–1 and H–2 are raised to a point corresponding roughly with the general level in Lake Michigan.

The evidence that the use of deep trap nets in Lake Huron led to an excessively great, and ultimately ruinous, expansion of the whitefish fishery should not be taken to signify that overfishing did not take place in Lake Michigan also. The capacity for overfishing is not an exclusive characteristic of any one type of gear. Emphasis has been placed on overfishing by the deep trap net merely because its extraordinary efficiency made possible the extreme condition of overfishing observed in central and southern Lake Huron. Obviously the removal of an equal quantity of whitefish by any other gear would have proved equally disastrous.

Although the maxima of production were relatively lower in Lake Michigan than in Lake Huron, it must be considered probable that in some of the Lake Michigan districts the catch of whitefish was sufficiently great to affect adversely the abundance of the species in later years. In M–1, for example, the high fishing intensity (tables 19 and 20) that made possible the production of roughly a million pounds of whitefish in



Figures 13 to 20 show the annual fluctuations in the production (solid lines) and abundance (long dashes) of whitefish and in the intensity of the whitefish fishery (short dashes) over the period, 1929–1939, in each of the eight statistical districts of Lake Michigan (see fig. 4). In each figure the central horizontal line represents the average conditions for the 11 years, 1929–1939.

FIGURE 13.—First district, M-1.

the four consecutive years, 1929–1932 (table 15), may well have contributed to the sharp decline in abundance in 1933 (table 21). Similarly, in other districts the declines in abundance that followed years of increased fishing intensity and high yields might have been less severe had the fishery of the preceding years been less intensive. The actual detection of the possible effects of high production on the abundance of whitefish in later years is difficult, since in Lake Michigan as in Lake Huron a decline from the peak of abnormal abundance was to be anticipated whether or not extensive overfishing occurred. Furthermore, the data for Lake Michigan do not provide the sharp contrasts that made the presence and effects of overfishing in Lake Huron so easy to detect. (Compare especially the annual fluctuations in the production and fishing intensity in the various districts of the two lakes—figs. 5–10 for Lake Huron and 13–20 for Lake Michigan.)

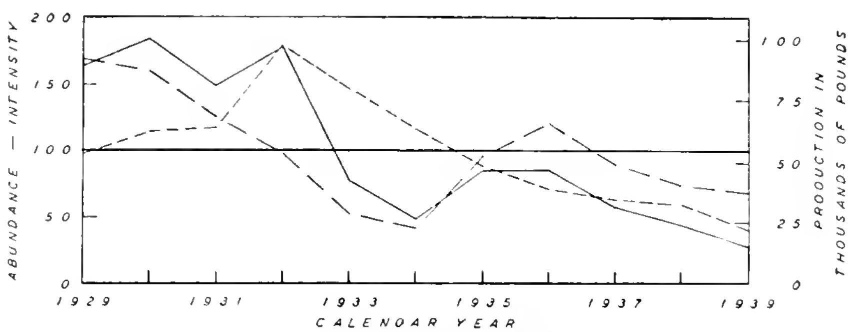


Figure 14.—Second district, M-2.

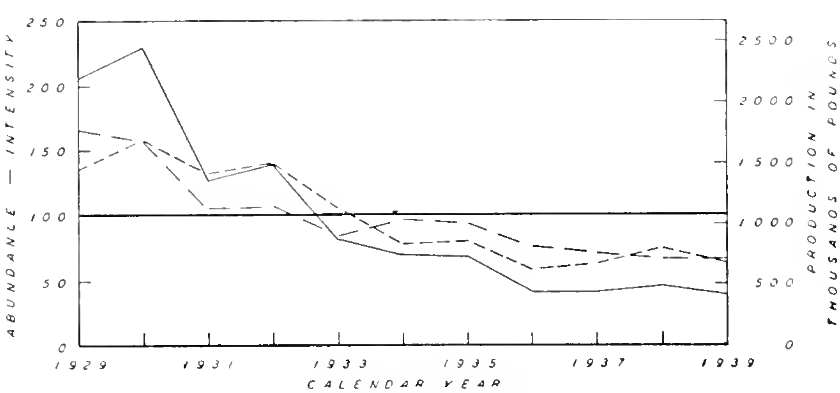


Figure 15.—Third district, M-3.

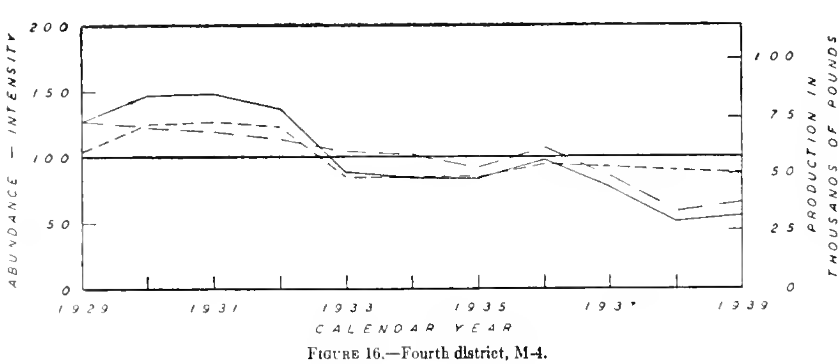


Figure 16.—Fourth district, M-4.

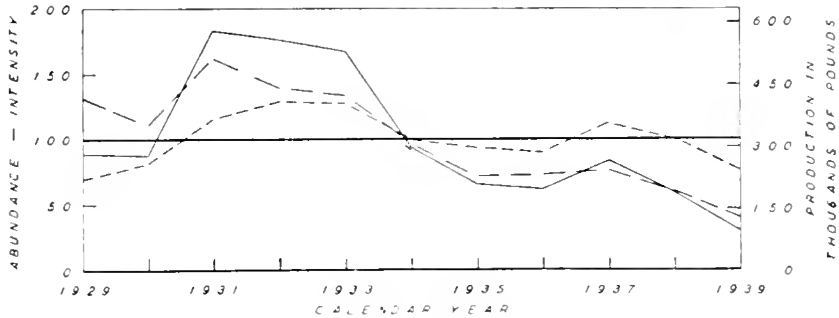


FIGURE 17.—Fifth district, M-5.

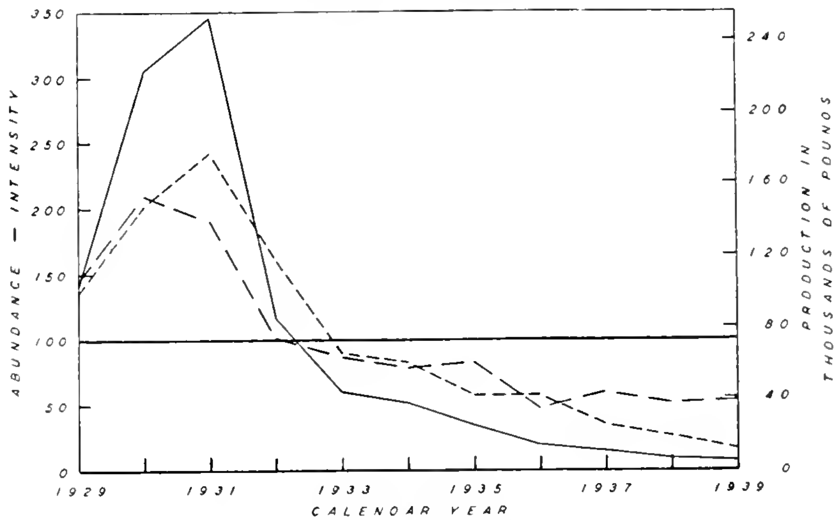


FIGURE 18.—Sixth district, M-6.

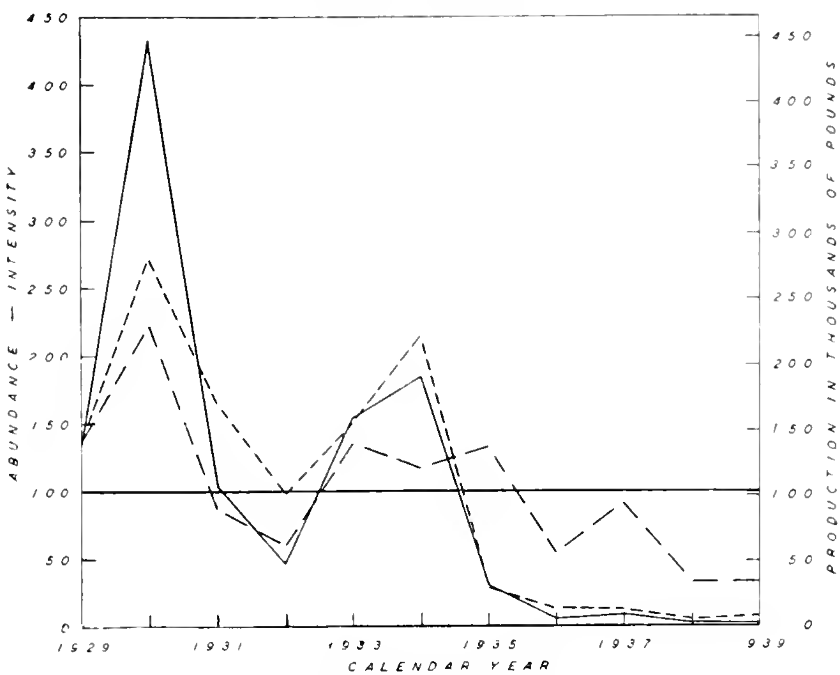


FIGURE 19.—Seventh district, M-7.

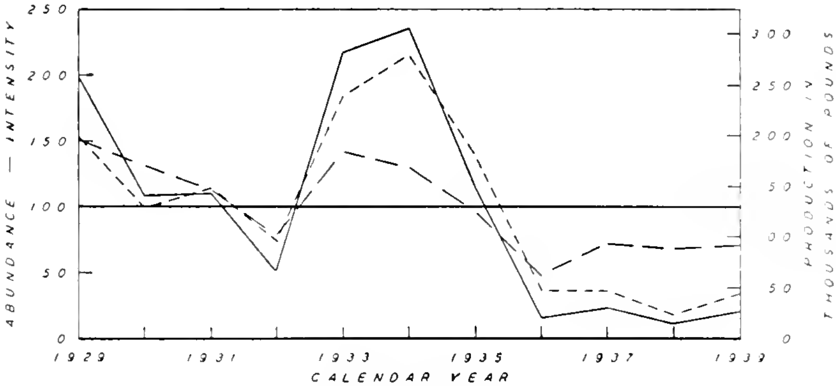


FIGURE 20.—Eighth district, M-8.

TABLE 19.—*Annual fluctuations in the intensity of the fishery for whitefish in each district of Lake Michigan*

[Expressed as percentages of the average 1929–1939 intensity in the district]

District	Fishing intensity as percentage of average in year										
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
M-1	149	173	196	174	84	68	45	28	38	80	65
M-2	98	115	118	180	147	117	89	71	64	60	41
M-3	136	159	133	141	107	79	81	59	64	76	65
M-4	104	125	127	123	85	85	85	95	93	90	88
M-5	70	82	116	129	128	100	94	90	113	101	77
M-6	135	201	242	160	89	82	57	57	35	26	16
M-7	136	271	165	98	150	214	28	14	12	5	7
M-8	152	99	114	74	183	215	139	36	36	18	34

TABLE 20.—*Annual fluctuations in the intensity of the whitefish fishery for all eight districts of Lake Michigan combined (third row from bottom) and distribution of each year's intensity among the districts*

[The average annual intensity for the entire lake, 1929–1939, is 100.0. In parentheses are the intensity values of the deep-trap-net fishery. The value of one unit is 1/1100 of the total expected catch (p. 314) of all districts, 1929–1939]

District or area	Fishing intensity in year											Total	Percentage of intensity represented by deep trap nets
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939		
M-1	32.1 ------	37.5 (1.2)	42.3 (4.8)	37.7 (7.0)	18.1 (6.1)	14.7 (3.3)	9.7 (1.1)	6.1 ------	8.2 ------	17.3 ------	14.0 ------	237.7 (23.5)	9.9
M-2	2.6 ------	3.0 ------	3.1 (0.7)	4.6 (2.3)	3.8 (2.6)	3.1 (1.7)	2.3 (0.8)	1.8 ------	1.7 ------	1.6 ------	1.1 ------	28.7 (8.1)	28.2
M-3	63.6 ------	74.7 (3.7)	62.6 (11.8)	66.1 (21.4)	50.4 (19.4)	37.4 (12.2)	37.9 (11.1)	27.7 ------	30.0 ------	35.4 ------	30.8 ------	516.6 (79.6)	15.4
M-4	2.7	3.3	3.4	3.3	2.3	2.2	2.3	2.5	2.5	2.4	2.3	29.2	------
Northern Lake Michigan (M-1, M-2, M-3, & M-4)	101.0 ------	118.5 (4.9)	111.4 (17.3)	111.7 (30.7)	74.6 (28.1)	57.4 (17.2)	52.2 (13.0)	38.1 ------	42.4 ------	56.7 ------	48.2 ------	812.2 (111.2)	13.7
Central Lake Michigan (M-5)	10.3	12.1	17.2	19.1	18.9	14.7	13.9	13.2	16.7	14.9	11.5	162.5	------
M-6	3.4	5.1	6.1	4.0	2.3	2.1	1.5	1.4	0.9	0.6	0.4	27.8	------
M-7	4.9	9.7	5.9	3.5	5.4	[1]7.7	1.0	0.5	0.4	0.2	0.2	39.4	7.4
M-8	8.0	5.2	6.1	3.9	9.6	11.3	7.4	1.9	1.9	1.0	1.8	58.1	------
Southern Lake Michigan (M-6, M-7, & M-8)	16.3	20.0	18.1	11.4	17.3	21.1	9.9	3.8	3.2	1.8	2.4	125.3	2.3
Lake Michigan (all 8 districts)	127.6 ------	150.6 (4.9)	146.7 (17.3)	142.2 (30.7)	110.8 (28.1)	93.2 [1](20.1)	76.0 (13.0)	55.1 ------	62.3 ------	73.4 ------	62.1 ------	1,100.0 (114.1)	10.4
Percentage of intensity represented by deep trap nets	------	3.3	11.8	21.6	25.4	21.6	17.1	------	------	------	------	10.4	------

[1] Intensity represented by deep-trap-net operations in M-7 in 1934 was 2.9.

TABLE 21.—*Annual fluctuations in the abundance percentages for whitefish in the various districts and areas of Lake Michigan, 1929–1939*

[Expressed as percentages of average 1929-1939 abundance. In the computation of percentages for areas of more than one district and for the entire lake the abundance percentage for each district was weighted according to the percentage of the total 1929-1939 production contributed by that district]

District or area	Abundance percentage in year										
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
M-1	170	137	135	113	63	86	84	71	62	98	81
M-2	169	161	126	99	53	42	96	121	90	74	69
M-3	166	158	106	108	85	98	95	77	72	68	67
M-4	127	123	120	114	104	102	92	107	86	59	66
Northern Lake Michigan (M-1, M-2, M-3, and M-4)	166	150	116	109	78	93	92	78	70	77	71
Central Lake Michigan (M-5)	132	111	162	140	134	97	72	73	77	61	41
M-6	144	209	190	101	86	78	82	47	59	51	53
M-7	136	222	86	60	135	117	133	54	91	33	33
M-8	151	131	113	78	142	130	96	48	72	68	71
Southern Lake Michigan (M-6, M-7, and M-8)	144	180	123	78	126	113	105	50	75	52	54
Lake Michigan (all 8 districts)	158	149	123	109	92	96	91	73	72	72	65

A suggestion of overfishing is provided by the data for M–7. In this district the greatest maximum yield (433 percent of the 1929–1939 average) was associated with the lowest relative abundance (33 percent) in 1939 (table 18). Abundance in 1939 was low also in M–6 (53 percent), the district with the second highest maximum production percentage (345). The maximum fishing intensity also was relatively high in both M–6 and M–7 (242 and 271, respectively). On the other hand, the 1939 abundance was low (41 percent) in M–5, where there was no indication of overfishing in 1929–1939 (maximum production, 183 percent of normal; maximum intensity, 129 percent of normal).

Although, as stated previously, overfishing cannot be disregarded as a possible contributing factor in the decline in abundance of the Lake Michigan whitefish, there can be no doubt that overfishing was relatively unimportant in Lake Michigan as compared with Lake Huron. In the discussion of the data for Lake Huron emphasis was placed on the unreasonable expansion of fishing intensity and especially on the fact that this intensity remained abnormally high even in the face of decreasing abundance. The data for Lake Michigan, on the contrary, reveal a much more rational relationship between abundance and fishing intensity (and hence between abundance and yield).

Despite certain exceptions it can be said that in the Lake Michigan districts, as a whole, periods of relatively high abundance were also periods of relatively high fishing intensity and production (tables 15, 19, and 21; figs. 13 to 20). It is true that the changes in fishing intensity tended to lag somewhat behind the changes in abundance. Commonly the peak of fishing intensity occurred a year or two later than the peak of abundance, and the subsequent decline in fishing intensity was delayed correspondingly. Nevertheless, fishing intensity and yield were above average in a large majority of the years in which the abundance of whitefish was above average, and, conversely, fishing intensity and production were below average in the majority of the years in which the abundance of whitefish was below average. There was a tendency also for the percentages of fishing intensity and catch to be greater than the abundance percentages when abundance was above average and less than the abundance percentages when abundance was below average. The curves of fishing intensity tended to lie outside (with reference to the average) the curves of abundance, and the curves of production tended to fall outside both the curves of abundance and fishing intensity.

The tendency for the Lake Michigan fishermen to regulate their fishing activities according to the abundance of whitefish is brought out further by the fact that the coefficient of correlation between the percentages of fishing intensity and abundance over the 11-year period (88 pairs of percentages) was 0.70. For Lake Huron, where intensive fishing frequently was carried on despite a low abundance of whitefish, the coefficient of correlation between the percentages of fishing intensity and abundance (66 pairs of percentages) was only 0.23.

The statement that fishing intensity and production were better adjusted to the abundance of whitefish in Lake Michigan than in Lake Huron applies to the data for the entire lakes (table 22) as well as to the data for the individual districts. (Compare also figs. 11 and 21.) In Lake Michigan the fishing intensity for whitefish was

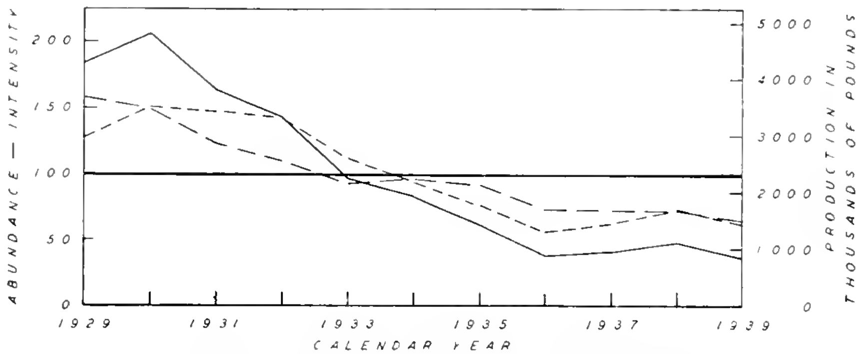


FIGURE 21.—Annual fluctuations in the production (solid line) and abundance (long dashes) of whitefish and in the intensity of the whitefish fishery (short dashes) in Lake Michigan (all eight districts combined), 1929–1939.

above average in every year in which the abundance was above average and was less than average in 6 of the 7 years in which abundance was below average. Furthermore, the intensity percentage exceeded the abundance percentage in 3 of the 4 years in which abundance was above 100 but was less than the abundance percentage in 5 of the 7 years in which abundance was below 100. Every year in which the abundance of whitefish was above average was a year of greater than average production; the catch of whitefish was below average, however, in every year in which the abundance of the species was below average. The production percentage exceeded the abundance percentage in every year in which abundance was above average, but the former was less than the latter in 6 of the 7 years with abundance below average.

TABLE 22.—*Production and abundance of whitefish and the intensity of the whitefish fishery in the State of Michigan waters of Lakes Michigan and Huron*

[Expressed as percentages of the 1929–1939 average]

Lake	Item	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
Michigan	Production	184	206	164	143	96	83	61	38	41	48	36
	Fishing intensity	128	151	147	142	111	93	76	55	62	73	62
	Abundance	158	149	123	109	92	96	91	73	72	72	65
Huron	Production	68	134	193	189	155	120	88	67	48	26	12
	Fishing intensity	46	69	100	120	155	125	139	112	100	88	46
	Abundance	152	195	195	140	89	77	67	61	55	38	31

Altogether different was the relationship of fishing intensity and production to the abundance of whitefish in Lake Huron. In that lake the fishing intensity was above average in 5 (exactly 100 percent in 1 year) of the 7 years in which abundance was below average; furthermore, the intensity percentage exceeded the abundance percentage in every one of these 7 years. The catch also was disproportionately high in periods of low abundance. The catch percentage exceeded the abundance percentage in

4 of the 7 years in which abundance was less than 100. The circumstance that fishing intensity was so much below the maximum in the years in which the abundance of the Lake Huron whitefish was above average should not be taken to indicate that the Lake Huron fishermen were less prompt than the Lake Michigan fishermen to take advantage of this abnormal abundance. In fact, the fishing intensity rose sharply in Lake Huron as the increase from 46 in 1929 to 100 in 1931 shows. The 1931 intensity was more than twice that of 2 years earlier. The fishing intensity in these early years of the 11-year period is represented by small percentages simply because the excessive use of deep trap nets led to a 1929–1939 average of fishing intensity that was far above a level that could reasonably be considered normal. It is doubtful whether without the use of deep trap nets the intensity would have reached the high level recorded for 1932, and much less have risen to still higher levels and maintained itself above the 1932 intensity until 1936. These considerations serve to bring out again the immensity of the overfishing that occurred in Lake Huron.

From the mass of evidence obtained from the statistical data of the whitefish fisheries of Lakes Huron and Michigan the following general conclusions may be drawn.

Lake Huron.—The deep-trap-net fishery, expansion of which was fostered by an abnormal abundance of whitefish that reached its peak in 1930–1931, was the primary cause of excessive overfishing in Lake Huron. This overfishing led to the collapse of the whitefish fishery in central and southern Lake Huron and contributed to the decline of the fishery in the northern part of the lake.

Lake Michigan.—A similar abnormal abundance of whitefish in Lake Michigan, with the peak probably in 1929, was accompanied by increases in fishing intensity and production. Although this intensive fishery may have affected adversely the later abundance of whitefish, there is no evidence of overfishing comparable to that which occurred in Lake Huron. The decline of the whitefish in Lake Michigan was pronounced but not disastrous. The difference in the course of the fishery in the two lakes can be attributed to the relatively limited use of deep trap nets in Lake Michigan.

PART III

BATHYMETRIC DISTRIBUTION OF WHITEFISH AND OF CERTAIN OTHER SPECIES IN THE SHALLOWER WATERS OF LAKES HURON AND MICHIGAN

The following sections are based on counts of whitefish and certain other species in 456 lifts of pound nets and deep trap nets in Lake Huron and 380 lifts in Lake Michigan in the years, 1931–1932. The original compilations of the data were much more detailed than those presented here. The tables showing the bathymetric distribution of the fish represent combinations of large-mesh (4 inches and larger, stretched measure) and small-mesh (less than 4 inches) nets of different dimensions, of different fishing grounds in the same general area, and of data for corresponding months in 1931 and 1932. However, these combinations were made only after a careful examination of the material demonstrated that the condensed data did not lead to conclusions that were at variance with those that would have been drawn from more detailed information.

In the main, the data have been compiled according to 10-foot depth intervals. However, for species other than the yellow pike, all lifts of nets from depths of 40 feet and less have been combined, as have also those from 41–60 feet. In deep water all lifts from more than 120 feet (more than 110 feet in Lake Michigan) have been combined. The greatest depth in which a deep trap net was set, so far as we know, was about 160 feet. This net was set in Lake Huron. Seldom were deep trap nets placed in water deeper than 140 feet. In Lake Michigan the whitefish grounds were located in much shallower water. Although a few pound nets set in more than 60 feet of water were visited and a few deep-trap-net lifts from depths of 60 feet or less were observed, for practical purposes the 60-foot contour may be considered as the line of separation of the two types of gear. The change from pound nets to deep trap nets at a depth of about 60 feet should not affect the value of the data, since we did not find any important differences in the catch of pound nets and deep trap nets that were fished in the same depth of water. All lifts observed from depths of more than 120 feet were made in Lake Huron.

As a convenience in reading the tables, asterisks have been employed to designate those depth intervals that contained the more significant peak concentrations of fish. As an additional convenience, whitefish and yellow pike frequently will be termed merely "legal" and "illegal" fish on the basis of a 2-pound and 1½-pound size limit, respectively, which limits were in effect in Michigan at the time of the investigation.

BATHYMETRIC DISTRIBUTION OF WHITEFISH IN LAKE HURON

NORTHERN LAKE HURON (CHEBOYGAN AND ROGERS CITY)

The number of lifts (20) of pound nets and deep trap nets observed in northern Lake Huron was insufficient to provide reliable data on the bathymetric distribution of the whitefish. The largest lifts of legal-sized whitefish were taken from depths of 71–80 feet in July and August and of 61–70 feet in September (table 23). The greatest numbers of illegal-sized fish occurred in lifts from 71–80 and 91–100 feet. (Only one lift from the latter depth was observed.)

ALPENA-OSSINEKE GROUNDS

Although a fairly large number (158) of pound-net and deep-trap-net lifts was examined on the Alpena and Ossineke grounds, the scarcity of data for the shallower water makes a detailed description of the depth distribution of whitefish in this area impossible (table 24). Nearly half of the lifts were from depths of 111–120 feet and the bulk of the remainder were from depths of 81–110 feet. For no month were data available for all waters. Outstanding features of the Alpena-Ossineke data were the comparative scarcity of legal whitefish and the great abundance of undersized individuals.

TABLE 23.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in northern Lake Huron (ports of Cheboygan and Rogers City), 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of legal whitefish per lift at depth (in feet)					Month	Number of illegal whitefish per lift at depth (in feet)				
	41–60	61–70	71–80	81–90	91–100		41–60	61–70	71–80	81–90	91–100
July	...	20.0 (2)	51.2 (4)	...	...	July	...	46.5 (2)	40.0 (4)	...	...
August	...	...	19.0 (2)	3.0 (2)	12.0 (1)	August	...	...	88.0 (2)	17.5 (2)	69.0 (1)
September	9.0 (1)	26.2 (5)	12.3 (3)	...	...	September	6.0 (1)	5.8 (5)	5.7 (3)	...	...
Average	9.0 (1)	24.4 (7)	31.1* (9)	3.0 (2)	12.0 (1)	Average	6.0 (1)	17.4 (7)	39.2* (9)	17.5 (2)	69.0 (1)

TABLE 24.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in the Alpena-Ossineke area, 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of legal whitefish per lift at depth (in feet)							
	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May	...	...	...	20.0 (1)	...	20.0 (1)	34.0 (23)	54.0* (4)
June	9.8 (4)	9.0 (1)	...	39.0 (1)	23.0 (1)	23.7* (6)	14.7 (18)	15.0 (5)
July	7.0 (1)	...	24.0 (1)	43.2* (5)	37.3 (12)	12.6 (7)	36.0* (23)	...
August	42.0 (2)	71.0 (1)	92.7* (7)	50.4 (9)	44.3 (3)	21.0 (5)	35.2* (10)	...
September	...	...	...	...	...	96.8 (5)	198.5* (2)	...
Average	19.6 (7)	40.0 (2)	84.2* (8)	45.6 (16)	37.8 (16)	35.0 (24)	34.5 (76)	32.3 (9)

Month	Number of illegal whitefish per lift at depth (in feet)							
	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May	...	...	...	219.0 (1)	...	243.0 (1)	255.8* (23)	239.2 (4)
June	106.0 (4)	109.0 (1)	...	311.0 (1)	163.0 (1)	190.0* (6)	64.2 (18)	62.8 (5)
July	262.0 (1)	...	95.0 (1)	195.8* (5)	117.8 (12)	52.3 (7)	69.0* (23)	...
August	173.0* (2)	86.0 (1)	75.7 (7)	114.1* (9)	38.7 (3)	36.4 (5)	66.5* (10)	...
September	...	...	...	...	...	33.4 (5)	92.5* (2)	...
Average	147.4* (7)	97.5 (2)	78.1 (8)	158.5* (16)	105.8 (16)	87.4 (24)	124.7 (76)	141.2 (9)

Distribution of legal-sized whitefish.—In May the average numbers of legal whitefish taken in 111–120 feet and in "deep-water" (more than 120 feet) lifts were above those of the single lifts from 81–90 and 101–110 feet. In June, however, the average catches of the nets from the deeper water were exceeded by the catch of the 6 nets set in 101–110 feet. The 5 lifts in shallow water (41–70 feet) averaged only 9.0 and 9.8 fish for the two intervals involved. The largest average lifts in July occurred at depths of 81–90 feet (43.2) and 91–100 feet (37.3). However, the average number of fish in lifts from 111–120 feet was almost three times that of lifts from the 101–110 foot interval. The single lift in shallow water (41–60 feet) was again small (7.0 fish). The depth from which the largest lifts were made in August was shallower than that in July (71–80 feet). It is to be noted also that the average numbers of fish taken in the shallow water far exceeded the corresponding averages for June and July. In August, again, the catch of nets set at 111–120 feet was well above that of nets set at 101–110 feet. This agreement between the July and August data suggests that in late summer whitefish may be concentrated at more than one depth.[30] The September data cover only two intervals of depth. In this month the average number of legal whitefish per lift from 111–120 feet was twice that of nets from 101–110 feet, and in both intervals the numbers were relatively large, suggesting a return of the fish to deep water.

The data offer some evidence of an onshore movement of legal whitefish as the summer progresses. In May concentrations were greatest in the deepest water (beyond 110 feet). In June a general shift seemed to have occurred to waters between 80 and 111 feet deep, in July to waters of depths between 70 and 101 feet, and in August to depths between 60 and 91 feet.

In the averages for the entire season the number of legal fish per lift increased from shallow water to a maximum of 84.2 fish at depths of 71–80 feet. Beyond this depth interval there was a continuous decline in the average number of legal whitefish per lift.[31]

Distribution of illegal-sized whitefish.—The data on the bathymetric distribution of illegal whitefish bear considerable resemblance to those of legal fish. In both size groups the average number of fish per lift was greater at 111–120 feet than at 101–110 feet in every month but June. Furthermore, both groups appear to undertake an onshore movement as the summer progresses. A difference is found between the vertical distribution of legal and illegal whitefish in the greater abundance of the latter group in shallow water.

The averages for the entire season show heavy concentrations of young whitefish in the intervals: 41–60 feet, 81–90 feet, and more than 120 feet. These fish were least abundant in depths of 71–80 and 101–110 feet. These averages, however, are influenced by the shift in concentrations. The monthly figures indicate a heavy concentration in all depths beyond 80 feet in May, between 80 and 111 feet in June, between 80 and 101 feet in July, and in 81–90 feet in August. In September the number again increased in the 111–120 foot interval. A comparison of the seasons' averages reveals that the maximum concentration of illegal whitefish (81–90 feet) was in water 10 feet deeper than the maximum for legal fish (71–80 feet). However, legal fish did not share the inshore abundance of the smaller whitefish.

SAGINAW BAY AREA (OSCODA, EAST TAWAS, AND BAY PORT)

A total of 223 lifts of pound nets and deep trap nets was examined in the Saginaw Bay area. Despite this large total, the distribution of the lifts leaves certain depths of less than 91 feet poorly represented (table 25). With the exception of a few lifts on northerly and easterly courses out of Oscoda, the deep-trap-net lifts were made on the grounds of district H–4. (See fig. 4.) Most of the pound nets observed were in the neighborhood of East Tawas. The Saginaw Bay area differed from the Alpena-Ossineke grounds in the relatively high abundance of legal, as compared with illegal, fish.

[30] The evidence for more than one "concentration depth" is not strong (particularly for legal whitefish) in the Alpena-Ossineke data. The suggestion is brought out here because of the later conclusive evidence that there are two concentration zones in northeastern Lake Michigan (p. 353). No good evidence of a concentration at 111–120 feet was found in other Lake Huron waters.

[31] The September data obscure the presence of two concentrations of legal whitefish. If the September data are excluded the average numbers of legal whitefish per lift become 18.7 at 101–110 feet and 30.3 at 111–120 feet.

TABLE 25.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in the Saginaw Bay area (ports of Au Sable-Oscoda, East Tawas, and Bay Port), 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of legal whitefish per lift at depth (in feet)								
	<41	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May						1.0 (1)	23.0 (7)	30.8 (6)	93.0* (5)
June	15.8 (5)	7.6 (9)				11.0 (1)	37.3* (14)	31.2 (22)	18.6 (11)
July	0.2 (6)	18.0 (1)			71.5 (2)	87.7 (11)	129.1* (7)	45.2 (15)	84.3* (6)
August		51.8 (5)	24.0 (3)	111.5 (4)	190.9 (12)	216.8* (12)	176.9 (15)	171.7 (15)	117.0 (10)
September				200.0* (2)	4.0 (1)	15.5 (2)	44.0 (2)	299.8* (4)	250.5 (2)
October								108.0 (2)	167.3* (3)
Average	7.3 (11)	23.0 (15)	24.0 (3)	141.0 (6)	162.5* (15)	133.7 (27)	96.2 (45)	86.6 (64)	90.5 (37)

Month	Number of illegal whitefish per lift at depth (in feet)								
	<41	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May						7.0 (1)	82.3* (7)	56.3 (6)	15.2 (5)
June	30.2 (5)	14.3 (9)				20.0 (1)	52.0* (14)	21.8 (22)	3.7 (11)
July	2.3 (6)	21.0 (1)			17.0 (2)	16.2 (11)	21.0* (7)	5.7 (15)	7.3* (6)
August		25.8 (5)	47.0 (3)	99.8 (4)	150.9* (12)	115.2 (12)	47.6 (15)	30.7 (15)	13.4 (10)
September				63.0* (2)	14.0 (1)	40.5 (2)	85.0* (2)	74.8 (4)	66.5 (2)
October								24.5 (2)	44.0 (3)
Average	15.9 (11)	18.6 (15)	47.0 (3)	87.5 (6)	123.9* (15)	61.8 (27)	51.9 (45)	26.7 (64)	15.1 (37)

Distribution of legal-sized whitefish.—Again there is evidence of an onshore movement of legal whitefish during the summer followed by a return to deeper water in early autumn, apparently beginning in August. (See also p. 350.) The depths of maximum concentration in the different months were: May—more than 120 feet; June and July—101–110 feet (the shift was more toward shallower water in July than in June); August—91–100 feet; September—111–120 feet; October—more than 120 feet (only two intervals represented). There were two peaks in the August data (41–60 feet and 91–100 feet) and in the September data (71–80 feet and 111–120 feet). However, the number of lifts was so small at some depths that it cannot be concluded that the whitefish were concentrated at two depth intervals. The average number of legal whitefish per lift through the entire season increased continuously from shallow water (less than 41 feet) to the maximum at 81–90 feet, declined in the next three intervals, and increased slightly at depths greater than 120 feet.

Distribution of illegal-sized whitefish.—The data on the bathymetric distribution of young whitefish indicate an onshore movement followed by an offshore movement similar to that of legal fish. The depths of maximum concentration were: May, June, and July—101–110 feet (in each succeeding month, however, the shift was toward the shallower water); August—81–90 feet; September—101–110 feet; October—more than 120 feet. In the averages for the entire season the maxima for legal and illegal fish were in the same interval (81–90 feet). The strongest indication of two concentration zones of illegal fish is found in the scanty September data. Young whitefish were much scarcer in the shallower water of the Saginaw Bay area than at corresponding depths on the Alpena-Ossineke grounds.

HARBOR BEACH GROUNDS

The observations of 55 lifts of deep trap nets off Harbor Beach (no pound nets were observed here) were all made in the latter part of the 1932 season (table 26), when on the basis of the preceding data the whitefish would be expected to be concentrated in the deeper water. Actually here is where the deep trap nets were found in operation. Fifty of the lifts were made from depths greater than 90 feet. Consequently, no detailed description of the vertical distribution of whitefish at all depths in this area is possible. The maximum concentration of both legal and illegal whitefish occurred in the 101–110 foot interval in all three months. In the season's average the number of legal fish per lift was greater at 91–100 feet than in waters deeper than 110 feet, but the reverse relationship was found in the data for illegal whitefish. The single shallow-water lift (41–60 feet) contained no whitefish. The legal whitefish were more abundant than the illegal fish at all depths.

TABLE 26.—*Number of legal and illegal whitefish per lift of deep trap nets off Harbor Beach, 1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of legal whitefish per lift at depth (in feet)							
	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
August					251 0 (1)	420 5* (2)	408 3 (4)	135 8 (5)
September	0 0 (1)		101 0 (1)	42 0 (3)	270 5 (8)	291 7* (12)	134 2 (6)	163 0 (3)
October					62 5 (2)	117 3* (3)	34 5 (2)	46 0 (2)
Average	0 0 (1)		101 0 (1)	42 0 (3)	231 5 (11)	276 1* (17)	208 9 (12)	126 0 (10)

Month	Number of illegal whitefish per lift at depth (in feet)							
	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
August					150 0 (1)	298 0* (2)	266 8 (4)	79 0 (5)
September	0 0 (1)		65 0 (1)	33 3 (3)	73 2 (8)	167 2* (12)	67 7 (6)	75 3 (3)
October					32 0 (2)	67 7* (3)	32 0 (2)	55 5 (2)
Average	0 0 (1)		65 0 (1)	33 3 (3)	72 7 (11)	165 0* (17)	128 1 (12)	73 2 (10)

BATHYMETRIC DISTRIBUTION OF WHITEFISH IN LAKE MICHIGAN

GREEN BAY AREA (MARINETTE, ESCANABA, AND FAIRPORT)

The 30 lifts of pound nets and deep trap nets observed in the Green Bay area do not offer adequate information on the bathymetric distribution of the whitefish at any one time or on the seasonal movements of whitefish. The data of table 27, however, indicate rather clearly that legal whitefish in this region were in deeper water in September (61–80 feet) than in May (60 feet and less). Illegal whitefish were relatively numerous in May at depths less than 61 feet, and were present in large numbers also in the two lifts from the 81–90 foot interval. Few illegal whitefish were taken at any depth in September.

TABLE 27.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in the Green Bay area (ports of Marinette, Escanaba, and Fairport), 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of legal whitefish per lift at depth (in feet)						
	<41	41-60	61-70	71-80	81-90	91-100	101-110
May	61.4 (5)	51.2 (5)	16.0 (1)		23.5 (2)		
September	4.0 (1)	9.8 (4)	33.8 (5)	68.7* (3)		4.5 (2)	8.5 (2)
Average	51.8 (6)	32.8 (9)	30.8 (6)	68.7 (3)	23.5 (2)	4.5 (2)	8.5 (2)

Month	Number of illegal whitefish per lift at depth (in feet)						
	<41	41-60	61-70	71-80	81-90	91-100	101-110
May	56.0 (5)	65.8 (5)	11.0 (1)		183.0 (2)		
September	2.0 (1)	3.5 (4)	7.2 (5)	9.7* (3)		1.5 (2)	2.0 (2)
Average	47.0 (6)	38.1 (9)	7.8 (6)	9.7 (3)	183.0 (2)	1.5 (2)	2.0 (2)

NORTHEASTERN LAKE MICHIGAN (MANISTIQUE, EPOUFETTE, AND NAUBINWAY)

The data on the bathymetric distribution of the whitefish are more complete for northeastern Lake Michigan than for any other region. Not only was the number of lifts of pound nets and deep trap nets observed large (350) but these lifts were well distributed as to depth of water. Only the deep water (depths greater than 110 feet) was poorly represented, largely because few nets were set there owing to the comparative scarcity of whitefish.

Distribution of legal-sized whitefish.—Peak concentrations of legal whitefish in June occurred at 61–70 feet and 81–90 feet (table 28 and fig. 22). The average number of fish per lift in "deep water" (more than 110 feet) exceeded slightly the average in 101–110 feet but the deeper water was represented by only two lifts. There were again two peaks in July, but in this month they occurred in water 20 feet deeper (81–90 and 101–110 feet). This offshore movement was reflected also in the reduced catches of nets in all waters shallower than 71 feet. The depths of greatest concentration of legal whitefish were the same in August as in July although the small decrease in the average number of fish from nets set in 71–80 feet together with the increase in the catch per net from all deeper waters may be taken as an indication of possible further offshore movement. In September the average number of legal whitefish per lift was below the August average at all depths less than 91 feet. The single peak occurred in the 101–110 foot interval. (Nothing is known concerning the abundance of whitefish at depths greater than 110 feet in September.) The improved catches in the shallower water (less than 71 feet) in October offer evidence of a return onshore movement. In this same month the condition of two concentration zones reappeared although it was by no means pronounced.

The seasons' averages show a consistent increase in the number of legal fish per lift from shallow water (less than 41 feet) to the 81–90 foot interval, followed by a sharp decline at 91–100 feet and a rise to a second peak at 101–110 feet. The average of 7 lifts from the deepest water was about half that of lifts from the 101–110 foot interval.

Distribution of illegal-sized whitefish.—The data on the depth distribution of illegal whitefish resembled in general those for legal fish. Both groups were characterized by

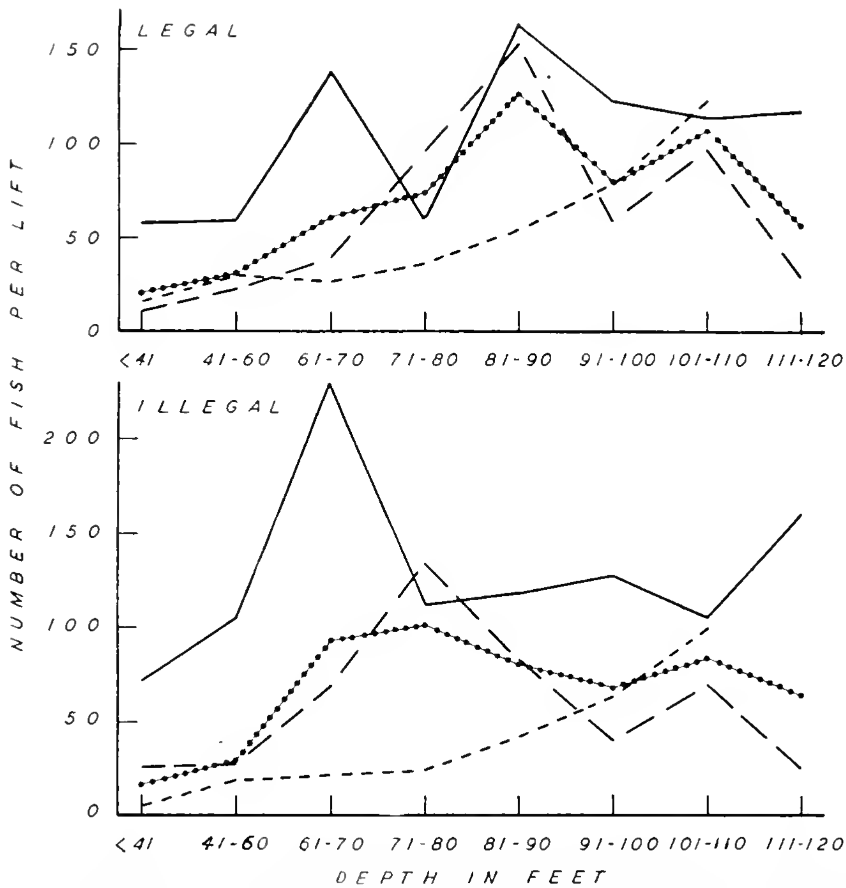


FIGURE 22.—Bathymetric distribution of legal- and illegal-sized whitefish in northeastern Lake Michigan as determined from the average numbers of fish per lift of pound nets and deep trap nets. June, solid line; July-August, long dashes; September-October, short dashes; entire season, dotted line.

two concentration zones in every month but September, and both showed an offshore movement of the fish during the summer. The two groups of data differed at times, however, as to the actual depths of the concentrations. A further difference lay in the lack of evidence of an onshore movement of illegal fish in October.

The June averages of the number of undersized whitefish per lift had peaks at 61–70 and 91–100 feet. With the illegal, as with the legal, fish the average for the deepest water (more than 110 feet) exceeded that for the 101–110 foot interval. The inshore concentration coincided with that of the legal fish, but the offshore concentration occurred 10 feet deeper. In July the movement toward deeper water increased the depth of each of the concentration zones of illegal whitefish by only 10 feet as compared with 20 feet for the legal fish. The depth intervals of the concentration zones remained unchanged in August although the decrease in the average number of fish per lift in all depths less than 91 feet points toward further offshore movement. The decrease in the number of illegal fish per lift at these depths continued in September. At the same time the number per lift increased in the 91–100 foot and 101–110 foot intervals. The September data had only one peak (at 101–110 feet) but there were again two concentration zones in October. The October averages for shallow-water lifts (depths less than 71 feet), contrary to the data for legal fish, showed no tendency to increase over those for September.

The seasons' averages indicated an increase in the number of illegal whitefish per lift from shallow water (less than 41 feet) to a peak at 71–80 feet, followed by a decline to 91–100 feet, a rise to a second peak at 101–110 feet, and yet another decrease in the

TABLE 28.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in northeastern Lake Michigan (ports of Manistique, Epoufette, and Naubinway), 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	<41	41–60	61–70	71–80	81–90	91–100	101–110	>110
	Number of legal whitefish per lift at depth (in feet)							
June	57.5 (8)	59.3 (3)	138.8* (4)	59.5 (8)	164.3* (23)	122.5 (11)	113.7 (7)	117.5 (2)
July	10.0 (7)	17.6 (5)	39.2 (5)	104.3 (11)	140.9* (17)	58.4 (5)	92.9* (13)	7.7 (3)
August	----------	44.0 (1)	----------	90.2 (16)	162.3* (22)	59.4 (15)	100.0* (15)	63.5 (2)
September	7.6 (20)	28.1 (9)	18.0 (3)	36.2 (13)	55.0 (14)	88.4 (17)	121.6* (8)	----------
October	23.1 (23)	31.5 (11)	35.7 (3)	----------	52.6* (13)	49.5 (6)	122.7* (7)	----------
Average	20.9 (58)	31.4 (29)	60.8 (15)	73.7 (48)	125.8* (89)	80.2 (54)	106.7* (50)	55.0 (7)
	Number of illegal whitefish per lift at depth (in feet)							
June	71.4 (8)	104.7 (3)	230.0* (4)	112.2 (8)	117.7 (23)	126.7* (11)	105.0 (7)	160.0 (2)
July	25.7 (7)	28.2 (5)	69.6 (5)	182.7* (11)	87.1 (17)	39.4 (5)	65.2* (13)	10.7 (3)
August	----------	24.0 (1)	----------	101.4* (16)	80.5 (22)	40.2 (15)	73.1* (15)	45.0 (2)
September	4.0 (20)	21.7 (9)	20.7 (3)	23.6 (13)	35.1 (14)	70.3 (17)	111.0* (8)	----------
October	5.5 (23)	15.9 (11)	22.7 (3)	----------	48.5* (13)	43.2 (6)	85.9* (7)	----------
Average	16.5 (58)	29.3 (29)	93.2 (15)	100.8* (48)	79.6 (89)	67.6 (54)	83.4* (50)	63.1 (7)

deepest water (more than 110 feet). The zones of concentrations of illegal fish (seasons' average) are separated by 30 feet (difference between average depths of the intervals) as compared with 20 feet in the legal fish. This same difference is to be found in the data for the three months—June, July, and August—but is lacking in October (relatively incomplete data, however).

In general, undersized whitefish tended to live in shallower water than did legal-sized individuals. This tendency is apparent not only from the lesser depth of the inshore concentration zone (71–80 feet for illegal fish and 81–90 feet for legal fish) but also from the large numbers of small whitefish per lift in the still shallower interval, 61–70 feet. Legal-sized fish were slightly the more numerous, however, at depths shallower than 61 feet.

The vertical movements of the whitefish in northeastern Lake Michigan are the reverse of those indicated by the Lake Huron data for the Alpena-Ossineke and Saginaw Bay areas (pp. 350 and 351). In each of these regions of Lake Huron the data indicated an onshore movement of both legal and undersized fish during the summer. Whitefish of both size groups made an offshore movement in northeastern Lake Michigan.

Possible significance of two concentration zones.—The occurrence of two concentration zones of both legal and illegal whitefish in northeastern Lake Michigan[32] raises the interesting question of the possible existence of distinct inshore and offshore populations or races. Certainly, the consistency of the occurrence and the seasonal move-

[32] There was some indication of a similar distribution of whitefish on the Alpena-Ossineke grounds (p. 350). The data for the Saginaw Bay area (p. 351) offered only a suggestion of two concentration zones.

ments of these two concentration zones are such as to label their existence as a real phenomenon, and not a chance result to be ascribed to inadequate data. However, the mere presence of two distinct groupings of whitefish throughout all or most of the season does not make absolutely necessary the assumption of two permanently separated stocks. It is possible that conditions within the lake at certain seasons may produce an "ecological division" of an otherwise homogeneous population.

Records of a number of vertical series of temperature readings made in northeastern Lake Michigan[33] failed to give a clue to the cause of two zones of concentration of whitefish. Both the inshore and offshore concentrations of legal fish were below the thermocline[34] in June, July, and August and hence were in a region with extremely small temperature gradients. Preferences for water of different temperature, therefore, do not provide a logical explanation for the presence of two concentrations. The illegal whitefish of the inshore concentration were in the region of the thermocline in July and August, hence in substantially warmer water than were the fish of the offshore concentration. However, both groups were below the thermocline in June, and an inshore concentration at the thermocline was lacking in September.

Important arguments in support of the assumption of the existence of inshore and deep-water populations of whitefish are:

(1) The separation into two groups involved both large (legal) and small (illegal) fish. Consequently, the two groups are not entirely the result of different reactions of fish of different size to the same or similar environmental factors. This statement holds even though the concentration zones of the legal and illegal fish were not always identical in the same month.

(2) The fish of both concentration areas have similar seasonal vertical movements. The similarity of vertical movements kept the two zones of concentration distinct in all months but September. The presence of only one peak in the September data may represent the temporary approximation of the two concentrations or may be the result of lack of information on the distribution of whitefish beyond the 110-foot contour.

(3) There is evidence that some whitefish seldom, if ever, spawn in shallow water. The introduction of the deep trap net on gill-net grounds or in areas beyond the reach of pound nets was marked by the capture of considerable numbers of whitefish of exceptionally large size. These large fish could not be taken on these same grounds by the gill nets commonly employed since their great size prevented their becoming gilled. Pound nets, which are selective only with respect to small fish, are fully capable of taking large individuals of any size. Consequently, their failure to capture many fish as large as those found in the early catches of the deep trap nets may be taken as evidence that these giant individuals were seldom, if ever, present on the inshore pound-net grounds, at least during the period of fishing operation.

It must be remembered, nevertheless, that there is no proof that the smaller mature fish of the offshore group of whitefish do not spawn in shallow water. The separation of the whitefish into two depth groups may represent only a summer and early-autumn condition. Possibly most of the small fish of both groups spawn in shallow water and most of the large fish of both groups spawn in deeper water. However, it also seems logical to hold that the giant fish taken in deep trap nets were members of a deep-water population (that lived beyond the reach of pound nets) that had survived to a size at which they could not be taken in gill nets, and hence had become exempt from capture in the commercial fishery.

Even if the inshore and offshore groups of whitefish are held to be semi-independent or independent, it must be recognized that both groups exhibit similar fluctuations in the fishery. The records of the catch per lift and of production in M-3 (table 17 and appendix B) demonstrate a close correlation between the annual fluctuations in the

[33] Temperature data were not available from the north channel (region north of the Beaver Island archipelago), the center of the deep-trap-net fishery. However, the relatively limited local variation in temperature conditions at stations southeast, south, and northwest of Beaver Island and southeast of Manistique suggests that the data from these localities may be indicative of conditions in the area in which the deep-trap-net fishery was centered.

[34] The average positions of the thermocline were: last half of June, 24-33 feet; July, 67-77 feet; August, 69-80 feet; first 10 days of September, 72-86 feet. The thermocline had not yet formed in the first half of June; no readings were made in the area after September 10.

abundance of whitefish on the pound-net (shallow-water) and gill-net (deep-water) grounds of the district and also between the production of whitefish by these two gears. A similar close resemblance between the statistical data for pound nets and gill nets is to be found in other districts.

It must be remembered also that any assumption of the existence of shallow-water and deep-water stocks of whitefish in northeastern Lake Michigan does not make a similar assumption valid for any other region. In districts H–3 and H–4 of Lake Huron, for example, the simultaneous collapse of the deep-trap-net and pound-net fisheries must be interpreted as strong evidence that both gears drew a large part of their production from the same stock. It is not known, even in northeastern Lake Michigan, to what extent there may be an interchange of individuals between the inshore and offshore groups of whitefish.

SUMMARY AND COMPARISON OF THE BATHYMETRIC DISTRIBUTION OF WHITEFISH IN LAKES HURON AND MICHIGAN, WITH SPECIAL REFERENCE TO THE REGULATION OF THE FISHERY

The present study of the bathymetric distribution of the whitefish was part of a program conducted to obtain reliable data upon which to base a sound regulation of the deep-trap-net fishery. One question was: "What regulation as to the depth of water in which deep trap nets should be fished will serve best the dual purpose of protecting

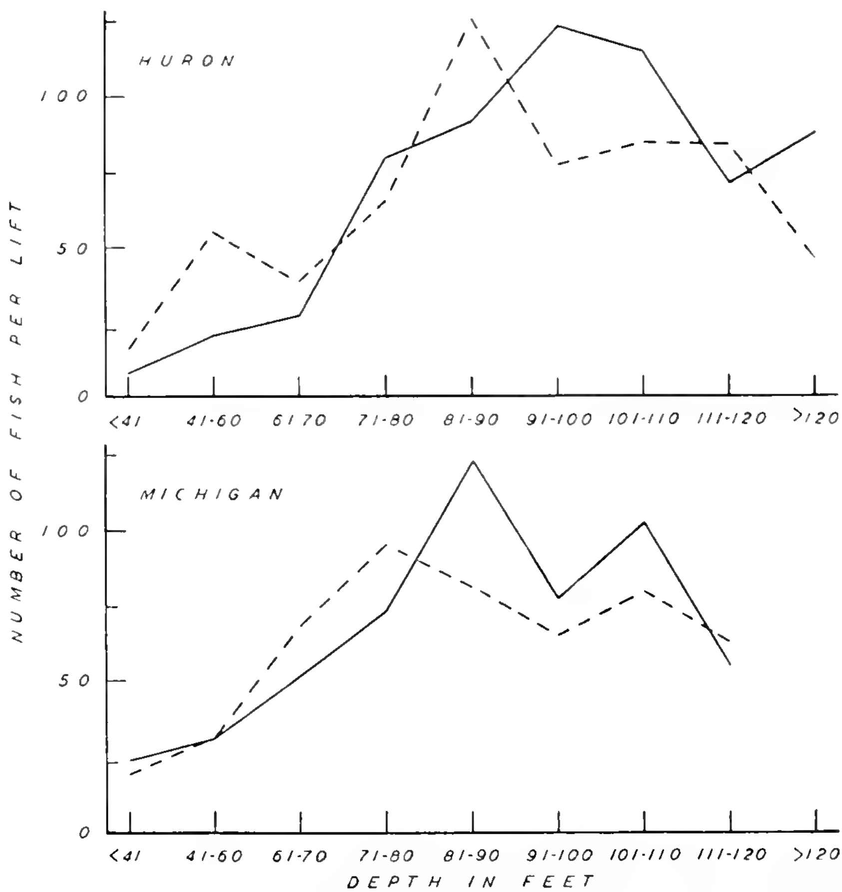


FIGURE 23.—Bathymetric distribution of legal-sized (solid lines) and illegal-sized (broken lines) whitefish in Lakes Huron and Michigan as determined from the combination of the data for all localities, years, and months in each lake.

young fish from capture and excessive handling, and of reducing production[35] to a level which does not threaten the extermination of the commercial stock?"

Ordinarily fishery legislation must be framed in conformity with average conditions during the entire season over a large part of a lake or an entire lake. Consequently, the most suitable data on the bathymetric distribution of whitefish in Lakes Huron and Michigan, as they pertain to fishery regulation, are those obtained by combining the available material for all grounds and all times in the fishing season in each of the two lakes. The data of table 29 (see also fig. 23) represent such combinations.

TABLE 29.—*Number of legal and illegal whitefish per lift of pound nets and deep trap nets in Lakes Huron and Michigan, 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Lake	Size group	Number of whitefish per lift at depth (in feet)								
		<41	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
Huron	Legal	7.3 (11)	20.5 (24)	26.9 (12)	79.2 (24)	91.6 (36)	123.1* (55)	114.7 (86)	70.2 (152)	87.5 (56)
	Illegal	15.9 (11)	54.9 (24)	38.2 (12)	65.3 (24)	125.8* (36)	76.9 (55)	84.2* (86)	83.7 (152)	45.7 (56)
Michigan	Legal	23.8 (64)	31.7 (38)	52.2 (21)	73.4 (51)	123.6* (91)	77.5 (56)	103.0* (52)	55.0 (7)	----------
	Illegal	19.4 (64)	31.5 (38)	68.8 (21)	95.4* (51)	81.8 (91)	65.2 (56)	80.2* (52)	63.1 (7)	----------

It should be pointed out, however, that recommendations based on the averages of table 29 which cover general conditions likewise cover very well the local conditions on the different grounds in the lake despite the variations in the bathymetric distribution of the legal and illegal whitefish in different localities.

In Lake Huron the average number of legal whitefish per lift increased continuously with increase in the depth of the water up to a maximum at 91–100 feet, decreased in the next two intervals, and increased slightly at more than 120 feet. The increase in the deepest water can be traced to the small number of lifts from this depth off Alpena, a region in which legal-sized whitefish were scarce. The limits of the general region of greatest abundance of legal fish may be set at approximately 81–110 feet. The number of undersized whitefish increased also from shallow to deeper water, but the maximum occurred at 81–90 feet, or 10 feet shallower than the depth of maximum abundance of legal fish. A second but lower peak in the number of illegal whitefish per lift was found at 101–110 feet. If legal fish are to be protected from excessive exploitation and illegal fish from frequent handling, the obvious depth limit beyond which impounding nets should not be fished in Lake Huron is 80 feet. Although this restriction curtails the production of deep trap nets severely, it cannot be considered extreme or oppressive, since a closely similar gear, the pound net, long supported a productive and prosperous fishery in even shallower water. (Few pound nets are fished in depths of more than 65 or 70 feet.)

The restriction of impounding nets in Lake Huron to depths of 80 feet or less does not mean the complete closure of the deeper waters to the commercial fishery for whitefish. These deeper areas are still open to the gill net, which was formerly the only gear fished in them. However, past experience has demonstrated that in these areas gill nets ordinarily did not catch whitefish in quantities dangerous to the stability of the stock. Furthermore, the selective action of the gill nets commonly employed precludes the capture of excessive numbers of small fish and also spares the large individuals that constitute the spawning reserve.

The Lake Michigan data differ from those of Lake Huron chiefly in the presence

[35] The present policy of fishery regulation in the State of Michigan waters of the Great Lakes does not include control of production through the limitation of the amount of gear fished or the setting of arbitrary limits on the season's catch.

of two distinct concentration zones for both legal and undersized fish and in showing a somewhat shallower habitat for the whitefish. The inshore concentrations, in both of which the numbers of fish per lift exceeded those of the offshore concentrations, were 10 feet shallower than the maxima for the corresponding size groups in Lake Huron. Consequently, the most suitable limit for the depth of water in which impounding nets should be operated in Lake Michigan is 70 feet, 10 feet shallower than in Lake Huron.

BATHYMETRIC DISTRIBUTION OF OTHER SPECIES

Other species were much less numerous in the catches of pound nets and deep trap nets than were whitefish. The data on the bathymetric distribution of these "miscellaneous" species, therefore, will not be given in the same detail as those on the distribution of whitefish.

LAKE TROUT

Nearly all of the lake trout (*Cristivomer namaycush*) were of legal size (minimum legal weight, 1½ pounds). As undersized lake trout were so few and because there was no evidence of important differences in the vertical distribution of legal and undersized fish, tables 30, 31, and 32 have been prepared from the records of all trout taken, regardless of size.

Lake Huron.—In the Alpena-Ossineke area (table 30) lake trout were numerous in May (31.0 to 39.8 fish per lift) at depths greater than 100 feet, but only one trout was taken in the lift from 81–90 feet. In June lake trout were fairly numerous in the shallower water (41–70 feet) while the average catch per lift declined (in comparison with the averages for May) in depths greater than 100 feet. The records for four lifts from depths between 40 and 71 feet in July and August suggest that most lake trout had abandoned the shallower water in these two months. Possibly this offshore movement accounts for the increase over the catch for the month of June in the average number of trout per lift from 81–120 feet. The average lifts in August were consistently below those of July from depths of 71–120 feet, and the September catches were smaller than those of August from the 101–120 foot interval. These decreases possibly may represent a movement of the lake trout to depths greater than those in which deep trap nets were operated.

TABLE 30.—*Number of lake trout per lift of pound nets and deep trap nets in the Alpena-Ossineke area, 1931–1932*

[Number of lifts in parentheses]

Month	Number of lake trout per lift at depth (in feet)							
	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May	....	....	....	1.0 (1)	....	31.0 (1)	37.4 (23)	39.8 (4)
June	21.3 (4)	40.0 (1)	....	12.0 (1)	8.0 (1)	16.9 (6)	11.8 (18)	18.8 (5)
July	0.0 (1)	....	56.0 (1)	40.2 (5)	35.5 (12)	26.2 (7)	50.0 (23)	....
August	5.0 (2)	1.0 (1)	7.9 (7)	19.7 (9)	25.5 (3)	22.4 (5)	26.7 (10)	....
September	....	....	....	....	....	6.6 (5)	15.5 (2)	....
Average	13.6 (7)	20.5 (2)	13.9 (8)	24.5 (16)	31.9 (16)	19.2 (24)	33.2 (76)	28.1 (9)

The seasons' averages indicate an irregular trend toward an increase in the abundance of lake trout with increase in the depth of the water. The decline in numbers in depths of 101–110 feet may be real since similar decreases occurred in the catch for July and August. The decline in depths greater than 120 feet may be the result of the lack of data for months later than June.

It should be emphasized that, in contrast to the whitefish data, those presented for the lake trout on the Alpena-Ossineke grounds and in other areas should not be taken as descriptive of the general distribution of trout in Lake Huron and northern Lake Michigan. The chief summer fishery for trout is conducted by gill nets at depths considerably greater than those from which the pound nets and deep trap nets were lifted. The data given here describe only the distribution of the presumably sparse inshore population of trout.

Lake trout were considerably less abundant in the Saginaw Bay area (table 31) than off Alpena and Ossineke. In four of the six months (all but July and September) the largest lifts were made from the deepest water (more than 120 feet). Trout were scarce in shallow water (less than 61 feet) in June and were not taken at all in July and August. The data fail to indicate whether the improved catches beyond 90 feet in July and August were the result of an offshore movement of an inshore group of trout or of an onshore movement of an offshore group. The averages for September and possibly October are suggestive of a migration toward deeper water.

TABLE 31.—*Number of lake trout per lift of pound nets and deep trap nets in the Saginaw Bay area (ports of Au Sable-Oscoda, East Tawas, and Bay Port), 1931–1932*

[Number of lifts in parentheses]

Month	Number of lake trout per lift at depth (in feet)								
	<41	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May	----	----	----	----	----	1.0 (1)	2.7 (7)	3.5 (6)	3.8 (5)
June	0.0 (5)	2.2 (9)	----	----	----	0.0 (1)	2.4 (14)	1.8 (22)	5.0 (11)
July	0.0 (6)	0.0 (1)	----	----	5.5 (2)	7.0 (11)	10.4 (7)	5.9 (15)	5.0 (6)
August	----	0.0 (5)	0.3 (3)	1.7 (4)	2.5 (12)	7.6 (12)	14.6 (15)	7.7 (15)	18.4 (10)
September	----	----	----	0.5 (2)	1.0 (1)	3.0 (2)	3.0 (2)	23.2 (4)	2.5 (2)
October	----	----	----	----	----	----	----	4.5 (2)	17.3 (3)
Average	0.0 (11)	1.3 (15)	0.3 (3)	1.3 (6)	2.8 (15)	6.5 (27)	7.8 (45)	5.7 (64)	9.3 (37)

The seasons' averages show a general tendency for the number of lake trout per lift to increase with increase in the depth of water.

Tabular data are not given on the bathymetric distribution of lake trout in northern Lake Huron (Cheboygan and Rogers City area) and on the Harbor Beach grounds. (For the number of lifts at the various depths of water at these localities see tables 23 and 26.) The average number of trout per lift in northern Lake Huron varied widely (from 1.5 to 76.5 fish) with the best catch in 81–90 feet in August. Lake trout were fairly scarce on the Harbor Beach grounds. The best catches were: 20.3 fish per lift from 111–120 feet in August; 19.8 fish from depths greater than 120 feet in August; and 15.5 fish from 111–120 feet in September. Catches of lake trout were uniformly small in water shallower than 101 feet. In October only three trout were taken in a total of nine lifts, all from depths greater than 90 feet; apparently the lake trout had migrated from the Harbor Beach deep-trap-net grounds in that month.

Lake Michigan.—The rather extensive data from northeastern Lake Michigan (table 32) suggest that in certain months the lake trout as well as the whitefish may occur in two concentration zones. (See p. 353, table 28, and fig. 22.) In June and

July inshore concentrations occurred at 61–70 feet and offshore peaks at more than 110 feet. The offshore concentration in August was still in deep water but the inshore maximum was at 81–90 feet or 20 feet deeper than in June and July. (The August data were inadequate, however, for depths of less than 71 feet.) The data for September and October yield no evidence of two concentration zones of lake trout in these two months. Data were lacking, however, for depths beyond 110 feet.

TABLE 32.—*Number of lake trout per lift of pound nets and deep trap nets in northeastern Lake Michigan (ports of Manistique, Epoufette, and Naubinway), 1931–1932*

[Number of lifts in parentheses. Asterisks indicate concentrations]

Month	Number of lake trout per lift at depth (in feet)							
	<41	41–60	61–70	71–80	81–90	91–100	101–110	>110
June	3.5 (8)	6.3 (3)	14.5* (4)	10.5 (8)	1.7 (23)	3.1 (11)	2.6 (7)	5.0* (2)
July	0.0 (7)	3.6 (5)	17.4* (5)	10.0 (11)	6.3 (17)	3.4 (5)	4.1 (13)	17.0* (3)
August		0.0 (1)		4.2 (16)	5.2* (22)	2.9 (15)	2.1 (15)	22.5* (2)
September	0.5 (20)	0.0 (9)	0.0 (3)	3.1 (13)	3.6* (14)	1.6 (17)	1.6 (8)	
October	0.3 (23)	0.2 (11)	1.3 (3)		1.6 (13)	2.2 (6)	5.6* (7)	
Average	0.8 (58)	1.3 (29)	9.9* (15)	6.3 (48)	3.7 (89)	2.5 (54)	3.1 (50)	15.1* (7)

There was no general agreement as to the actual location of the concentration zones of lake trout and whitefish. It is true that lake trout, large (legal) whitefish, and small (illegal) whitefish (table 28) were all concentrated at 61–70 feet in June and that both trout and legal whitefish exhibited peaks at 81–90 feet in August. On the other hand, the inshore concentration of lake trout was shallower in July than the concentration of either the legal or illegal whitefish, and the offshore concentrations of lake trout in June, July, and August were without exception deeper than the concentrations of whitefish. In October, however, a peak was evident at 101–110 feet in both lake trout and the whitefish (large and small).

Possibly it is not strictly proper to term as "concentrations" the increased abundance of lake trout at depths in excess of 110 feet, for these increases in the number per lift may be merely part of a general trend for trout to become more plentiful with increase in depth of water and not, as the term concentration implies, be indicative of a peak abundance bordered on either side by a lesser abundance.

The data of table 32 as a whole point toward an offshore movement of lake trout in northeastern Lake Michigan from June to October. (A few trout appear, however, to have returned to shallow water in October.) The seasons' averages show an increase in the catch per lift from shallow water (less than 41 feet) to a peak at 61–70 feet, followed in turn by a decline through the depth interval, 71–100 feet, and a secondary rise beyond 100 feet.

In the Green Bay region of Lake Michigan the best catches of lake trout were made in 41–60 feet in May (19.8 fish per lift). The September catches varied but little with depth of water, averaging 6.8 fish for 13 lifts in 41–80 feet and 5.0 for 4 lifts in 91–110 feet.

YELLOW PIKE

Yellow pike (*Stizostedion vitreum*) occurred in large numbers in the lifts of pound nets and deep trap nets only in the Saginaw Bay region (table 33). Because of the concentration of yellow pike in the shallower water of the area it was considered desirable in the preparation of the table to employ a greater number of intervals at depths less than 61 feet than was necessary in the tabulation of the data for the whitefish and the lake trout.

No data are available on the abundance of yellow pike in shallow water in May, but in June legal-sized fish (1½ pounds or larger) were plentiful in the lifts from 31–60 feet. In both May and June legal-sized yellow pike were totally lacking in all lifts from depths greater than 90 feet. The catch per lift in shallow water (less than 61 feet) declined in July and August. At the same time legal yellow pike penetrated to the greatest depths from which deep trap nets were lifted. The abundance at depths of more than 80 feet was generally higher in August than in July. Legal yellow pike were still present in the deeper water in September and October. The distribution in September was irregular. An average of 17.0 fish per lift was obtained at 111–120 feet, while yellow pike either were scarce or lacking in the lifts from other depths.

Undersized yellow pike as well as legal fish were abundant in 31–60 feet in June (with the greatest abundance in 31–40 feet) and absent from depths beyond 90 feet in both May and June. Illegal yellow pike had penetrated to a depth of 101–110 feet in July and 111–120 feet in August and September. None were taken in any month from water deeper than 120 feet.

Not only did illegal yellow pike fail to range as deep in summer as did fish of legal size, but apparently a smaller percentage of them left the shallow water. In

TABLE 33.—*Number of yellow pike per lift of pound nets and deep trap nets in the Saginaw Bay area (ports of Au Sable-Oscoda, East Tawas, and Bay Port), 1931–1932*

[Number of lifts in parentheses]

Month	<31	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
	Number of legal yellow pike per lift at depth (in feet)										
May	...	...	...	...	...	...	...	0.0 (1)	0.0 (7)	0.0 (6)	0.0 (5)
June	...	82.6 (5)	43.7 (6)	27.0 (3)	...	...	...	0.0 (1)	0.0 (14)	0.0 (22)	0.0 (11)
July	0.3 (3)	2.0 (3)	...	24.0 (1)	...	...	0.5 (2)	0.5 (11)	1.9 (7)	1.9 (15)	0.7 (6)
August	...	...	1.0 (1)	9.2 (4)	2.5 (3)	4.5 (4)	9.7 (12)	5.8 (12)	6.4 (15)	1.7 (15)	0.4 (10)
September	...	...	...	...	...	2.5 (2)	0.0 (1)	0.0 (2)	0.0 (2)	17.0 (4)	1.0 (2)
October	...	...	...	...	...	...	...	...	...	1.5 (2)	0.0 (3)
Average	0.3 (3)	52.4 (8)	37.6 (7)	17.7 (8)	2.5 (3)	3.8 (6)	7.8 (15)	2.8 (27)	2.0 (45)	1.9 (64)	0.3 (37)
	Number of illegal yellow pike per lift at depth (in feet)										
May	...	...	...	...	...	...	...	0.0 (1)	0.0 (7)	0.0 (6)	0.0 (5)
June	...	412.8 (5)	163.0 (6)	63.7 (3)	...	...	...	0.0 (1)	0.0 (14)	0.0 (22)	0.0 (11)
July	56.0 (3)	87.7 (3)	...	159.0 (1)	...	...	0.0 (2)	0.4 (11)	0.1 (7)	0.0 (15)	0.0 (6)
August	...	...	81.0 (1)	218.0 (4)	119.5 (3)	5.0 (4)	10.0 (12)	4.7 (12)	9.5 (15)	1.9 (15)	0.0 (10)
September	...	...	...	...	...	5.0 (2)	0.0 (1)	0.5 (2)	0.5 (2)	9.3 (4)	0.0 (2)
October	...	...	...	...	...	...	...	...	...	0.0 (2)	0.0 (3)
Average	56.0 (3)	290.9 (8)	151.3 (7)	152.8 (8)	119.5 (3)	5.0 (6)	8.0 (15)	2.3 (27)	3.2 (45)	1.0 (64)	0.0 (37)

the shallow-water lifts (less than 71 feet) the average numbers of illegal yellow pike per lift were consistently several times as great as the numbers of legal fish. Especially noteworthy were the large catches of undersized fish at these depths in July and August, months in which legal fish were scarce in shallow water. At the greater depths, however, the numbers of legal and illegal yellow pike per lift differed only slightly and in a random manner.

A total of seven yellow pike (all of legal size) was taken in northern Lake Huron (Cheboygan and Rogers City area). One of these fish was caught in 71–80 feet in July and the remaining six in 41–70 feet in September.

Yellow pike were scarce at all depths on the Alpena-Ossineke grounds, but were more numerous at depths less than 70 feet than at greater depths. No yellow pike were taken in water deeper than 90 feet before July. A few individuals (both legal and illegal) penetrated to depths of at least 111–120 feet in July and August. (No nets were lifted beyond 120 feet in these months and in September—see table 24.) In September a total of three legal fish but no illegal fish was taken from depths of 101–120 feet.

The single lift from shallow water (41–60 feet) off Harbor Beach contained eight legal and three illegal yellow pike. The maximum depths at which legal fish were taken were 111–120 feet in August and more than 120 feet in September and October. No illegal yellow pike were captured in August, but in September and October fish of this group penetrated to depths in excess of 120 feet.

Not one yellow pike was taken in the lifts of pound nets and deep trap nets in northeastern Lake Michigan. In May a total of five fish (all legal) was captured in the 10 lifts in the Green Bay area from depths of less than 61 feet and 28 yellow pike (10 legal and 18 illegal) were taken in the two lifts from 81–90 feet. No yellow pike were caught in the Green Bay area in September.

BURBOT

Because of the small total number captured and the sporadic occurrence of burbot (*Lota maculosa*) in the catches, a combination of the data for all localities appears to provide the most valid description of the inshore bathymetric distribution of the species in Lake Huron (table 34). This table cannot serve as the basis for a detailed discussion; attention will be called, however, to certain general trends. Burbot were scarce or lacking at all depths from which nets were lifted in both May and June. In June they occurred in both shallow water (less than 71 feet) and deep water (more than 100

TABLE 34.—*Number of burbot per lift of pound nets and deep trap nets in Lake Huron, 1931–1932 (data for all localities combined)*

[Number of lifts in parentheses]

Month	Number of burbot per lift at depth (in feet)								
	<41	41–60	61–70	71–80	81–90	91–100	101–110	111–120	>120
May	-----	-----	-----	-----	0.0 (1)	0.0 (1)	0.2 (8)	0.5 (29)	0.2 (9)
June	0.2 (5)	0.2 (13)	1.0 (1)	-----	0.0 (1)	0.0 (2)	0.3 (20)	0.6 (40)	0.8 (16)
July	0.0 (6)	0.0 (2)	0.0 (2)	0.6 (5)	2.3 (7)	3.1 (23)	0.6 (14)	0.8 (38)	0.3 (6)
August	-----	0.0 (7)	0.0 (4)	2.0 (13)	1.9 (23)	2.0 (17)	1.5 (22)	0.9 (29)	1.2 (15)
September	-----	0.0 (2)	0.8 (5)	2.6 (6)	1.2 (4)	1.3 (10)	2.2 (19)	3.2 (12)	2.8 (5)
October	-----	-----	-----	-----	-----	0.0 (2)	2.5 (3)	3.8 (4)	2.8 (5)
Average	0.1 (11)	0.1 (24)	0.4 (12)	1.9 (24)	1.8 (36)	2.1 (55)	1.1 (86)	1.0 (152)	1.1 (56)

feet). Burbot were absent from shallow water in July and August, and appeared to be concentrated at intermediate depths (81–100 feet in July and 71–110 feet in August). In September and October they apparently were concentrated in depths beyond 100 feet. The changes in the average number of fish per net at the various depths for the months, July-October, suggest a general tendency for the burbot to move toward deeper water. The regular increase from July to September in the catch from 71–80 feet provides an exception to this general trend. The seasons' averages show a scarcity of burbot at depths of less than 71 feet and the greatest abundance at intermediate depths (71–100 feet), with the abundance in deep water (more than 100 feet) about half that at intermediate depths.

TABLE 35.—*Number of burbot per lift of pound nets and deep trap nets in northeastern Lake Michigan (ports of Manistique, Epoufette, and Naubinway), 1931–1932*

[Number of lifts in parentheses]

Month	Number of burbot per lift at depth (in feet)							
	<41	41–60	61–70	71–80	81–90	91–100	101–110	>110
June	0.1 (8)	0.3 (3)	4.0 (4)	3.1 (8)	2.2 (23)	2.4 (11)	1.7 (7)	3.0 (2)
July	0.0 (7)	3.2 (5)	3.0 (5)	1.6 (11)	1.9 (17)	0.8 (5)	5.4 (13)	1.3 (3)
August	-----	0.0 (1)	-----	3.6 (16)	2.0 (22)	1.3 (15)	1.6 (15)	10.0 (2)
September	0.1 (20)	1.0 (9)	4.7 (3)	2.2 (13)	3.7 (14)	2.0 (17)	2.8 (8)	-----
October	1.8 (23)	4.6 (11)	10.7 (3)	-----	8.6 (13)	2.3 (6)	5.4 (7)	-----
Average	0.8 (58)	2.6 (29)	5.1 (15)	2.7 (48)	3.3 (89)	1.8 (54)	2.1 (50)	4.3 (7)

The data on the bathymetric distribution of the burbot in northeastern Lake Michigan (table 35) provide little evidence of any extensive vertical movements. Characteristic of the averages for each month appeared to be an inshore concentration at 41–60 or 61–70 feet (except in August when only one lift was observed from a depth of less than 70 feet), a reduced abundance at intermediate depths up to 101 feet (111 feet in June), and a second concentration at 101–110 feet or more than 110 feet. The average catches in October were greater than those in other months from every depth but 91–100 feet. (The average catch from 101–110 feet was the same in July and October.) The seasons' averages show an increase in the number of burbot from 0.8 in shallow water (less than 41 feet) to a maximum of 5.1 fish per lift at 61–70 feet. The average catch per net varied between 1.8 and 3.3 fish in depths of 71–110 feet and rose to 4.3 in water more than 110 feet.

WHITE SUCKER AND LONG-NOSED OR STURGEON SUCKER

Separate counts of white suckers (*Catostomus commersonnii*) and long-nosed or sturgeon suckers (*C. catostomus*) were obtained for only a limited number of lifts in the Alpena-Ossineke and Saginaw Bay areas of Lake Huron. The available data indicate that white suckers were most numerous in depths of less than 81 feet; only one individual was captured in deeper water (in 101–110 feet). Long-nosed suckers also were most plentiful inside the 81-foot contour, but were taken in fair numbers at greater depths. No long-nosed suckers were captured in depths beyond 110 feet.

PART IV

OBSERVATIONS ON THE FISHING ACTION OF POUND NETS AND DEEP TRAP NETS

EFFECT OF THE SIZE OF THE MESH ON THE CATCH OF LEGAL- AND ILLEGAL-SIZED WHITEFISH AND LAKE TROUT

The question of the proper legal minimum size of mesh is a highly controversial one that involves nearly all commercial fishing gears. Certainly the most desirable size of mesh is that which releases the greatest number of illegal-sized and immature fish without serious loss of legal-sized fish. However, a great diversity of opinion exists as to what this "desirable" size of mesh may be. Although there are a few exceptions, commercial fishermen usually oppose most vigorously any attempt to increase the legal minimum mesh size, and in practice generally fish the smallest mesh permitted by law.

The lack of proper legal regulations and enforcement in the early years of the deep-trap-net fishery led to a wide range of mesh size in this gear. Many of the early deep trap nets had meshes that were ridiculously small (as small as 2¼ inches, stretched measure as fished) for a gear designed to take a species with a 2-pound legal-size limit. Continued experience, however, led many deep-trap-net fishermen to increase the size of mesh in their nets. This increase in mesh size not only reduced the labor of sorting out the illegal fish and returning them to the lake, but also improved the catch of legal fish as will now be shown.

The data in tables 36 and 37 on mesh selectivity in pound nets and deep trap nets are based on comparison of the numbers of legal- and illegal-sized whitefish (2-pound size limit) taken in nets with meshes less than 4 inches (stretched measure as fished) and in nets with meshes of 4 inches and more. For convenience in the discussion, the two groups of nets will be termed "small-mesh" and "large-mesh" nets.[36]

Table 36 lists the total numbers of legal and illegal fish, the average numbers per lift, and the percentages of fish of both size groups in all lifts of large-mesh and small-mesh pound nets and deep trap nets observed in the course of the investigation. On the average, small-mesh nets took more fish per lift, both legal and illegal, than did large-mesh nets. The percentage of legal fish in the lift was higher (58.7 as compared with 51.3) in large-mesh nets.

TABLE 36.—*Comparison of total numbers, averages per lift, and percentages of legal and illegal whitefish taken in small-mesh and large-mesh pound nets and deep trap nets*

[The 1931-1932 data have been combined for all ports, all depths, and all months. Numbers of lifts in parentheses]

Item	Whitefish taken in mesh: Less than 4 inches, Legal	Less than 4 inches, Illegal	4 inches and more, Legal	4 inches and more, Illegal
Total number of whitefish taken	48,939	46,441	18,231	12,820
	(598)		(238)	
Average number of whitefish per lift	81.8	77.7	76.6	53.9
Corrected for equal commercial yields	81.8	77.7	81.8	57.6
Percentage legal and illegal	51.3	48.7	58.7	41.3

The unequal numbers of fish in the lifts of large-mesh and small-mesh nets make a comparison of their selective action difficult. A better comparison is made possible by the determination of the numbers of illegal fish that must be handled in nets of

[36] In the original compilations the nets were grouped according to mesh size by half-inch intervals. This grouping proved unsatisfactory, however, since nets that fell within some intervals of mesh size were fished chiefly on grounds with an abundance of undersized whitefish whereas the nets of other mesh sizes were fished predominantly on grounds where young whitefish were extremely scarce. In order to reduce irregularities from this source, only two size groups of mesh were employed in the preparation of data on the release of illegal-sized whitefish.

each mesh size when the commercial yields are equal. This determination (third row in body of table) shows that large-mesh nets that take an average of 81.8 legal fish may be expected to contain an average of 57.6 illegal individuals as compared with 77.7 undersized whitefish in small-mesh nets with equal commercial lifts.

From the averages of 77.7 and 57.6 illegal whitefish per lift it may be estimated that large-mesh nets released $100 \times \frac{77.7 - 57.6}{77.7}$ or 25.9 percent of the undersized individuals. For every 100 illegal whitefish taken in small-mesh nets, 74.1 should be taken by large-mesh nets with the same commercial catch.

The data of table 36 and the computations based upon them are open to the very serious objection that the actual numbers and the percentages of legal and illegal fish taken in nets of any size of mesh vary according to the nature of the stock at the place and time the nets are fished. Truly discriminating data on selectivity must be founded on the lifts of nets that are identical except for the size of mesh and that are fished under strictly comparable conditions, that is, on the same grounds, at the same depth, in the same year, and at the same time within the season.

Table 37 contains comparisons of the catch of large-mesh and small-mesh pound nets and deep trap nets, based on lifts made in the same year (1932), in the same month, on the same grounds, and at the same depth. The data are confined to comparisons in which nets of both sizes of mesh are represented by at least 5 lifts. The necessary restrictions reduced the number of possible comparisons. However, the averages of the 10 independent sets of observations are reasonably reliable.

TABLE 37.—*Comparison of the numbers of legal and illegal whitefish per lift in small-mesh and large-mesh pound nets and deep trap nets fished in the same year (1932) and month, on the same grounds, and at comparable depths*

[Number of lifts in parentheses]

Fishing grounds	Month	Depth (feet)	Number of whitefish per lift in nets of mesh size: Less than 4 inches, Legal	Less than 4 inches, (lifts)	Less than 4 inches, Illegal	4 inches and more, Legal	4 inches and more, (lifts)	4 inches and more, Illegal	Percentage legal in nets of mesh size: Less than 4 inches	4 inches and more
Northeastern Lake Michigan	October	<61	16.8	(6)	4.8	22.3	(22)	2.9	77.8	88.5
	August	71–80	62.8	(11)	80.1	150.4	(5)	148.2	43.9	50.4
	June	81–90	176.0	(15)	150.1	142.5	(8)	57.1	54.0	71.4
	July	81–90	158.6	(10)	97.5	130.7	(6)	78.8	61.9	62.4
	August	81–90	121.9	(14)	64.8	233.0	(8)	108.1	65.3	68.3
	August	91–100	39.4	(8)	25.1	82.3	(7)	57.4	61.1	58.9
	September	91–100	81.5	(6)	79.3	76.8	(8)	44.0	50.7	63.6
Alpena-Ossineke	May	>110	41.2	(20)	288.1	24.9	(7)	154.0	12.5	13.9
	June	>110	14.2	(18)	73.2	6.0	(5)	30.6	19.0	16.4
	July	>110	26.5	(14)	54.3	49.5	(8)	97.9	32.8	33.6
Average			74.2		91.7	91.8		77.9	44.7	54.1
Corrected for equal commercial yields			91.8		113.4	91.8		77.9		

The averages of the 10 comparisons show that the large-mesh pound nets and deep trap nets took more legal whitefish and fewer illegal fish than the small-mesh nets fished under comparable conditions. In round numbers, small-mesh nets took an average of 92 undersized individuals in producing 74 fish of marketable size, whereas large-mesh nets took only 78 illegal whitefish for a commercial production of 92 fish. The correction for equal commercial production shows that small-mesh pound nets and deep trap nets with a commercial catch equal to that of large-mesh nets (92 fish) may be expected to capture 113 illegal whitefish to only 78 in large-mesh nets. The release of undersized fish by large-mesh nets is, therefore, $100 \times \frac{113.4 - 77.9}{113.4}$ or 31.3 percent. This percentage of release is more reliable than the release of 25.9 percent computed from the average catches of the two groups of nets without consideration of the effects of locality, depth, and time.

That the undersized whitefish, as well as the lake trout commonly taken with them, do escape from the pots of impounding nets with the larger meshes is further suggested by the progressive increase in the average sizes of these fish with each increase in the size of mesh (table 38).

The controversy concerning the proper size of mesh in the pots of impounding nets does not, however, revolve so much around the release of undersized fish as around the escape of legal-sized fish, both whitefish and lake trout. It is not believed that any legal-sized whitefish can go through meshes smaller than 4½ inches as found in use (the minimum size required by Michigan's law), but it is most probable that some legal-sized lake trout escape as is suggested by the larger average size of these fish in the bigger-meshed nets (table 38).

Table 38.—*Average size of whitefish and lake trout taken from Lakes Huron and Michigan in 1931 and 1932 in impounding nets with different sizes of mesh in the pot*

[Sizes of mesh represent stretched measurements as found in use. Numbers of fish employed are shown in parentheses]

Size of mesh (inches) in impounding nets	Undersized whitefish (less than 2 pounds)		Lake trout: Undersized (less than 1½ pounds)	Lake trout: Legal-sized	
	Average total length (inches)	Average weight (lbs. and oz.)	Average weight (lbs. and oz.)	Average total length (inches)	Average weight (lbs. and oz.)
<3			1-4.6 (3)	18.4 (10)	2-7.2 (45)
3-3 7/16	14.1 (54)	0-13.1 (54)		21.6 (49)	2-11.4 (90)
3 1/2-3 15/16	17.6 (123)	1-9.6 (123)	1-5.2 (18)	22.1 (189)	2-11.2 (395)
4-4 7/16	17.8 (36)	1-10.2 (36)	1-5.4 (4)	23.5 (20)	2-14.9 (203)
4 1/2-4 15/16					3-8.6 (7)

Additional information on this question of escapement is provided by the length and weight frequencies of the whitefish and lake trout gilled in the different sizes of mesh (tables 39, 40, 41, and 42). Table 39 shows that all of the whitefish gilled in meshes smaller than 3 inches were undersized. Presumably, then, no legal-sized whitefish can escape through these meshes. It was not until a mesh of 3½ to 3 15/16 inches (about 4 to 4 7/16 inches as manufactured) was used that legal-sized whitefish were gilled in any numbers, although 91 percent of the gilled fish were still below the 2-pound legal limit. Even the largest meshes for which data are adequate (4 to 4 7/16 inches) did not permit many of the smaller fish to escape as 79 percent of the gilled individuals in these meshes were undersized, and the average weight of all fish was noticeably less than 2 pounds (1 pound, 11 ounces).

It is of interest to note from the frequencies that the bulk of the gilled whitefish varied from 1 to 2 pounds in weight in meshes of 3 to 3 15/16 inches and from 1 to 2¼ pounds in the larger meshes—a range of only 1 or 1¼ pounds. The corresponding range in length of these fish (table 40) was 3½ inches (15 – 18½; 15½ – 19; 16 – 19½ inches).

The progressive increase in the average weight of the undersized gilled whitefish, as well as in the average length (table 40), with each increase in the size of mesh indicates that some of the smallest individuals escaped. The average weight of the legal-sized, gilled whitefish, however, did not increase progressively with an increase in mesh size (the average length showed a slight increase), thus suggesting that virtually no whitefish of 2 pounds or larger passed through any of the meshes for which there were adequate data.

TABLE 39.—*Weight frequencies and average weights of whitefish gilled in the pots of impounding nets of Lakes Huron and Michigan, 1931–1932*

[The weight intervals apply to fish with weights up to but not including the upper limit. Undersized fish were separated on the basis of a 2-pound limit]

Weight interval (pounds)	Sizes of stretched mesh (inches) as found in use					Total number
	<3	3–3 7/16	3 1/2–3 15/16	4–4 7/16	4 1/2–4 15/16	
1/4 to 1/2	2	1	1			4
1/2 to 3/4	7	7	4			18
3/4 to 1	2	5	9	6		22
1 to 1 1/4	3	24	75	29		131
1 1/4 to 1 1/2	1	23	118	45		187
1 1/2 to 1 3/4		27	114	50		191
1 3/4 to 2	2	16	63	35		116
2 to 2 1/4		2	20	24		46
2 1/4 to 2 1/2		1	14	10	1	26
2 1/2 to 2 3/4		1	3	4		8
2 3/4 to 3				4		4
3 to 3 1/4			1	2		3
5 to 5 1/4				1		1
Total	17	107	422	210	1	757
Number of undersized fish	17	103	384	165	0	669
Number of legal-sized fish	0	4	38	45	1	88
Percentage of undersized fish	100 0	96 3	91 0	78 6	0 0	88 4
Average weight of all fish	0–14 4	1–6 1	1–8 0	1–11 0	2–4 0	1–8 4
Average weight of undersized fish	0–14 4	1–5 5	1–6 9	1–7 7		1–6 6
Average weight of legal-sized fish		2–5 1	2–3 8	2–5 6	2–4 0	2–4 8

TABLE 40.—*Length frequencies and average lengths of whitefish gilled in the pots of impounding nets of Lakes Huron and Michigan, 1931–1932*

[The total-length intervals apply to fish with lengths up to but not including the upper limit. The average lengths of legal-sized and undersized fish were based only on those individuals for which records of weight also were available (number of specimens in parentheses). Undersized fish were separated on the basis of a 2-pound limit, not on length]

Total length interval (inches)	Sizes of stretched mesh (inches) as found in use					Total number
	<3	3–3 7/16	3 1/2–3 15/16	4–4 7/16	4 1/2–4 15/16	
11 1/2 to 12	1		1			2
12 to 12 1/2		1				1
12 1/2 to 13	2					2
13 to 13 1/2	5	1	4			10
13 1/2 to 14		6	1	1		8
14 to 14 1/2	1	2	2	2		7
14 1/2 to 15	1	5	3	5		14
15 to 15 1/2	1	12	13	6		32
15 1/2 to 16		12	45	9		66
16 to 16 1/2	2	14	58	19		93
16 1/2 to 17	2	10	65	25		102
17 to 17 1/2	1	12	86	32		131
17 1/2 to 18		14	53	20		87
18 to 18 1/2	2	15	40	27		84
18 1/2 to 19		6	22	27		55
19 to 19 1/2		5	15	18	1	39
19 1/2 to 20			7	5		12
20 to 20 1/2			6	9		15
20 1/2 to 21			1	3		4
21 to 21 1/2			1	2		3
24 to 24 1/2				1		1
Total	18	115	423	211	1	768
Average total length (inches) of all fish	14 7	16 5	17 0	17 6	19 2	17 0
Average total length (inches) of undersized fish	14 5 (17)	16 5 (103)	16 7 (356)	17 0 (160)		16 7 (636)
Average total length (inches) of legal-sized fish		18 9 (4)	19 1 (36)	19 4 (43)	19 2 (1)	19 2 (84)

TABLE 41.—*Weight frequencies and average weights of lake trout gilled in the pots of impounding nets of Lakes Huron and Michigan, 1931–1932*

[The weight intervals apply to fish with weights up to but not including the upper limit. Undersized fish were separated on the basis of a 1 1/2-pound limit]

Weight interval (pounds)	Sizes of stretched mesh (inches) as found in use				Total number
	<3	3-3 7/16	3 1/2-3 15/16	4-4 7/16	
1 to 1 1/4	3	2	6		11
1 1/4 to 1 1/2	1	5	12		18
1 1/2 to 1 3/4		9	39	2	50
1 3/4 to 2		6	36	5	47
2 to 2 1/4		3	34	5	42
2 1/4 to 2 1/2		1	21	8	30
2 1/2 to 2 3/4		2	4	1	7
2 3/4 to 3		1	4	1	6
3 to 3 1/4				2	2
3 1/4 to 3 1/2			1		1
3 3/4 to 4			1	1	2
Total	4	29	158	25	216
Number of undersized fish	4	7	18	0	29
Number of legal-sized fish	0	22	140	25	187
Percentage of undersized fish	100 0	24 1	11 4	0 0	13 4
Average weight of all fish	1-2 8	1-11 8	1-14 4	2-4 6	1-14 6
Average weight of undersized fish	1-2 8	1-4 9	1-5 0		1-4 7
Average weight of legal-sized fish		1-14 0	1-15 6	2-4 6	2-0 8

TABLE 42.—*Length frequencies and average lengths of lake trout gilled in the pots of impounding nets of Lakes Huron and Michigan, 1931–1932*

[The total-length intervals apply to fish with lengths up to but not including the upper limit. The average lengths of legal-sized and undersized fish were based only on those individuals for which records of weight also were available (number of specimens in parentheses). Undersized fish were separated on the basis of a 1 1/2-pound limit, not on length]

Total length interval (inches)	Sizes of stretched mesh (inches) as found in use				Total number
	<3	3-3 7/16	3 1/2-3 15/16	4-4 7/16	
15 1/2 to 16			1		1
16 to 16 1/2	2	1			3
16 1/2 to 17		1	4		5
17 to 17 1/2	3	1	13		17
17 1/2 to 18		2	21		23
18 to 18 1/2		6	27		33
18 1/2 to 19		3	30		33
19 to 19 1/2		7	28	3	38
19 1/2 to 20		1	22	1	24
20 to 20 1/2		4	13	8	25
20 1/2 to 21			13	5	18
21 to 21 1/2		2	19	3	24
21 1/2 to 22		1	6	2	9
22 to 22 1/2			2	2	4
22 1/2 to 23			5		5
23 to 23 1/2				1	1
23 1/2 to 24			1		1
24 to 24 1/2				1	1
Total	5	29	205	26	265
Average total length (inches) of all fish	16 8	18 8	19 1	20 7	19 2
Average total length (inches) of undersized fish	16 9 (4)	17 3 (7)	17 2 (18)		17 2 (29)
Average total length (inches) of legal-sized fish		19 3 (22)	19 4 (136)	20 6 (24)	19 5 (182)

The situation with respect to the lake trout was somewhat different. The few trout gilled in meshes smaller than 3 inches were all undersized (less than 1½ pounds) (table 41). The legal-sized trout started to gill noticeably in meshes of 3 to 3 7/16 inches. Only 24 percent of the gilled fish in these meshes were undersized, and the average weight (1 pound, 11.8 ounces) of all gilled fish was well over the legal size limit. The percentage of undersized gilled trout decreased to 11.4 in the 3½- to 3 15/16-inch meshes, and no illegal-sized fish were gilled in larger meshes. An examination of the frequencies and averages indicates that probably few legal-sized trout escaped through the meshes of 3½ to 3 15/16 inches (about 4 to 4 7/16 inches as manufactured) since the modal weight of the fish in these meshes (between 1½ and 1¾ pounds) was the same as in the 3- to 3 7/16-inch meshes and the average weight of legal-sized fish increased only 1.6 ounces in nets of the latter sizes of mesh. Individuals of these sizes did escape through meshes larger than 3 15/16 inches. It is doubtful, however, whether many fish of 1¾ pounds or larger were able to pass through meshes of exactly 4 inches (about 4½ inches as manufactured).

It may be observed from the frequencies of weights that the bulk of the gilled trout shifted to a higher weight-interval with each increase in the mesh between 3 and 4 7/16 inches, but the fish were always concentrated within a relatively small range of weight (¾ to 1 pound). The majority of the gilled trout weighed between 1¼ and 2 pounds in the 3- to 3 7/16-inch mesh, between 1½ and 2½ pounds in the 3½- to 3 15/16-inch mesh, and between 1¾ and 2½ pounds in the 4- to 4 7/16-inch mesh. The ranges in length of the bulk of the trout (table 42) varied from about 1 to 2½ inches in these various meshes (18 – 19½; 17½ – 20; 20 – 21 inches).

The average weight of the undersized gilled trout, as well as the average length (table 42), increased with an increase in the size of mesh from less than 3 inches to 3 to 3 7/16 inches (indicating release of some small fish). The size of fish did not change, however (slight increase in weight; slight decrease in length), with a further increase of ½ inch in mesh size suggesting that, though additional undersized fish were released by the larger meshes, the size of mesh was not yet sufficiently large to permit the larger undersized trout to escape. An increase of another ½ inch in the size of the mesh apparently did permit this escapement for no undersized trout were gilled in meshes of 4 to 4 7/16 inches. Even though these meshes or larger ones are used, it may not be assumed that no undersized fish would remain in the net. They do not all attempt to escape.

The average weight and length of the legal-sized gilled trout increased slightly with an increase in mesh size from 3 to 3 7/16 to 3½ to 3 15/16 inches (indicating release of only a few fish), but increased to a greater degree with a further ½-inch increase of mesh size, suggesting that some of the smaller fish of legal size had escaped. Nearly all of the trout gilled in meshes of 4 to 4 7/16 inches weighed 1¾ pounds or more.

In general, the data on the gilled fish and on the average sizes of fish retained in the impounding nets indicate that Michigan's minimum size of mesh (4½ inches as found in use) prescribed for the pots of impounding nets employed in catching whitefish and lake trout should not be reduced. This mesh is in fact too small to liberate a large proportion of the undersized whitefish found in the nets, although on the other hand it is too large to hold the smaller individuals of the legal-sized trout. A 4-inch mesh as found in use would probably prove more effective for the capture of trout at the present size limit of 1½ pounds. A better solution than a reduction in mesh to prevent the escape of legal-sized trout would be a substantial increase in the legal size limit since most lake trout (especially the females) under 3 pounds are sexually immature. It is not practicable to prescribe different meshes for whitefish and trout as both species are usually taken together on the same grounds. Further, a 4½-inch mesh is also prescribed for gill nets employed for both species.

DESTRUCTION OF WHITEFISH THROUGH GILLING IN THE MESHES OF POUND NETS AND DEEP TRAP NETS

The gilling of undersized fish in the meshes of impounding nets constitutes a certain source of destruction since death follows soon after the individual is enmeshed. It is, therefore, of importance to know what percentage of the illegal-sized whitefish become gilled in commercial pound nets and deep trap nets, and how this percentage varies with the size of the mesh. The death of legal individuals through gilling is of lesser importance, although the market value of such fish may be impaired and large numbers of gilled fish of any size add considerably to the fishermen's labor in clearing their nets.

The data of table 43 on the numbers and percentages of gilled whitefish in pound nets and deep trap nets are based on a combination of all nets of similar sizes of mesh irrespective of fishing grounds, depth of water, and the month and year in which the nets were fished.[37] None of these variables was found to affect the percentage of gilled fish.

TABLE 43.—*Numbers and percentages of legal and illegal whitefish gilled in large-mesh and small-mesh pound nets and deep trap nets, 1931–1932 data combined for all localities and all depths of water*

[The table is based only on the lifts in which gilled fish were counted and separated according to size]

Item	Whitefish taken in nets of mesh size			
	Less than 4 inches		4 inches and more	
	Legal	Illegal	Legal	Illegal
Total number of whitefish taken	48,441	44,759	18,024	12,613
Number of whitefish gilled	154	1,077	161	340
Percentage of gilled whitefish	0.3	2.4	0.9	2.7

A larger percentage of both the legal and the illegal whitefish became gilled in large-mesh nets than in small-mesh nets. The percentage of the legal fish gilled in large-mesh nets although small was three times that gilled in small-mesh nets, but the percentage of the illegal fish gilled in large meshes was only slightly above that in small meshes. It may be considered probable that the greater ability of large meshes to gill the larger illegal fish is compensated by the numbers of smaller illegal fish that can pass through the meshes.

The percentages of gilled illegal whitefish in pound nets and deep trap nets (2.4 percent in small meshes and 2.7 percent in large meshes) do not point to gilling as a very important source of destruction of undersized fish in a single lift. Should the same fish be taken repeatedly the risk of death by gilling would be increased.

BLOATING OF LIVE WHITEFISH IN POUND NETS AND DEEP TRAP NETS

Another possible source of destruction of illegal-sized whitefish is the bloating (the result of changing pressure) that frequently occurs when nets are lifted. It cannot be stated exactly how serious the effects of bloating may be. It is possible that many fish that are not visibly bloated when a net reaches the surface may have been injured seriously by the change of pressure, particularly if the net was lifted rapidly. On the other hand, visibly bloated fish often appear to make a complete recovery, and swim away vigorously upon return to the water.

Table 44 shows the relationship between the depth of water from which nets were lifted and the extent of bloating of whitefish of legal and illegal size. The percentage

TABLE 44.—*Relationship between the depth of water and the bloating of live whitefish in pound nets and deep trap nets, 1931–1932 data combined for all localities*

Depth of water (feet)	Total number of fish[1]	Number of bloated fish	Percentage bloated fish	Percentage bloated legal fish[2]	Percentage bloated illegal fish[2]
<61	7,206	0	0.00	0.00	0.00
61 to 80	14,811	66	0.45	0.46	0.44
81 to 100	45,109	223	0.49	0.31	0.72
101 to 110	24,493	265	1.08	0.65	1.66
>110	31,029	527	1.70	1.33	2.08
Total or average	122,648	1,081	0.88	0.63	1.17

[1] Includes only lifts in which bloated fish were counted.
[2] Only 63 percent of the bloated fish were separated as to size.

[37] Fish were considered to be gilled only when it was obvious that they had become enmeshed while the net was actually fishing. Freshly gilled live fish were considered to have become enmeshed during the lifting process, and were not counted; usually they were not injured.

of bloated fish (legal and illegal fish combined) in the lift rose consistently as the depth of water increased. No fish were bloated in nets (mostly pound nets) set at depths of 60 feet and less. At depths of 61–80 and 81–100 feet slightly less than one-half of one percent were bloated. The percentage of bloated whitefish increased to 1.08 in 101–110 feet, and rose still further to 1.70 percent in deep water (more than 110 feet).

The data on the percentages of the legal and of the illegal whitefish that were bloated reveal that both sizes of fish share the general trend toward increased bloating with increase in the depth of the water. The greater percentage of bloated legal fish at 61–80 feet in comparison with the percentage at 81–100 feet constitutes the only exception. At all depths beyond 80 feet relatively more of the illegal whitefish than of the legal whitefish were bloated. This difference was probably due to the thinner body wall of the younger fish. The averages for fish taken at all depths show that 0.63 percent of all legal fish and 1.17 percent of all illegal fish were bloated.

The bloating of live whitefish was probably an unimportant source of destruction of undersized individuals. Only 1.17 percent of all illegal fish were bloated and the maximum percentage of bloated fish at any one depth was 2.08 (deep water). However, the repeated capture of undersized fish would increase the risk of injury or death through bloating.

DEAD WHITEFISH IN POUND NETS AND DEEP TRAP NETS

Commercial fishermen opposed to the use of deep trap nets contended that confinement in this type of gear was fatal to whitefish and that dead illegal fish were very numerous in the lifts. The data of table 45, which show the number and percentage of dead fish (exclusive of dead gilled fish) at three different depths and the percentages of the legal and of the illegal fish found dead at these same depths, do not, in general, support this contention.

TABLE 45.—*Relationship between the depth of the water and the numbers and percentages of dead whitefish in deep trap nets in Lakes Huron and Michigan, 1931–1932 data combined for all localities in each lake*

Lake	Depth of water (feet)	Total number of fish[1]	Number of dead fish	Percentage dead fish	Percentage dead legal fish[2]	Percentage dead illegal fish[2]
Huron	<81	4,734	107	2.26	0.44	3.96
	81 to 110	35,736	209	0.58	0.32	0.90
	>110	30,313	195	0.64	0.45	0.84
	All depths	70,783	511	0.72	0.38	1.10
Michigan	<81	11,613	24	0.21	0.05	0.35
	81 to 110	36,215	69	0.19	0.08	0.35
	>110	827	2	0.24	0.26	0.22
	All depths	48,655	95	0.20	0.08	0.35

[1] Includes only lifts in which dead fish were counted.
[2] Only 72 percent of the dead fish were separated as to size.

Almost 4 percent of the undersized whitefish were dead in the Lake Huron deep trap nets lifted from depths of 80 feet or less. However, at that time (1931–1932) relatively few deep trap nets were fished in such shallow water. Less than 1 percent of the illegal whitefish were dead in nets lifted from greater depths. The average percentage of the undersized fish found dead in the lifts of all deep trap nets observed in Lake Huron was slightly above 1 percent. The percentage of the dead among the legal whitefish in Lake Huron deep trap nets was small (average, 0.38 percent) and showed little variation with the depth of the water.

The percentages of both the legal and the illegal whitefish found dead in deep trap nets were much smaller in Lake Michigan than in Lake Huron. The shallow-water lifts (80 feet and less) in particular had relatively few dead fish as compared with nets from the same depth in Lake Huron. The percentages of dead whitefish in Lake

Michigan do not appear to vary according to the depth of the water. (The data for deep-water lifts are too scanty to be reliable.)

Although it cannot be said that deep-trap-net lifts contained large numbers of dead whitefish, there is good evidence that pound-net lifts contained even fewer. Not one dead whitefish was found in all the pound-net lifts observed in Lake Michigan. In Lake Huron pound nets only 0.61 percent of the whitefish were dead (0.94 percent of the legal fish and 0.45 percent of the illegal fish). The percentage of dead legal fish was rather high, but the percentage of dead undersized fish was far below that for deep trap nets in shallow water (80 feet and less).

ESTIMATES OF THE PROBABLE DESTRUCTION OF ILLEGAL-SIZED WHITEFISH IN CERTAIN LOCALITIES AND YEARS

It may be stated that the percentage of undersized whitefish handled by the fishermen and destroyed in the lifting of pound nets and deep trap nets was small, although that percentage was somewhat larger for deep trap nets than for pound nets. If we define as "known destruction" the quantities of whitefish dead at the time the nets were lifted (including dead gilled fish), the data of the preceding sections make possible the following estimates of the percentages of the undersized whitefish destroyed in Lakes Huron and Michigan in pound nets and deep trap nets of different sizes of mesh:

Lake	Mesh size	Pound nets	Deep trap nets
Huron	Less than 4 inches	2.85	3.50
	4 inches and more	3.15	3.80
Michigan	Less than 4 inches	2.40	2.75
	4 inches and more	2.70	3.07

These estimates, percentages of "known destruction," range from 2.40 to 3.80. To the "known" destruction of undersized whitefish must be added the undetermined loss that resulted from the death of bloated live fish (this loss could not have been much greater than 1 percent—see table 44) and of fish killed or injured fatally during the sorting of the catch.

Despite the fact that the percentage of the undersized whitefish that was destroyed in a single lift was relatively small, the total destruction during the entire season may have been considerable, especially in those localities where the fishery was intensive and young whitefish were abundant. It is of some interest, therefore, to have estimates of the total number of undersized whitefish captured by pound nets and deep trap nets and of the total "known" destruction in certain fishing areas (table 46).

The estimates of the total number of young whitefish captured were based on the known number of nets lifted (as determined from fishermen's reports) and the average

TABLE 46.—*Estimated numbers of illegal-sized whitefish captured by pound nets and deep trap nets in certain areas of Lakes Huron and Michigan in certain calendar years, and the estimated known destruction (fish dead at time of lifting) of undersized whitefish*

Statistical districts	Year	Undersized fish taken			Known destruction		
		Pound nets	Deep trap nets	Both	Pound nets	Deep trap nets	Both
H-2	1931	127,000	321,000	448,000	3,600	11,400	15,000
	1932	64,000	180,000	244,000	1,900	6,400	8,300
H-3, H-4	1931	198,000	124,000	322,000	5,600	4,400	10,000
	1932	113,000	269,000	382,000	3,200	9,600	12,800
H-5	1932		130,000	130,000		4,600	4,600
	1933		616,000	616,000		21,700	21,700
M-2, M-3	1931	136,000	169,000	305,000	3,600	4,800	8,400
	1932	120,000	315,000	435,000	3,200	8,900	12,100

number of undersized whitefish per lift (as determined from our observations in the field). Estimates were made separately for large-mesh (4 inches and greater) and small-mesh (less than 4 inches) nets and combined to obtain the totals listed in the table. It was necessarily assumed that the relative numbers of large-mesh and small-mesh nets in the general fishery were the same as those observed by our investigators in the field. Estimates were made of the capture and destruction of illegal-sized whitefish by deep trap nets in H–5 in both 1932 and 1933, although field observations[38] were made only in 1932. The computations for 1933 (based on the assumption that the abundance of young whitefish and the relative numbers of large-mesh and small-mesh nets were the same in that year as in 1932) were carried out merely to provide a rough idea of the large numbers of whitefish that probably were handled during the years of intensive fishing in southern Lake Huron.

The estimated numbers of young whitefish handled by pound-net and deep-trap-net fishermen in the various districts and years were large (130,000 to 616,000). The estimated destruction, however, appeared to be relatively small (4,600 to 21,700). The combination of the data for all districts and years indicates a loss of 2.8 percent of all undersized whitefish taken in pound nets and of 3.4 percent of those captured by deep trap nets. These figures should not be taken as indicative of the percentage loss of the total population of undersized fish (of the sizes handled) as many fish may have been captured more than once and others, doubtless, were not captured at all.

Estimates were made also of the loss of small whitefish in the entire lakes (Michigan waters) in 1932, the year of our most extensive field observations. The 1932 pound-net yield in districts H–2 to H–5, inclusive, amounted to 43.5 percent of the catch of whitefish in pound nets in the entire lake. The "known" destruction of whitefish by pound nets in these districts in 1932 amounted to 5,100 individuals (table 46). If the average conditions of the pound-net fishery (abundance of young fish on the grounds and relative numbers of large-mesh and small-mesh nets) in H–1 and H–6 are assumed to have been similar to those of the fishery in H–2 to H–5, the "known" destruction of undersized whitefish in the pound nets of all Michigan waters of Lake Huron in 1932 can be calculated as 5,100/0.435 or 11,700 fish. Similarly, the deep trap nets of districts H–2 to H–5 accounted for 93.8 percent of the total deep-trap-net catch and for the estimated destruction of 20,600 young whitefish. The estimated "known" destruction for all six districts was, therefore, 20,600/0.938 or 22,000 fish. The combined "known" destruction of pound nets and deep trap nets in Lake Huron in 1932 was 33,700 whitefish.

The same calculations for the Michigan waters of Lake Michigan showed that in 1932 districts M–2 and M–3 yielded 52.1 percent of the total catch of whitefish in pound nets and 76.5 percent of the deep-trap-net production. These percentages applied to the figures on "known" destruction in table 46 yielded the following estimates of the loss of undersized whitefish in all eight districts: pound nets—6,100; deep trap nets—11,600; pound nets and deep trap nets—17,700.

The estimates of the "known" destruction of undersized whitefish by deep trap nets in all Michigan waters of Lakes Huron and Michigan in 1932 (22,000 and 11,600 individuals, respectively) can not be termed large. If that gear was extremely harmful to the stocks of small fish the loss must have occurred through the death of fish that were killed or injured fatally in the sorting of the catch.

The opinions of the fishermen concerning the ability of the whitefish to withstand handling were found to vary widely. Some (particularly those who were opposed to the use of deep trap nets) contended that whitefish are extremely delicate—that they are unable to survive removal from the water for even short periods of time and will die as the result of the least amount of handling. Others (especially deep-trap-net fishermen) held that the whitefish is exceptionally hardy—that with only reasonable care very few or none at all are injured during the sorting of the catch.

Data are not available to show which of the above diametrically opposite viewpoints is the more nearly correct. However, the fact that 101 or 22.1 percent of 457

[38] The pound-net fishery for whitefish was negligible in H-5 in 1932 and 1933 (appendix B). Our investigators observed no pound-net lifts in this district.

young whitefish tagged in Lake Michigan were later recovered (Smith and Van Oosten, 1940)[39] suggests that they successfully withstand careful handling.

Our field investigators reported that almost all deep-trap-net fishermen were extremely careful in the sorting of the catch. To be sure, they may have been more than ordinarily painstaking when the investigators were aboard their craft. Nevertheless, most of them appeared to be following a well established routine that involved a minimum of handling of illegal-sized whitefish and a minimum length of time out of the water. Only one fisherman was observed whose method of sorting was considered likely to result in the death of a high percentage of the undersized whitefish.

The fact that the illegal whitefish taken by the deep trap nets in Lakes Huron and Michigan were so near the legal size increased greatly the potential harm resulting from the destruction of undersized individuals. It was estimated that practically all of the illegal-sized whitefish observed would have attained the legal weight of 2 pounds within another year, as their average weight at capture was 1 pound, 9.7 ounces (17.6 inches, total length). However, the illegal-sized whitefish from the pound nets of Lake Huron (no data from Lake Michigan pound nets) were relatively small (13.1 ounces and 14.1 inches, total length).

SHRINKAGE OF THE TWINE IN POUND NETS AND DEEP TRAP NETS

The fact that pound-net and deep-trap-net twine is treated regularly (usually in the spring of each year) with tar or copper oleate as a preservative gives rise to a troublesome question as to whether the minimum legal size of the mesh shall be designated "as found in use" or "as manufactured." It is well known that the application of a net preservative to cotton twine is almost always accompanied by some shrinkage. However, the exact extent of this shrinkage is not predictable for individual nets. The amount of shrinkage of the twine varies with the method of applying the treatment, the number of times the webbing is treated, the nature of the webbing as received from the manufacturer, and possibly with the type of preservative employed. If the minimum legal mesh size is defined "as found in use," honest fishermen conceivably might find themselves confronted with the problem of large amounts of expensive gear rendered useless by unexpected high shrinkage. On the other hand, if the minimum mesh size is defined "as manufactured," unscrupulous fishermen may so control the type of twine purchased and the method of preservation as to shrink the mesh to a size far below the intended legal minimum. Regardless of how the legal minimum mesh size is designated, it is of importance to have data available on the average amount and the range of the shrinkage of pound-net and deep-trap-net twine following the application of a preservative.

The results of 648 measurements of pound-net and deep-trap-net meshes as found in use are recorded in table 47.[40] The data have been grouped according to the size of the mesh (extension measure) as manufactured and to the type of preservative applied. The former grouping (as to size of mesh when manufactured) is based entirely on the fishermen's statements. The meshes were measured by inserting a thin steel rule in one end of the collapsed mesh, pulling the twine taut, and reading the length between and inside the knots (not from the centers of the knots). Measurements were made both parallel with the selvage (first measurement of each series in table 47) and at right angles to it (second measurement).

Although most of the fishermen who were interviewed believed that tar shrinks webbing more than does copper oleate, their belief is not entirely supported by the data of table 47. It is true that tarred nets of 4¼-inch and 4½-inch original mesh size suffered greater shrinkage than nets of the same mesh size treated with copper oleate. On the other hand, nets with a factory measurement of 3½ inches shrank considerably more under copper-oleate treatment than did nets of the same mesh size treated with tar; a slightly greater shrinkage from copper oleate was found also for 4-inch-mesh nets. If all sizes of mesh are considered together, there appears to be little difference between the

[39] Smith, Oliver H. and John Van Oosten. Tagging Experiments with Lake Trout, Whitefish, and Other Species of Fish from Lake Michigan. Trans. Am. Fish. Soc., vol. 69, (1939) 1940, pp. 63–84.

[40] The data of table 47 do not represent 648 different nets as some nets were visited more than once. Several nets of mesh size larger than 4½ inches as manufactured were measured, but there were not enough of any single mesh size to yield reliable averages.

Table 47.—*Shrinkage of pound-net and deep-trap-net twine following the application of tar or copper oleate as preservatives*

[The average amounts of shrinkage are given in parentheses below the average measurements of the meshes as found in use. All averages are to the nearest sixteenth of an inch]

Type of treatment	Size of mesh as manufactured							
	3 1/2 inches		4 inches		4 1/4 inches		4 1/2 inches	
	Number of measurements	Mesh size as fished	Number of measurements	Mesh size as fished	Number of measurements	Mesh size as fished	Number of measurements	Mesh size as fished
Tar	38	3 1/8x3 1/8 (6/16x6/16)	144	3 9/16x3 5/8 (7/16x6/16)	59	3 13/16x3 15/16 (7/16x5/16)	206	3 7/8x3 15/16 (10/16x9/16)
Copper oleate	47	2 15/16x3 (9/16x8/16)	80	3 9/16x3 9/16 (7/16x7/16)	34	3 15/16x4 (5/16x4/16)	40	4 1/16x4 1/8 (7/16x6/16)
Total or average	85	3x3 1/16 (8/16x7/16)	224	3 9/16x3 5/8 (7/16x6/16)	93	3 7/8x4 (6/16x5/16)	246	4x4 (9/16x8/16)

shrinkage produced by tar and by copper oleate. With both treatments measurements made parallel with the selvage showed on the average 1/16 inch greater shrinkage than did those made at right angles to the selvage.

The data for individual nets showed a variation from "no shrinkage" to a maximum shrinkage of 1 inch. It is this wide range of variation in shrinkage that makes the designation of the legal minimum mesh in terms of "size as manufactured" so eminently undesirable. The average shrinkage of meshes measured in this study was 7/16 inch or slightly less than 1/2 inch. If it were known that the shrinkage of all nets closely approximated this average, the designation of a legal minimum mesh size (as manufactured) 1/2 inch larger than that intended for nets as found in use might prove reasonably satisfactory. However, the wide range of shrinkage makes such a procedure impractical. If the legal minimum mesh is to be defined "as manufactured," allowance should be made not for the average observed shrinkage but for the maximum possible shrinkage. A further objection to the designation of the legal minimum mesh size "as manufactured" lies in the fact that illegal nets can be fished with impunity if they have been treated before examination by a conservation officer. In other words, there is no exact means of determining the original mesh size of a treated net.

The conclusion is obvious that the most satisfactory method of designating minimum legal mesh sizes of pound nets and deep trap nets is on the basis of mesh size "as found in use." The wide experience of most commercial fishermen with different kinds of webbing and preservatives is certainly sufficient to preclude excessive losses as the result of undue shrinkage of their twine.

SUMMARY

1. The present investigation of the whitefish fishery of Lakes Huron and Michigan was undertaken because of the threat to the whitefish stocks offered by the introduction and rapid expansion in the use of a new and tremendously efficient gear, the deep trap net. This net, which was developed in Lake Ontario, was introduced into Lake Huron off Alpena, Mich., in 1928. Beginning in 1930, the use of the deep trap net expanded rapidly throughout the State of Michigan waters of Lake Huron and northern Lake Michigan. Operations with this gear were relatively limited in other waters (Wisconsin waters of Lake Michigan; Indiana waters of Lake Michigan; Michigan waters of Lake Superior and southern Lake Michigan). The greatest development of the deep-trap-net fishery occurred in the Michigan waters of central and southern Lake Huron.

2. The investigation was carried out along the following general lines:

a. A review of the available statistics on the production of whitefish in Lakes Huron and Michigan over the period, 1879–1939.

b. A detailed analysis of the fluctuations in the production and abundance of whitefish and in the intensity of the whitefish fishery in the different areas of the Michigan waters of Lakes Huron and Michigan in the years, 1929–1939, with special reference to the effects of the operations with deep trap nets. The methods of analysis are described.

c. A study of the bathymetric distribution of whitefish of legal and illegal size in order to obtain data on which to base recommendations for possible restrictions on the depth of water in which deep trap nets may be fished.

d. Observations in the field on the fishing action of pound nets and deep trap nets –particularly on the extent of the destruction of undersized whitefish. The field work was carried out in 1931 and 1932.

3. Although the fluctuations in the yield of whitefish in the various areas of Lakes Huron and Michigan over the period, 1879–1939, were by no means the same, certain general trends may be described. Production was high in all areas in the early years of the period. Later declines brought the catch to a much lower, and in some waters remarkably stable, level about which the production fluctuated for several decades. A pronounced general increase in the yield of whitefish occurred in the late 1920's and/or early 1930's. This increase was relatively greater and the subsequent decline was relatively more severe in the State of Michigan waters of Lake Huron than in other regions of the Great Lakes. Graphical representations of the history of whitefish production in different areas of Lakes Huron and Michigan are given in figures 2 and 3.

4. The increase in the abundance of whitefish that occurred in the late 1920's and early 1930's complicated greatly the problem of detecting the effects of deep-trap-net operations on the whitefish fishery of the State of Michigan waters of Lakes Huron and Michigan. This increase would have brought about a rise in both fishing intensity and catch even had deep trap nets not been introduced. Furthermore, a decline from this abnormally high level of yield and abundance was logically to be expected; the mere occurrence of a decline could not be interpreted as the result of the use of deep trap nets.

5. Despite this difficulty, the following observations demonstrated conclusively the disastrously harmful effects of extensive deep-trap-net operations on the stocks of whitefish:

a. The regions in which the deep-trap-net fishery underwent its greatest expansion (the four southernmost statistical districts of Lake Huron—see fig. 4) suffered an unreasonable multiplication of fishing intensity. In these districts of central and southern Lake Huron (H–3 to H–6) the maximum yield of whitefish was 4.3 to 26.6 times the 1929 catch; the maximum fishing intensity was 3.8 to 42.1 times the 1929 intensity. In the two northerly districts (H–1 and H–2)—areas in which the use of deep trap nets was much less extensive—the respective maximum productions were only 2.6 and 3.2 times the 1929 catch; the maximum fishing intensity was 2.3 times that of 1929 in each district.

b. In all districts of Lake Huron the introduction of the deep trap net brought about a tremendous increase in the catch of whitefish. After about two years of high production the catch fell sharply. This decrease in yield was accompanied by a rapid decline in the abundance of whitefish. However, these declines were relatively greater in central and southern Lake Huron. The 1939 production of whitefish, expressed as a percentage of the 1929 catch, was 38 in H–1 and 23 in H–2. These percentages were only 1 and 5 in H–3 and H–4. In H–5 and H–6 the 1939 yields were only 19 and 46 percent, respectively, of the 1929 production despite fishing intensities that were 4.3 and 4.9 times those of 1929. The 1939 abundance of whitefish, expressed as a percentage of the 1929 abundance, was 41 in H–1 and 43 in H–2. In central and southern Lake Huron these percentages were: H–3, 6; H–4, 7; H–5, 5; H–6, 10. These figures demonstrate that whereas the whitefish fishery merely declined in those districts (H–1 and H–2) in which the use of the deep trap net was relatively moderate, it collapsed in the districts (H–3 to H–6) in which deep-trap-net operations underwent their greatest expansion. The excessive use of deep trap nets, therefore, may be stated positively to be the cause of the present critical condition of the whitefish fishery in Lake Huron. The severity of the depletion is illustrated by the fact that the 1939 production of only

255,000 pounds was less than half the previously reported all-time low (555,000 pounds in 1900).

c. The statistics of the whitefish fishery of northern Lake Michigan (districts M-1, M-2, and M-3) for the years, 1929–1939, lend support to the conclusions based on the data for Lake Huron. In these Lake Michigan districts as in H-1 and H-2 the development of the deep-trap-net fishery may be termed relatively moderate. Although the whitefish fishery of northern Lake Michigan underwent a decline—a decline to which the use of deep trap nets may have contributed substantially—the severity of the decreases did not approach that of the decreases of central and southern Lake Huron; rather the changes resembled those that took place in northern Lake Huron. The deep trap net was of no significance in the State of Michigan waters south of district M-3, except in M-7 where it was the dominant gear for the production of whitefish in the single year, 1934.

6. The harmful effects of the deep-trap-net fishery can be traced to its great efficiency for the capture of whitefish in comparison with pound nets and large-mesh gill nets. Pound nets, which are held in position by stakes driven into the bottom of the lake, occupy the same position throughout the season, can be set only on soft bottom, and seldom are fished in water deeper than 60 feet. Deep trap nets, which are held in position by anchors and buoys, can be set on almost any kind of bottom and can be moved readily to any depth of water in which whitefish occur abundantly. These characteristics of the gear made possible the heavy exploitation of the whitefish at the time of their summer concentration in relatively deep water—far beyond the reach of pound nets. Gill nets have long been fished in these depths of the summer concentration of whitefish but in the modern fishery this gear has proved to be relatively unsuccessful for the capture of whitefish, except under certain special conditions (as during the spawning run or in limited local areas).

7. Records of the catch per lift of deep trap nets revealed that the gear was much less successful in northern Lake Huron (districts H-1 and H-2) and Lake Michigan (districts M-1, M-2, M-3, and M-7) than in central and southern Lake Huron (H-3 to H-6) This situation doubtless accounted in part (see p. 339) for the relatively less extensive development of the deep-trap-net fishery in Lake Michigan and northern Lake Huron.

8. Counts of legal- and illegal-sized whitefish in lifts of pound nets and deep trap nets from different depths of water were employed in a study of the bathymetric distribution and vertical movements of the species during the summer and early autumn.

9. The combined data for the months, May to October, inclusive, indicated that legal-sized whitefish were most abundant in Lake Huron at depths of 81 to 110 feet with the peak concentration in 91 to 100 feet. Illegal-sized fish were most abundant in 71 to 110 feet with a maximum concentration at 81 to 90 feet, 10 feet shallower than the depth of greatest abundance of legal fish. The records for the grounds off Alpena and in the Saginaw Bay area suggest that both legal- and illegal-sized whitefish may move onshore during the summer and return to deeper water in the autumn.

10. The whitefish lives in shallower water in northern Lake Michigan than in Lake Huron. The averages for the entire season (May to October, inclusive) showed legal-sized whitefish to be most abundant in 71 to 110 feet (peak concentration at 81–90 feet) and illegal-sized fish in 61 to 110 feet (peak at 71–80 feet). The depths of the peak concentrations were 10 feet shallower in northern Lake Michigan than in Lake Huron for fish of corresponding size.

11. The records for the individual months indicated that both legal- and illegal-sized whitefish in northeastern Lake Michigan moved toward deeper water from June to September. The October data provided some indication of a return migration in the autumn. These movements are the reverse of those indicated by the data for the Lake Huron whitefish.

12. The vertical distribution of whitefish in northeastern Lake Michigan was characterized by the presence of two concentration zones of both legal- and illegal-sized fish. Although the actual depths at which the zones occurred varied from month to month with the offshore and onshore movements of the fish, the two concentrations remained

distinct nevertheless in every month but September in the 5-month period, June to October. The inshore and offshore concentrations of legal-sized whitefish were separated by a difference in depth of 20 feet in each of the four months in which both were present. The offshore concentration of illegal-sized whitefish was 30 feet deeper than the inshore concentration in June, July, and August, but was only 20 feet deeper in October.

13. The persistent occurrence of two concentration zones of whitefish in northeastern Lake Michigan throughout most of the summer and early autumn raises the question of the possible existence of distinct inshore and offshore populations or races. Arguments were outlined briefly for and against this interpretation of the two concentrations; available data do not, however, permit a definite decision.

14. On the basis of the observations on the bathymetric distribution of whitefish, it was suggested that young fish would be protected from excessive handling and possible destruction and legal-sized fish from ruinous exploitation if the operations of deep trap nets were limited in Lake Huron to depths of 80 feet and less and in Lake Michigan to depths of 70 feet and less. The proposed restriction has been effective in Lake Huron since August 1, 1934; the use of deep trap nets was made illegal in Lake Michigan after 1935.

15. A limited amount of information was presented on the bathymetric distribution and seasonal movements of the lake trout, yellow pike, burbot, white sucker, and long-nosed or sturgeon sucker.

16. Comparisons of the average numbers of fish per lift of large-mesh (meshes of 4 inches or more, extension measure, in the pot) and small-mesh (less than 4 inches) pound nets and deep trap nets operated under comparable conditions (on the same grounds, in the same calendar year and month, and in the same depth of water) revealed that in general the large-mesh nets took the greater numbers of legal-sized whitefish and the lesser numbers of illegal-sized individuals. Large-mesh nets took 31.3 percent fewer undersized whitefish than did small-mesh nets that captured an equal number of legal-sized fish. Further evidence for the escape of undersized whitefish from the nets with larger mesh sizes was provided by the regular increase, with increase in the size of mesh, in the average length and weight of illegal-sized whitefish captured in pound nets and deep trap nets or gilled in the meshes of the lifting pot. On the basis of the selectivity data a minimum mesh size of $4\frac{1}{2}$ inches or greater (extension measure as found in use) in the pots was recommended for pound nets and deep trap nets employed for the capture of whitefish and lake trout. (This size of mesh is prescribed by the present State of Michigan law.) Although the data indicated that meshes of $4\frac{1}{2}$ inches or more will permit the escape of the smaller legal-sized lake trout, a smaller mesh cannot be recommended because lake trout and whitefish ordinarily are taken together. Furthermore, data on the size of lake trout at first maturity indicate the need for an increase in the size limit (now $1\frac{1}{2}$ pounds) rather than a decrease in the minimum legal mesh size of pound nets and deep trap nets.

17. Observations of the lifting of pound nets and deep trap nets did not indicate the destruction of illegal-sized whitefish to be excessive even in those areas in which it was estimated that hundreds of thousands of young fish were captured in a single season. The "known" destruction of undersized fish (individuals dead from gilling or other causes at the time of lifting) ranged from 2.40 to 3.80 percent according to the lake, type of net, and size of mesh. These percentages tended to be higher for deep trap nets than for pound nets. To the "known" destruction must be added the undetermined losses from the later death of live bloated fish (only a little more than 1 percent of the live illegal-sized whitefish were bloated) and of fish killed or injured fatally during the sorting of the catch. Field observations indicated, however, that most (but not all) fishermen attempted to avoid rough handling of small whitefish and returned them to the water as soon as possible.

18. Extensive measurements were obtained of meshes in the pots of pound nets and deep trap nets in order to determine the amount of shrinkage produced by different types of preservatives applied to the twine. No significant difference could be found between the shrinkage brought about by treatment with tar and copper oleate. The mesh size

of treated nets averaged a little less than a half inch smaller than the mesh size as manufactured. The amount of shrinkage varied widely, however, in the individual nets. Because of this variation the minimum legal size of mesh should be specified "as found in use" rather than "as manufactured." Once a net has been treated, it is impossible to determine exactly the original size of the mesh.

APPENDIX A

SOURCES OF THE DATA ON PRODUCTION, 1879-1939

The following paragraphs contain the details concerning the sources of the production data of table 1. Where more than one source was available for any single year, preference usually was given to that with the most continuous record over a period of years.

(1) Sessional Papers of the Parliament, Dominion of Canada: all data for the Canadian waters of Lake Huron, 1879–1905.

(2) Annual Reports of the Game and Fisheries Department of the Province of Ontario: all data for the Canadian waters of Lake Huron, 1906–1939.

(3) Reports of the United States Commissioner of Fisheries and his administrative successors: all data for United States waters, 1879 (repeatedly listed erroneously in the reports as for 1880) and 1885; United States waters, except the Wisconsin waters of Lake Michigan, 1890 (including the total for the Lake); Wisconsin waters of Lake Michigan, 1926–1939; total for Lake Michigan, 1925; Indiana and Illinois waters of Lake Michigan, 1879, 1885, 1890, 1897, 1903, 1917, 1922, and 1925–1939 (actually, no whitefish catch was reported from these States in 1938 and 1939). The Indiana and Illinois catches of whitefish in Lake Michigan for the above years, although not recorded in table 1, have been included in the Lake Michigan totals. All other Lake Michigan totals for individual years, except 1889 and 1908, are exclusive of the Indiana and Illinois catches.

(4) Reports of the State of Michigan Department of Conservation and its administrative predecessors: State of Michigan waters of Lake Michigan, 1911; State of Michigan waters of Lakes Huron and Michigan, 1912–1928.

(5) United States Bureau of the Census—Fisheries of the Great Lakes, Census Bulletin no. 173: all United States waters (including catches in Illinois and Indiana), 1889. Fisheries of the United States, Special Report: Wisconsin waters of Lake Michigan, 1908; Indiana and Illinois waters of Lake Michigan, 1908 (not listed in table 1 but included in the total for the lake).

(6) Compilations made from original State records:

Wisconsin.—Wisconsin waters of Lake Michigan, 1890, 1892–1897, 1899, 1903, and 1909–1925.

Michigan.—Michigan waters of Lakes Huron and Michigan, 1891–1908.

Michigan.—Compilations from the daily reports of commercial fishermen—State of Michigan waters of Lakes Huron and Michigan, 1929–1939. (These data are treated in detail in part II.)

Although certain data are available for earlier years, the statistical records for the whitefish fisheries of the United States waters of Lakes Huron and Michigan may be assumed for practical purposes to begin with 1889 and 1891. The 1879, 1885, and 1890 catches included longjaws, blackfins, and Menominee whitefish in Lake Michigan, and Menominee whitefish in Lake Huron. The only clue as to the extent of the errors brought about by these inclusions is provided by the fact that in 1890 longjaws, blackfins, and Menominee whitefish made up about 26 percent of the reported catch of whitefish in Lake Michigan (1,398,238 pounds in a total of 5,455,079 pounds). The 1890 total for the Wisconsin waters of Lake Michigan is based on State records and is not known to include any species other than whitefish. However, Wisconsin contributes a relatively small part of the total whitefish catch in Lake Michigan.

As has been mentioned previously, the Lake Michigan totals for several individual years do not include the catch of whitefish in Indiana and Illinois waters. However, the error involved is small, as the following catches for the years in which the production in these two States is known will show:

Year	*Pounds*	*Year*	*Pounds*	*Year*	*Pounds*
1885	[1]247,086	1922	20,800	1933	6,600
1889	37,375	1926	12,094	1934	4,600
1890	[2]94,736	1927	22,436	1935	1,500
1897	[3]39,760	1928	15,454	1936	6,500
1899	10,558	1929	36,375	1937	3,800
1903	2,905	1930	10,695	1938	No catch
1908	65,000	1931	9,755	1939	do.
1917	37,750	1932	12,450		

[1] Includes longjaws, blackfins, and Menominee whitefish.
[2] Includes longjaws, blackfins, and Menominee whitefish—the total listed for the lake does not, however, include these species.
[3] Fiscal year.

The tabulation of the statistics of the production of whitefish in the Canadian waters of Lake Huron has been started with 1879, the first year for which statistics are available for United States waters. Available statistics on the production of whitefish in the Canadian waters of Lake Huron for the earlier years, 1867–1878, have been omitted from table 1 because of the lack of comparative data for United States waters. These earlier Canadian records also are open to the criticism that in a number of years the production reported for Huron proper included the catch in the St. Clair River and in Lake St. Clair to the point of inflow of the Thames River. The catches listed under "Huron proper" for the years, 1879–1921, were taken between the tip of the Saugeen Peninsula at Cape Hurd, Ontario, and the extreme southern end of Lake Huron. Beginning in 1922 the islands of the open lake and the westerly shore of Manitoulin Island to the north of the Saugeen Peninsula were included in "Huron proper."

As stated in footnote 8, the catches listed under the heading, "Georgian Bay," represent a combination of the take in the Bay and in the North Channel and Manitoulin Island regions to the north and west except in 1922 and later years as explained above. This combination was made partly in an attempt to reduce the size and complexity of table 1 and partly because of variation in the extent of the waters included in the two areas. For example, reports for certain of the earlier years listed the catches along the east shore of Georgian Bay as far south as Penetanguishene as part of the production in the Manitoulin Island and North Channel area.

Reference should be made here to the Canadian records compiled for the International Board of Inquiry for the Great Lakes Fisheries and published after this manuscript was completed.[41] The districts employed by Ford are not always the same as those used in this report and her statistics for these areas are therefore not always comparable with ours. However, both records of the total Canadian catch of Lake Huron should be the same. Minor discrepancies occur for some years because, in contrast to our records, Ford's figures were rounded to the nearest hundredweight. In other years the discrepancies are larger, though still insignificant. The reason for these differences is not known. A check with the published records of the Game and Fisheries Department of Ontario reveals that our figures agree with theirs. At any rate our conclusions would remain the same whether we utilized Ford's data or our own.

The accuracy of the catches recorded for the Ontario waters of Huron proper in 1908 and 1909 has been considered so questionable that the values were not plotted in figure 2 and were omitted in the computation of averages for periods that included these 2 years. The contrast between the catches for 1908 and 1909 and the production in the years immediately preceding and immediately following is in itself sufficiently great to give just grounds for suspicion. This suspicion is heightened by the observation that the large 1908 and 1909 catches are to be traced to reports of excessive quantities of whitefish as barrels of salt whitefish. In 1908 3,515 barrels (703,000 pounds) and in 1909 550 barrels (110,000 pounds) of salt whitefish were reported. In other years of the period, 1900–1917, the number of barrels of salt whitefish reported for Huron proper did not exceed 82, and averaged only 12 barrels.

Barrels of salt fish have been converted to fresh fish at the rate of 200 pounds per barrel. Catches given as numbers of fish have been converted to pounds at the rate of 2 pounds per fish.

[41] International Board of Inquiry for the Great Lakes Fisheries. Report and Supplement. Washington, 1943.
Ford, Marjory A. Annual Landings of Fish on the Canadian Side of the Great Lakes from 1867 to 1939 as Officially Recorded. Ottawa, 1943

APPENDIX B

DETAILED STATISTICS ON WHITEFISH PRODUCTION IN STATE OF MICHIGAN WATERS OF LAKES HURON AND MICHIGAN, 1929–1939

TABLE 48.—*Production of whitefish in pounds according to gear in the several districts of the State of Michigan waters of Lakes Huron and Michigan, 1929–1939*

[The districts of Lake Huron are numbered H-1, H-2, *** and of Lake Michigan, M-1, M-2, ***. In districts M-4, M-5, M-6, and M-8 the catch of deep trap nets is included under "Other."]

DISTRICT H-1

Year	Gear				Total annual production	Percentage of average annual production
	Large-mesh gill net	Deep trap net	Pound net	Other		
1929	232,063	-	142,182	1,332	375,577	81
1930	174,851	386,453	291,765	2,293	755,362	163
1931	246,897	375,122	337,805	27,642	987,466	213
1932	135,059	170,313	306,938	11,360	623,670	135
1933	121,664	64,251	161,133	18,635	365,683	79
1934	105,582	104,699	166,877	947	378,105	82
1935	106,498	163,465	98,512	4,399	372,874	80
1936	82,464	346,821	100,282	11,825	541,392	117
1937	43,626	236,196	93,428	505	373,755	81
1938	54,834	73,184	51,035	1,074	180,127	39
1939	40,368	73,406	25,876	1,401	141,051	30
Average 1929–1939	122,173	172,174	161,439	7,401	463,187	100

DISTRICT H-2

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	12,708	87,121	173,904	907	274,640	160
1930	48,151	358,872	187,443	60	594,526	345
1931	18,252	376,887	83,679	151	478,969	278
1932	3,785	94,527	18,823	297	117,432	68
1933	5,641	28,540	22,386	178	56,745	33
1934	7,331	44,153	39,041	2,591	93,116	54
1935	3,653	94,584	19,025	1,025	118,287	69
1936	1,197	46,602	3,346	4,461	55,606	32
1937	1,923	14,009	-	4,881	20,813	12
1938	25	34,315	229	6,794	41,363	24
1939	8	41,980	-	297	42,285	25
Average 1929–1939	9,334	111,054	49,807	1,967	172,162	100

DISTRICT H-3

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	43,426	-	54,536	856	98,818	107
1930	63,216	157,248	21,998	5,110	247,572	269
1931	44,336	395,230	7,121	23,736	470,423	511
1932	7,644	85,236	475	44,108	137,463	149
1933	4,218	9,912	-	-	14,130	15
1934	1,791	12,558	-	50	14,399	16
1935	928	7,964	9	6	8,907	10
1936	439	7,567	-	-	8,006	9
1937	799	1,934	-	65	2,798	3
1938	187	8,910	42	24	9,163	10
1939	230	277	-	50	557	1
Average 1929–1939	15,201	62,440	7,653	6,728	92,022	100

DISTRICT H-4

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	85,186	-	437,848	48,571	571,605	83
1930	137,402	68,748	757,720	79,525	1,043,395	152
1931	96,986	932,357	446,010	472,732	1,948,085	283
1932	46,400	1,934,325	224,285	257,948	2,462,958	358
1933	2,969	620,125	105,255	33,213	761,562	111
1934	4,687	116,849	44,192	29,217	194,945	28
1935	183	138,446	51,002	22,882	212,513	31
1936	-	75,438	21,829	31,450	128,717	19
1937	260	121,796	12,716	20,319	155,091	23
1938	158	38,224	5,708	11,795	55,885	8
1939	176	18,785	2,319	4,665	25,945	4
Average 1929–1939	34,037	369,554	191,717	92,029	687,337	100

TABLE 48.—*Production of whitefish in pounds according to gear in the several districts of the State of Michigan waters of Lakes Huron and Michigan, 1929–1939—Continued*

[The districts of Lake Huron are numbered H-1, H-2, *** and of Lake Michigan, M-1, M-2, ***. In districts M-4, M-5, M-6, and M-8 the catch of deep trap nets is included under "Other."]

DISTRICT H-5

Year	Gear				Total annual production	Percentage of average annual production
	Large-mesh gill net	Deep trap net	Pound net	Other		
1929	61,052		1,935		62,987	19
1930	84,803		4,879	1,811	91,493	27
1931	66,647		6,125	1,266	74,038	22
1932	29,080	479,916	4,413		513,409	152
1933	15,114	1,658,753	2,565		1,676,432	496
1934	253	783,606	345	11	784,215	232
1935	270	272,746	405		273,421	81
1936		119,103	37		119,140	35
1937	137	66,688			66,825	20
1938	83	41,832			41,915	12
1939		12,247			12,247	4
Average 1929–1939	23,404	312,263	1,882	281	337,840	100

DISTRICT H-6

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	55,526		13,291	3,924	72,741	19
1930	105,329		38,781	2,982	147,092	37
1931	146,397		30,200	4,194	180,791	46
1932	163,598		14,764	17,040	195,402	50
1933	119,665	322,995	13,890	2,799	459,349	117
1934	70,057	999,618	7,752	26,026	1,103,453	281
1935	21,257	810,137	3,327	74,084	908,805	232
1936	4,851	571,176	1,606	11,675	589,308	150
1937	3,192	393,541	1,077	1,589	399,399	102
1938	390	226,608	1,799	719	229,516	58
1939	290	31,822	716	270	33,098	8
Average 1929–1939	62,777	305,082	11,564	13,209	392,632	100

DISTRICT M-1

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	596,743		535,227	7,658	1,139,628	217
1930	582,761	37,655	445,969	9,363	1,075,748	205
1931	500,828	111,523	575,457	7,161	1,194,969	227
1932	353,998	191,979	344,086	20,043	910,106	173
1933	72,722	77,161	85,755	2,531	238,169	45
1934	74,682	56,918	130,407	998	263,005	50
1935	97,241	22,783	50,246	4,367	174,637	33
1936	51,937		37,899	367	90,203	17
1937	54,767		50,039	83	104,889	20
1938	233,314		120,829	92	354,235	68
1939	100,381		136,660	468	237,509	45
Average 1929–1939	247,216	45,274	228,416	4,830	525,736	100

DISTRICT M-2

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	62,339		27,678	2	90,019	164
1930	84,555		16,070		100,625	184
1931	55,593	13,645	12,374	6	81,618	149
1932	36,610	59,303	1,330	5	97,248	178
1933	11,288	30,753	236		42,277	77
1934	15,278	11,580			26,858	49
1935	42,643	3,621			46,264	85
1936	46,465				46,465	85
1937	31,489			4	31,493	57
1938	24,221				24,221	44
1939	15,402				15,402	28
Average 1929–1939	38,717	10,809	5,244	2	54,772	100

DISTRICT M-3

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	805,344		1,396,439	281	2,202,064	206
1930	920,784	97,454	1,442,083	335	2,460,656	230
1931	484,121	273,282	622,686	361	1,380,450	129
1932	430,866	596,246	462,360		1,489,472	140
1933	277,322	318,260	295,309	8	890,899	83
1934	251,308	251,012	259,511		761,831	71
1935	368,955	177,374	202,793	544	749,666	70
1936	289,502		156,446	19	445,967	42
1937	297,274		153,176	169	450,619	42
1938	294,479		203,261	36	497,776	47
1939	228,482		196,998	15	425,495	40
Average 1929–1939	422,585	155,784	490,097	161	1,068,627	100

TABLE 48.—*Production of whitefish in pounds according to gear in the several districts of the State of Michigan waters of Lakes Huron and Michigan, 1929–1939—Continued*

[The districts of Lake Huron are numbered H-1, H-2, *** and of Lake Michigan, M-1, M-2, ***. In districts M-4, M-5, M-6, and M-8 the catch of deep trap nets is included under "Other."]

DISTRICT M-4

Year	Gear				Total annual production	Percentage of average annual production
	Large-mesh gill net	Deep trap net	Pound net	Other		
1929	30,433		42,158	38	72,629	127
1930	41,335		42,784		84,119	147
1931	43,753		40,235	265	84,253	148
1932	44,552		32,857	1,362	78,771	138
1933	22,683		26,758	1,569	51,010	89
1934	6,435		41,386	548	48,369	85
1935	7,663		35,864	4,451	47,978	84
1936	26,807		29,377	50	56,234	98
1937	16,671		27,179	16	43,866	77
1938	17,707		11,525	17	29,249	51
1939	18,735		13,022	10	31,767	56
Average 1929–1939	25,161		31,195	757	57,113	100

DISTRICT M-5

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	271,324		13,296		284,620	89
1930	259,351		21,345	5	280,701	88
1931	548,048		32,488		580,536	183
1932	532,784		21,992	3,797	558,573	176
1933	493,070		33,070	3,557	529,697	167
1934	272,782		25,675	40	298,497	94
1935	198,864		9,790	153	208,807	66
1936	189,741		9,013	47	198,801	62
1937	263,057		4,236	92	267,385	84
1938	176,421		13,203	34	189,658	60
1939	90,359		6,899	10	97,268	31
Average 1929–1939	299,618		17,364	703	317,685	100

DISTRICT M-6

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	102,934		463		103,397	141
1930	140,707		80,916	525	222,148	304
1931	195,233		47,905	8,877	252,015	345
1932	77,457		7,450	173	85,080	116
1933	37,498		3,058	2,625	43,181	59
1934	29,405		4,125	3,920	37,450	51
1935	24,415		444	2	24,861	34
1936	9,998		4,065		14,063	19
1937	10,887		210	3	11,100	15
1938	4,717		2,070		6,787	9
1939	2,600		2,037	16	4,653	7
Average 1929–1939	57,805		13,886	1,467	73,158	100

DISTRICT M-7

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	123,905		15,647	138	139,690	135
1930	202,878		244,882		447,760	433
1931	41,836	347	65,023		107,206	104
1932	24,096	3,819	19,970	49	47,934	46
1933	118,728	6,240	32,725	6	157,699	153
1934	66,400	74,956	49,178	48	190,582	184
1935	26,090	3,079	638	699	30,506	30
1936	4,243		893	76	5,212	5
1937	7,306		705	6	8,017	8
1938	550		559	28	1,137	1
1939	1,022		471	44	1,537	1
Average 1929–1939	56,096	8,040	39,154	99	103,389	100

DISTRICT M-8

Year	Large-mesh gill net	Deep trap net	Pound net	Other	Total annual production	Percentage of average annual production
1929	251,071		1,175	3,576	255,822	197
1930	106,791		34,277		141,068	108
1931	117,167		25,408	361	142,936	110
1932	64,142		622	336	65,100	50
1933	274,632		8,276		282,908	217
1934	284,784		20,788	14	305,586	235
1935	145,208		1,592	2,205	149,005	114
1936	16,591		2,815	60	19,466	15
1937	28,064		982	452	29,498	23
1938	14,007			9	14,016	11
1939	25,820		401	4	26,225	20
Average 1929–1939	120,752		8,758	638	130,148	100

APPENDIX C

INVESTIGATION OF POUND NETS AND DEEP TRAP NETS IN THE WISCONSIN WATERS OF LAKE MICHIGAN, 1931[42]

The brief investigation of the pound-net and deep-trap-net fisheries of the Door peninsula was conducted for the specific purpose of determining the validity of the strenuous complaints of commercial fishermen against the use of the deep trap net. The objections against the deep trap net as a dangerously efficient gear, as a source of destruction to young fish, and as a usurper of pound-net grounds were in general the same as those put forward by Michigan fishermen, and, consequently, need not be outlined in detail here. (See p. 298.) The procedure of the investigation involved observations of the lifting of pound nets and deep trap nets, interviews with operators of both types of nets (including a public hearing attended by more than 250 fishermen at Fish Creek, July 10, 1931), and the compilation of statistics on (1) the production of whitefish in the Wisconsin waters of Green Bay and Lake Michigan, beginning in 1889, and (2) the production of whitefish and the catch per lift in pound nets and deep trap nets of the Door peninsula, 1930–1931.

PRODUCTION OF WHITEFISH IN THE GREEN BAY AND LAKE MICHIGAN WATERS OF WISCONSIN, 1889-1939

The data on whitefish production in the State of Wisconsin waters of Green Bay and Lake Michigan (table 49) were compiled from original records in the files of the Wisconsin Conservation Department.[43]

TABLE 49.—*Production of whitefish in pounds in Green Bay and Lake Michigan, 1889–1939*

[Compiled from State records at Madison, Wis.]

Year	Green Bay	Lake Michigan	Green Bay and Lake Michigan	Year	Green Bay	Lake Michigan	Green Bay and Lake Michigan
1889	248,810	78,450	327,260	1920	42,411	89,022	131,433
1890	181,692	5,750	187,442	1921	171,896	190,519	362,415
1892	54,540	279,540	334,080	1922	80,658	82,543	163,201
1893	450,000	20,325	470,325	1923	74,484	363,439	437,923
1894	392,100	25,000	417,100	1924	182,989	64,115	247,104
1895	500,000	20,325	520,325	1925	147,556	94,823	242,379
1896	525,000	28,000	553,000	1926	249,976	90,479	340,455
1897	568,367	317,991	886,358	1927	191,779	122,453	314,232
1899	37,685	37,670	125,355	1928	430,386	123,681	554,067
1903	5,949	110,815	116,764	1929	287,648	44,965	332,613
1909	83,114	50,139	133,253	1930	500,996	34,832	535,828
1910	49,340	28,221	77,561	1931	462,117	235,663	697,780
1911	36,424	88,095	124,519	1932	183,002	93,522	276,524
1912	102,080	78,203	180,283	1933	86,051	37,402	123,453
1913	41,750	76,175	117,925	1934	82,105	17,591	99,696
1914	21,435	19,230	40,665	1935			263,900
1915	60,835	60,081	120,916	1936	49,046	93,555	142,601
1916	12,049	96,172	108,221	1937	45,587	91,270	136,857
1917	20,853	106,080	126,933	1938	60,962	80,663	141,625
1918	21,012	233,067	254,079	1939	27,200	86,620	113,820
1919	83,184	118,935	202,119				

Green Bay.—Whitefish production was large in the early and middle nineties, but there was a sharp drop in the catch at about the turn of the century. Production remained rather consistently at a low level over the years, 1909–1923; only two years (1912 and 1921) of this period had yields in excess of 100,000 pounds. Beginning in 1924 the production of whitefish in Green Bay followed an irregular but definite upward trend that culminated in a yield of a half million pounds in 1930. This catch (1930) was the greatest since 1897 and was the third largest in the known history of the fishery.

[42] This section is condensed from the unpublished "Report to the Conservation Commission of the State of Wisconsin on the Investigation of Deep Trap Nets, Conducted Jointly by the State Fisheries Department and the United States Bureau of Fisheries during the Period, July 6 to 11, 1931, in the Waters of Door County, Wisconsin." The investigation was made by Dr. John Van Oosten of the United States Bureau of Fisheries (now the Fish and Wildlife Service) and Messrs. B. O. Webster and Ira G. Smith of the Wisconsin Conservation Department.

[43] There are certain discrepancies between the data of table 49 of this appendix and those of table 1 of part 1. These arise from the fact that the former table has been based entirely on State of Wisconsin records (in order to have data for Green Bay and Lake Michigan separately) whereas the records of whitefish production in Wisconsin waters in the latter table were obtained from several sources. (See appendix A.)

Production was still high in 1931; however, the years, 1932–1939, comprised a period of rapid decline. The 1939 catch of 27,200 pounds was the lowest since 1918.

Lake Michigan.—The Lake Michigan data are much more variable than those for Green Bay, and it is correspondingly difficult to speak of definite periods of high or low production. Frequently exceptionally good or poor years are isolated (as, for example, 1892 and 1931). The period of most consistently low production was 1909–1916 (all years below 100,000 pounds) and the most extended era of heavy yield was 1917–1923 (all but two years above 100,000 pounds). The best of the more recent years was 1931 with a catch of 236,000 pounds. The 1931 catch was exceeded by that of only one year (1923) since 1897 and was the fourth highest in the history of the fishery. Production was consistently below 100,000 pounds in the years, 1932–1939 (no data for 1935).

Green Bay and Lake Michigan.—The data for all of the State of Wisconsin waters of Lake Michigan show a fairly consistent high level of yield for the years, 1889–1897. Available data indicate a relatively low production in the period, 1899–1917; only once (1912) did the catch exceed 150,000 pounds in the 11 years for which there are records, and it fell below 100,000 pounds in 2 of them (1910 and 1914). An upturn occurred in 1918. Over the period, 1918–1925, production fell below 200,000 pounds only twice (1920 and 1922) and exceeded 400,000 pounds in 1923. A still higher level was maintained during the six years, 1926–1931. All of the annual yields were above 300,000 pounds and 3 years had catches in excess of 500,000 pounds. The 1931 take of 698,000 pounds was the largest since 1897 and the second largest in history. Production was at a relatively low level in the years, 1932–1939. The catch exceeded 200,000 pounds in only two of these years (1932 and 1935). The 1934 catch was the lowest since 1914 and the third lowest on record.

A striking feature of the State of Wisconsin data is the lack of agreement between the statistics for Green Bay and Lake Michigan. Some years were good or poor in both areas, as for example, 1897, 1931, and 1934. It is true also that the data for the two areas occasionally agreed rather well in general trend over a period of several years as in 1909–1917 and 1931–1934. On the other hand, there were numerous years that had a very high catch in one area and exceptionally poor production in the other. Outstanding examples of such disagreements occurred over the period, 1890–1896, and in the years 1918, 1923, 1926, 1929, and 1930.

POUND-NET AND DEEP-TRAP-NET FISHERY, 1930-1931

Table 50 contains data on the pound-net and deep-trap-net fisheries for whitefish in Door County waters, 1930–1931. (Practically all of Wisconsin's whitefish are produced in these waters.) The comparison of the average catch per lift of the two gears in corresponding months confirms the contention of fishermen that the deep trap net is the more effective gear. The catch per lift of deep trap nets was 2.7 times that of pound nets in May 1931, 2.2 times in June, and 2.3 times for May and June com-

TABLE 50.—*Production of whitefish and catch per lift in pound nets and deep trap nets of Door County, Wis., 1930–1931*

Date or period	Pound net			Deep trap net		
	Number of lifts	Production (pounds)	Catch per lift (pounds)	Number of lifts	Production (pounds)	Catch per lift (pounds)
1930						
May	265	23,427	88 4			
June	595	85,546	143 7			
May and June	860	108,973	126 7			
1931						
April				17	803	47 2
May	253	21,524	85 1	130	29,652	228 1
June	391	66,364	169 7	184	69,359	376 4
July				43	11,509	267 6
April to July				374	111,323	297 3
May and June	644	87,888	136 4	314	99,011	315 3

bined. The data do not, however, support the complaint that the deep-trap-net fishery was extremely harmful to the pound-net fishery in 1931. It is true that the total production in pound nets was less in 1931 than in 1930, but the decline was the result of reduced fishing intensity. The average catch of whitefish per lift of pound nets was approximately 10 pounds greater in 1931 than in 1930.

Although the average lifts of whitefish in deep trap nets in 1931 were 2.3 times those of pound nets, this advantage depended only on the greater depth of water in which deep trap nets were fished. The effect of the depth of water on the size of the lift is brought out by the comparison of the lifts of whitefish in shallow pound nets, deep pound nets (more than 50 feet of water), and deep trap nets (table 51). There was little difference between the size of the lifts of deep pound nets and deep trap nets, but both took more than 8 times as many fish per lift as shallow pound nets (less than 50 feet of water). It is obvious, therefore, that any indictment of the deep trap net in Door County waters as a dangerously effective gear must apply also to deep pound nets.[44]

TABLE 51.—*Comparison of the catch of whitefish of shallow pound nets, of deep pound nets, and of deep trap nets fished in Door County, Wisconsin waters, June 1931*

Gear	Number of lifts	Total production (pounds)	Catch per lift (pounds)
Shallow pound net	58	2,566	44.2
Deep pound net	60	21,861	364.3
Deep trap net	184	69,359	376.4

Further conclusions based on observations of pound nets and deep trap nets in Door County waters are summarized as follows:

(1) The sorting of fish was more difficult in deep trap nets than in pound nets. However, less sorting was necessary with deep trap nets than with pound nets which ordinarily had 2-inch mesh (stretched measure). Very few illegal whitefish (legal size limit, 13 inches, total length, at the time of the investigation) were seen in deep trap nets, the mesh of which ranged from 3½ to 4½ inches. On several occasions small fish were seen to escape through the meshes as deep trap nets were lifted.

(2) Very few gilled fish were observed in deep trap nets, and most of the fish gilled were of legal size. A 3½-inch-mesh net allows the escape of whitefish of 13 to 13½ inches, total length, and smaller; 4½-inch meshes release whitefish about 16 inches long, and smaller.

(3) The observations did not support the contention that illegal whitefish brought to the surface in deep trap nets die. Small whitefish and herring were seen to pass through the bottom of the trap nets when they reached the surface, apparently uninjured and certainly not bloated.

REGULATIONS RECOMMENDED FOR THE DEEP TRAP NET IN WISCONSIN WATERS

The investigating committee submitted the following recommendations for the regulation of the deep trap net in Wisconsin waters (almost entirely direct quotation from report):

1. The size of the mesh in the lifting pot must be not less than 4½ inches but the side of the pot where fish are bagged may be of smaller mesh.
2. The length of the lead shall be not more than 50 rods.
3. A buoy must be attached to every anchor and each buoy must have a flag attached to it, extending not less than 30 inches above the surface of the water.
4. The shortest distance between strings of trap nets or between trap nets and pound nets shall be not less than one-half mile. A trap net as here defined refers to any part of the net constructed of webbing and includes the pot, tunnel, heart, and lead (not the anchors, ropes, buoys, and flags).

[44] Both gears can operate on the concentrations of whitefish at depths of 50 or 60 feet. Attempts of deep-trap-net fishermen to locate whitefish in deeper water (*ca.* 100 feet) were unsuccessful.

5. A trap net shall not be set in water more than 60 feet deep. A trap net under this ruling is the same as that defined under regulation no. 4.

6. No more than two trap nets shall be placed in one string and an open space free from netting of not less than 50 feet shall be left between the nets.

7. In the event of a dispute between a trap-netter and a pound-netter concerning the distance between nets, priority consideration shall be given the pound-netter if it is established that he has fished for several years the grounds where his nets had been set. Such consideration shall be given even though the trap-netter was the first to set his nets on the disputed grounds at the beginning of the season.

8. A trap net or a string of trap nets must be set approximately at a right angle to the shore line or shoal or reef.

9. Regulations 2, 4, 5, 6, and 8 have been recommended for trap nets on the assumption that they will be observed by pound-netters also. Enforcement is to be contingent on the adherence of pound-netters to these regulations.

APPENDIX D

THE WHITEFISH FISHERY OF LAKES HURON AND MICHIGAN, 1940-1942

Because of unavoidable delays in publication, statistics of the whitefish fishery have become available for three additional years (1940, 1941, and 1942) since the preparation of the main body of this paper and appendices A, B, and C. The data for these years are presented in this appendix. Discussion is brief and is concerned chiefly with the demonstration that the new information substantiates the conclusions drawn previously. Emphasis is placed on the detailed statistics for the State of Michigan waters although production data are given for other areas.

TABLE 52.—*Production of whitefish in pounds in the State of Michigan waters of Lake Huron, 1940–1942*

District or area	Year	Production in gear				Total	Percentage of total catch of lake	Percentage of 1929–1939 average
		Large-mesh gill net	Deep trap net	Pound net	Other			
H-1	1940	43,661	52,996	25,637	415	122,709	65.2	26
	1941	24,282	41,987	28,298	367	94,934	83.5	21
	1942	22,657	29,450	23,527	104	75,738	79.7	16
H-2	1940	149	11,421	11	790	12,371	6.6	7
	1941		3,384		466	3,850	3.4	2
	1942	818	343		5,914	7,075	7.4	4
Northern Lake Huron (H-1 and H-2)	1940	43,810	64,417	25,648	1,205	135,080	71.8	21
	1941	24,282	45,371	28,298	833	98,784	86.9	16
	1942	23,475	29,793	23,527	6,018	82,813	87.1	13
H-3	1940	28	1,282	4	435	1,749	0.9	2
	1941	10		10	459	479	0.4	1
	1942	668		48		716	0.7	1
H-4	1940	80	25,454	3,847	2,172	31,553	16.8	5
	1941	217	8,604	977	1,719	11,517	10.1	2
	1942	907	5,068	60	1,263	7,298	7.7	1
Central Lake Huron (H-3 and H-4)	1940	108	26,736	3,851	2,607	33,302	17.7	4
	1941	227	8,604	987	2,178	11,996	10.5	2
	1942	1,575	5,068	108	1,263	8,014	8.4	1
H-5	1940		8,702			8,702	4.6	3
	1941		633			633	0.6	[1] 0
	1942						0.0	0
H-6	1940		10,795	82	153	11,030	5.9	3
	1941	256	1,996	37	25	2,314	2.0	1
	1942	135	3,238	188	706	4,267	4.5	1
Southern Lake Huron (H-5 and H-6)	1940		19,497	82	153	19,732	10.5	3
	1941	256	2,629	37	25	2,947	2.6	[1] 0
	1942	135	3,238	188	706	4,267	4.5	1
Lake Huron (all 6 districts)	1940	43,918	110,650	29,581	3,965	188,114		9
	1941	24,765	56,604	29,322	3,036	113,727		5
	1942	25,185	38,099	23,823	7,987	95,094		4

[1] Less than 0.5.

WHITEFISH FISHERY OF LAKE HURON, 1940-1942

The downward trend in the production of whitefish in the State of Michigan waters of Lake Huron which got under way in 1933, and in 1939 had carried the annual yield to less than half the previously recorded minimum (555,000 pounds in 1900), continued through 1940–1942 (table 52 of this appendix—for further data on production see also table 1 of part I, tables 3, 4, 5, and 6 of part II, and appendix B). The production of 95,000 pounds in 1942 amounted to only 4 percent of the 1929–1939 average for Lake Huron,[45] and was only 2 percent of the 1931 maximum yield. Aside from unimportant increases in H–2, H–3, and H–6 in 1942 the trend was downward in all districts during the 3-year period.

With the exception of H–1, where the production percentages ranged from 16 to 26, the 1940–1942 yields of all districts amounted to only 7 percent (H–2 in 1940) or less of the 1929–1939 mean. The 1942 production was nil in H–5, a district that yielded 1,676,000 pounds of whitefish in 1933.

H–1 accounted for 65.2 to 83.5 percent of the total whitefish yield of the lake in 1940–1942. The only other district that yielded as much as 10 percent of the total in a single year was H–4 (1940 and 1941). The dominance of H–1 in this limited fishery was even more pronounced than in the early years, 1891–1908.

The progressive decline in production in the years, 1940–1942, can be attributed to a continued general decrease in fishing intensity (tables 53 and 54—see tables 8 and

TABLE 53.—*Annual fluctuations in the intensity of the fishery for whitefish in each district of Lake Huron, 1940–1942*

[Expressed as percentages of the average 1929–1939 intensity in the district]

District	Intensity as percentage of mean for district			District	Intensity as percentage of mean for district		
	1940	1941	1942		1940	1941	1942
H-1	54	18	23	H-4	35	13	9
H-2	28	7	4	H-5	18	1	(2)
H-3	(1)	(1)	3	H-6	14	3	2

[1] Inadequate data.
[2] No production.

TABLE 54.—*Annual fluctuations in the intensity of the whitefish fishery for all six districts of Lake Huron combined (third row from bottom of right half of table) and distribution of each year's intensity among the districts*

[The average annual intensity for the entire lake, 1929–1939, is 100.0. In parentheses are the intensity values of the deep-trap-net fishery. The value of one unit is 1/1,100 of the total expected catch of all districts, 1929–1939]

District or area	Intensity as percentage of mean for entire lake			District or area	Intensity as percentage of mean for entire lake		
	1940	1941	1942		1940	1941	1942
H-1	11.3 (5.1)	8.1 (3.2)	4.8 (1.5)	H-5	3.6 (3.6)	0.1 (0.1)	(2)
H-2	1.7 (1.7)	0.5 (0.5)	0.2 (0.2)	H-6	3.9 (3.8)	0.8 (0.7)	0.6 (0.5)
Northern Lake Huron (H-1 and H-2)	13.0 (6.8)	8.6 (3.7)	5.0 (1.7)	Southern Lake Huron (H-5 and H-6)	7.5 (7.4)	0.9 (0.8)	0.6 (0.5)
H-3	(1)	(1)	0.1 (0.0)				
H-4	8.2 (7.2)	3.1 (2.6)	2.0 (1.8)	Lake Huron (all 6 districts)	28.7 (21.4)	12.6 (7.1)	7.7 (4.0)
Central Lake Huron (H-3 and H-4)	8.2 (7.2)	3.1 (2.6)	2.1 (1.8)	Percentage of intensity represented by deep trap nets	74.6	56.3	51.9

[1] Inadequate data.
[2] No production.

[45] In this appendix as in part II references to "Lake Huron," "Lake Michigan," "the entire lake," or "the lake" should be understood to mean the State of Michigan waters only, unless otherwise specified

TABLE 55.—*Annual fluctuations in the abundance of whitefish in the various districts and areas of Lake Huron, 1940–1942*

[Expressed as percentages of average 1929–1939 abundance. In the computation of percentages for areas of more than one district and for the entire lake, the abundance percentage for each district was weighted according to the percentage of the total 1929 production contributed by that district]

District or area	Abundance percentage in year			District or area	Abundance percentage in year		
	1940	1941	1942		1940	1941	1942
H-1	52	56	75	H-5	12	21	(2)
H-2	32	36	24	H-6	14	13	28
Northern Lake Huron (H-1 and H-2)	44	48	53	Southern Lake Huron (H-5 and H-6)	13	17	28
H-3	(1)	(1)	41				
H-4	17	15	15	Lake Huron (all 6 districts)	29	31	35
Central Lake Huron (H-3 and H-4)	17	15	19				

[1] Inadequate data.
[2] No production.

9 of part II) brought about by a level of abundance (tables 55 and 56—see tables 10 and 11 of part II) that made profitable operations impossible.

Although the abundance percentages (table 55) and records of catch per unit effort (table 56) can not be considered very reliable for the districts in which the production reached extremely low figures, the data of table 55 nevertheless give some indication that with respect to the entire lake the abundance, which began to decline in 1932, reached its lowest level in 1940 (29 percent of the 1929–1939 average) and improved slightly in 1941 (31 percent) and 1942 (35 percent).[46] These small increases in the abundance percentages can not be taken as the basis for optimism concerning a possible early recovery of the whitefish fishery. On the contrary, it is to be considered most probable that the abundance and production of whitefish will continue to be low for years to come. The fishing intensity which was relatively low in all districts in 1940–1942 (table 53) and which had declined to 7.7 percent of average in 1942 for all districts combined (table 54) can not be expected to increase materially until abundance has risen to a level that permits profitable fishing. If a significant recovery occurs at all in the whitefish fishery of Lake Huron it may be expected to be slow. It is conceivable, of course,

TABLE 56.—*Annual fluctuation in the catch of whitefish per unit of fishing effort of gill nets, deep trap nets, and pound nets in the various districts of Lake Huron, 1940–1942*

Gear and unit of effort	District	Catch of whitefish (pounds) per unit of effort		
		1940	1941	1942
Gill net (unit lift of 10,000 feet)	H-1	39.7	39.5	50.3
	H-2	10.1		37.9
	H-3			10.0
	H-4	2.9	3.2	11.8
	H-5			
	H-6		13.2	7.0
Deep trap net (unit lift of one net)	H-1	45.1	57.8	84.9
	H-2	24.9	28.0	6.2
	H-3			
	H-4	29.5	27.8	23.8
	H-5	32.0	57.5	
	H-6	44.8	42.5	98.1
Pound net (unit lift of one net)	H-1	32.2	30.0	40.9
	H-2	1.6		
	H-3			
	H-4	4.5	3.1	1.4
	H-5			
	H-6	1.2	1.8	11.1

[46] Tables 53, 54, 55, and 56 contain no figures for H-3 in 1940 and 1941 and for H-5 in 1942. In H-3 the small catches of whitefish in 1940 and 1941 were mostly reported by fishermen using a gear (shallow trap net) not considered in our estimations of abundance or by operators whose reports did not contain information on the amount of gear lifted. No whitefish were produced in H-5 in 1942.

that unusual conditions in the lake which permitted an abnormally high survival of young in one or more years may restore the stock at a much higher rate than the present depleted condition of the population would give reason to expect.

Not only did the Michigan production of Lake Huron continue its decline after 1939, but the Canadian yield showed a similar trend (table 57), although not to the same disastrous degree. In Lake Huron proper (see p. 304 for its boundaries) the Canadian catch fell to 92,000 pounds in 1940 and increased only 1,000 pounds in 1941. These records are the lowest two for these waters since 1922 and comprise 42 percent of the average catch (219,513 pounds) for the period, 1923–1939. In Georgian Bay (includes the North Channel—see p. 304) the take decreased progressively from 1,275,000 pounds in 1939 to 833,000 pounds in 1941, the lowest production recorded for this area at least since 1922. This figure represents 58 percent of the average yield (1,427,564 pounds) for the years, 1923–1939. In the Michigan waters the 1941 catch equaled only 6 percent of the average production (2,052,331 pounds) during the period, 1922–1937, a value considerably less than the comparable Canadian percentages of 42 and 58. The 1939–1941 records of total catch for all waters (United States and Canadian) represent the lowest three ever recorded for the lake.

TABLE 57.—*Production of whitefish in pounds in Lakes Michigan and Huron, 1939–1942*

Year	Lake Michigan			Lake Huron			
	Wisconsin	Michigan	Entire lake	Michigan	Ontario: Huron proper	Ontario: Georgian Bay	Entire lake
1939	110,700	839,856	950,556	255,183	115,061	1,275,255	1,645,499
1940	196,600	754,115	954,815	188,114	92,403	1,006,082	1,286,599
1941	400,538	896,474	1,286,354	113,727	93,058	833,111	1,039,896
1942	279,363	1,061,056	1,340,419	95,094	----------	----------	----------

WHITEFISH FISHERY OF LAKE MICHIGAN, 1940-1942

The production of whitefish in the State of Michigan waters of Lake Michigan, which had declined irregularly from the modern peak of 4,813,000 pounds in 1930, reached an all-time recorded low of 754,000 pounds in 1940 (table 58—for further data on production see also table 1 of part I, tables 13, 14, 15, and 16 of part II, and appendix B). Although this yield amounted to only 32 percent of the 1929–1939 average, it was relatively much higher than the 1940 catch in Lake Huron (9 percent of the 1929–1939 mean—table 52). The take of whitefish in Lake Michigan improved substantially in 1941 (896,000 pounds; 38 percent) and 1942 (1,061,000 pounds; 46 percent). The 1940–1942 trend of production was consistently upward in northern and northeastern Lake Michigan (M–2, M–3, and M–4) and in the Grand Haven-Muskegon district (M–7), but was consistently downward in Green Bay (M–1) or irregular in the remaining districts (M–5, M–6, and M–8).

In all three years M–3 contributed considerably more than half of the total production (63.8, 58.4, and 67.5 percent in 1940, 1941, and 1942, respectively). The Green Bay district (M–1) ranked second each year but contributed a constantly decreasing percentage of the total (16.3, 12.9, and 8.7 percent). Third position was held by M–5 in 1940 and 1941 (11.5 and 10.0 percent) and by M–4 in 1942 (6.7 percent). The percentage of the total yield produced in the districts that ranked lower than third ranged from 7.5 percent in M–4 in 1941 to 0.1 percent in M–7 in 1940. It may be noted that the percentages of total production in the various districts in 1940–1942 resembled the corresponding figures for 1891–1908 much more closely than they did those for 1929–1939.

The abundance percentages, records of catch per unit of effort, and figures on fishing intensity (tables 59, 60, 61, and 62—see tables 17, 19, 20, and 21 of the main body of this paper) show that but for a low level of fishing intensity, production would have been much higher in 1940–1942, particularly in the last two years of the period. The abundance of whitefish which had dropped to an extremely low level in 1940 (23

TABLE 58.—*Production of whitefish in pounds in the State of Michigan waters of Lake Michigan, 1940–1942*

District or area	Year	Production in gear			Total	Percentage of total catch of lake	Percentage of 1929–1939 average
		Large-mesh gill net	Pound net	Other			
M-1	1940	50,170	71,015	1,618	122,803	16.3	23
	1941	73,707	41,982	63	115,752	12.9	22
	1942	66,654	25,884	8	92,546	8.7	18
M-2	1940	8,310	1,463		9,773	1.3	18
	1941	25,883			25,883	2.9	47
	1942	60,494			60,494	5.7	110
M-3	1940	225,939	254,771	66	480,776	63.8	45
	1941	280,571	241,884	629	523,084	58.4	49
	1942	384,704	331,228	54	715,986	67.5	67
M-4	1940	28,726	11,572	37	40,335	5.3	71
	1941	28,435	39,024	28	67,487	7.5	118
	1942	26,277	44,108	261	70,646	6.7	124
Northern Lake Michigan (M-1, M-2, M-3, and M-4)	1940	313,145	338,821	1,721	653,687	86.7	38
	1941	408,596	322,890	720	732,206	81.7	43
	1942	538,129	401,220	323	939,672	88.6	55
Central Lake Michigan (M-5)	1940	85,118	1,970	6	87,094	11.5	27
	1941	89,132	280	10	89,422	10.0	28
	1942	57,802			57,802	5.4	18
M-6	1940	925	108	130	1,163	0.2	2
	1941	6,348			6,348	0.7	9
	1942	1,823		62	1,885	0.2	3
M-7	1940	706	131	14	851	0.1	1
	1941	24,965	2,672	26	27,663	3.1	27
	1942	22,315	6,804		29,119	2.7	28
M-8	1940	11,312		8	11,320	1.5	9
	1941	36,460	4,375		40,835	4.5	31
	1942	31,559	1,014	5	32,578	3.1	25
Southern Lake Michigan (M-6, M-7, and M-8)	1940	12,943	239	152	13,334	1.8	4
	1941	67,773	7,047	26	74,846	8.3	24
	1942	55,697	7,818	67	63,582	6.0	21
Lake Michigan (all 8 districts)	1940	411,206	341,030	1,879	754,115		32
	1941	565,501	330,217	756	896,474		38
	1942	651,628	409,038	390	1,061,056		46

to 73 percent of the 1929–1939 average in the individual districts and 63 percent for the 8 districts combined—table 61) improved in every district in 1941. This general improvement was reflected in a rise in the abundance percentage from 63 to 91 for the lake as a whole. Further increases in 1942 in M–2, M–3, and M–8 more than compensated for declines in the remaining districts and carried the abundance percentage for all districts combined to the still higher level of 95. The abundance of whitefish was above the 1929–1939 average in three districts (M–4, M–6, and M–7) in 1941 and in five districts (M–2, M–3, M–4, M–7, and M–8) in 1942. Conspicuous among the percentages are the high value of 257 in M–6 in 1941 and the low figures of 45 and 34 in M–5 in 1941 and 1942. M–5 was the only district with abundance below 85 in 1941 or below 76 in 1942.

TABLE 59.—*Annual fluctuations in the intensity of the fishery for whitefish in each district of Lake Michigan, 1940–1942*

[Expressed as percentages of the average 1929–1939 intensity in the district]

District	Intensity as percentage of mean for district			District	Intensity as percentage of mean for district		
	1940	1941	1942		1940	1941	1942
M-1	38	30	27	M-5	71	64	55
M-2	47	48	91	M-6	4	5	4
M-3	67	61	64	M-7	5	23	27
M-4	108	96	126	M-8	18	44	27

Table 60.—*Annual fluctuations in the intensity of the whitefish fishery for all eight districts of Lake Michigan combined (bottom of right half of table) and distribution of each year's intensity among the districts*

[The average annual intensity for the entire lake, 1929–1939, is 100.0. The value of one unit is 1/1,100 of the total expected catch of all districts, 1929–1939]

District or area	Intensity as percentage of mean for entire lake			District or area	Intensity as percentage of mean for entire lake		
	1940	1941	1942		1940	1941	1942
M-1	8.3	6.5	5.8	M-6	0.1	0.1	0.1
M-2	1.2	1.3	2.4	M-7	0.2	0.8	1.0
M-3	31.4	28.8	29.9	M-8	1.0	2.3	1.4
M-4	2.9	2.5	3.3				
Northern Lake Michigan (M-1, M-2, M-3, and M-4)	43.8	39.1	41.4	Southern Lake Michigan (M-6, M-7, and M-8)	1.3	3.2	2.5
Central Lake Michigan (M-5)	10.5	9.5	8.1	Lake Michigan (all 8 districts)	55.6	51.8	52.0

Table 61.—*Annual fluctuations in the abundance of whitefish in the various districts and areas of Lake Michigan, 1940–1942*

[Expressed as percentages of average 1929–1939 abundance. In the computation of percentages for areas of more than one district and for the entire lake, the abundance percentage for each district was weighted according to the percentage of the total 1929–1939 production contributed by that district]

District or area	Abundance percentage in year			District or area	Abundance percentage in year		
	1940	1941	1942		1940	1941	1942
M-1	70	85	76	M-6	45	257	80
M-2	38	99	121	M-7	23	161	147
M-3	73	87	115	M-8	57	85	108
M-4	68	128	101				
Northern Lake Michigan (M-1, M-2, M-3, and M-4)	71	88	103	Southern Lake Michigan (M-6, M-7, and M-8)	43	152	114
Central Lake Michigan (M-5)	40	45	34	Lake Michigan (all 8 districts)	63	91	95

Table 62.—*Annual fluctuation in the catch of whitefish per unit of fishing effort of gill nets and pound nets in the various districts of Lake Michigan, 1940–1942*

Gear and unit of effort	District	Catch of whitefish (pounds) per unit of effort		
		1940	1941	1942
Gill net (unit lift of 10,000 feet)	M-1	83.0	124.6	92.0
	M-2	16.7	35.2	43.1
	M-3	45.0	59.9	80.8
	M-4	27.4	33.6	30.6
	M-5	31.2	35.5	27.0
	M-6	19.5	98.1	30.7
	M-7	31.4	221.7	161.1
	M-8	59.4	91.5	113.5
Pound net (unit lift of one net)	M-1	44.4	39.0	39.5
	M-2	14.6	.....	.....
	M-3	98.9	106.2	135.0
	M-4	40.0	123.9	74.3
	M-5	41.0	56.0	.....
	M-6	18.0	.....	.....
	M-7	6.0	27.3	68.7
	M-8	.....	64.3	84.5

Despite the markedly improved abundance of whitefish in the State of Michigan waters of Lake Michigan in 1941 and 1942, fishing intensity was relatively low. For the eight districts combined (table 60) the intensity, which was lower in 1940 (55.6 percent) than in any year except 1936 (55.1 percent) of the period, 1929–1939, decreased even further in 1941 (51.8 percent) and remained at about the same level (52.0 percent) in 1942. Among the individual districts (table 59) fishing intensity tended to be relatively high in M–2, M–3, M–4, and M–5 and low in southern Lake Michigan (M–6, M–7, and M–8) and Green Bay (M–1).

The significance of the most recent figures for the whitefish fishery of the State of Michigan waters of Lake Michigan may be summarized in the one statement that the abundance of whitefish appears to be returning to an approximately normal level while production is held in check by a low fishing intensity.

Whether this statement is equally true for the whitefish of the Lake Michigan waters of other States is not known. Virtually no whitefish production is recorded for Illinois and Indiana in 1940–1942. The Wisconsin statistics (table 57) suggest some improvement in that State. In contrast to the Michigan catch, that of Wisconsin increased in both 1940 and 1941, reaching a relatively high level in 1941, although again in contrast to Michigan's yield, it decreased to approximately the normal level in 1942. With respect to the entire lake (all States) the trend of production is upward, after 2 years of extremely low yields.

BEARING OF THE 1940-1942 STATISTICS OF THE WHITEFISH FISHERIES OF LAKES HURON AND MICHIGAN ON THE VALIDITY OF EARLIER CONCLUSIONS

The 1940–1942 statistics of the whitefish fishery of the State of Michigan waters of Lakes Huron and Michigan do not give the slightest reason for modifying the summary paragraphs at the end of part II of the main body of this paper. In Lake Huron the "collapse of the whitefish fishery" proved to be even more devastating than had been anticipated. The belief that in Lake Michigan the decline of the whitefish was "not disastrous" has been substantiated by the return of the whitefish to nearly normal abundance (91 and 95 percent) in 1941 and 1942.

The contrast between conditions in the whitefish fisheries of Lake Huron and Lake Michigan in 1940–1942 is brought out sharply by the data of table 63 (see also table 22 of part II). In Lake Huron, production and fishing intensity, already at an extremely low level in 1940, continued to decline in 1941 and 1942. Any improvement that did occur in the status of the whitefish was relatively small. The abundance of whitefish was relatively much higher in 1940 in Lake Michigan (63 percent of average) than in Lake Huron (29 percent). Furthermore, the abundance in Lake Michigan rose sharply in 1941 and increased again in 1942. The production of whitefish also increased significantly in 1941 and 1942. Only fishing intensity declined (in 1941) or remained unchanged (in 1942). The supplementary data of this appendix, therefore, support the conclusion that overfishing traceable to deep-trap-net operations brought about the ruin of the whitefish fishery in Lake Huron. Although overfishing admittedly may have occurred in Lake Michigan and may have contributed to the decline that culminated in 1940, this overfishing was much less severe than in Lake Huron and did not carry the level of abundance of whitefish so low as to make rapid recuperation of the stock impossible. In fact, only low fishing intensity prevented nearly normal production of whitefish in Lake Michigan in 1941 and 1942.

TABLE 63.—*Production and abundance of whitefish and the intensity of the whitefish fishery in the State of Michigan waters of Lakes Michigan and Huron*

[Expressed as percentages of the 1929–1939 average]

Lake	Item	Year		
		1940	1941	1942
Michigan	Production	32	38	46
	Fishing intensity	56	52	52
	Abundance	63	91	95
Huron	Production	9	5	4
	Fishing intensity	29	13	8
	Abundance	29	31	35

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