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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 encountered 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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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).

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[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

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[1] 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.

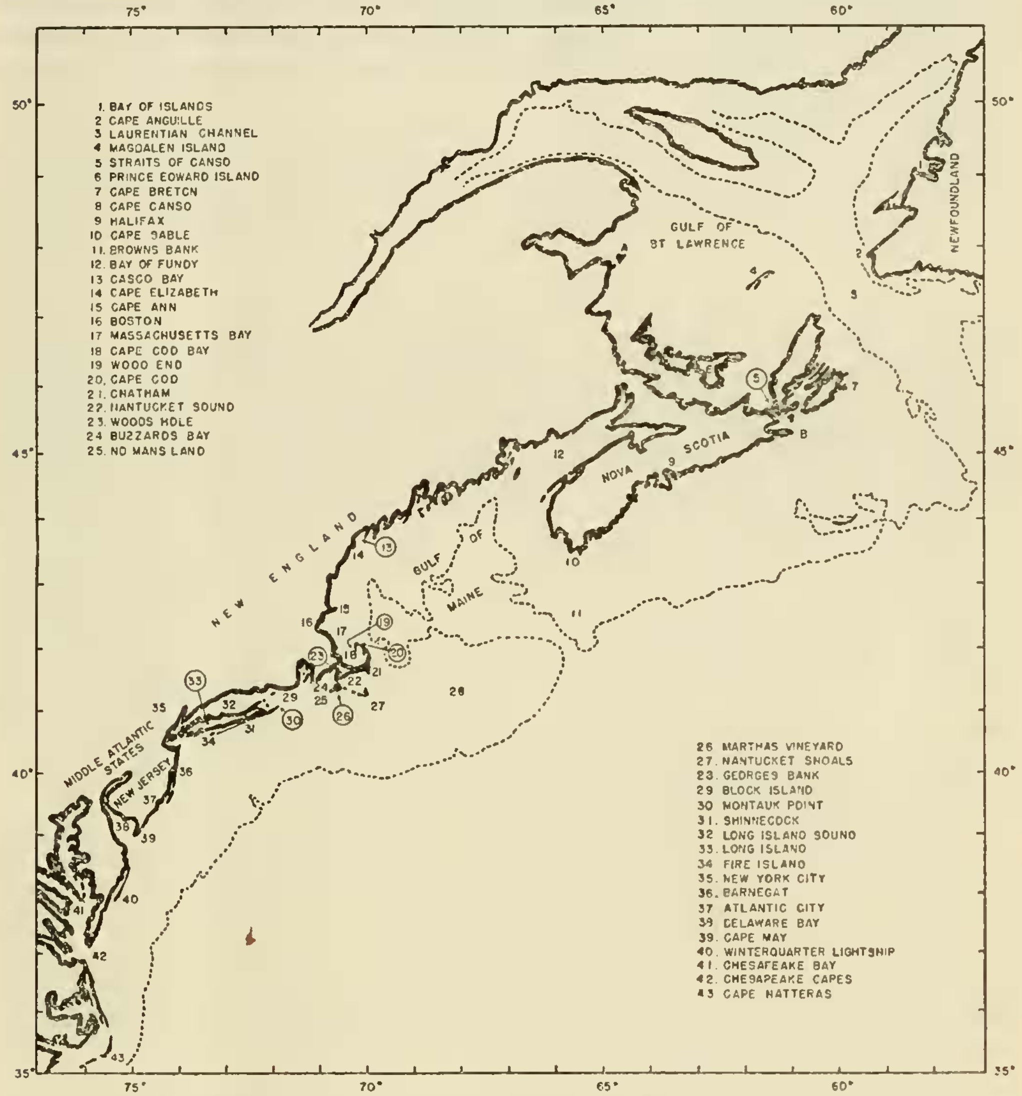

Figure 1.—Geographical features and landmarks mentioned in the text.

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 1⅛ 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 statistically 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.

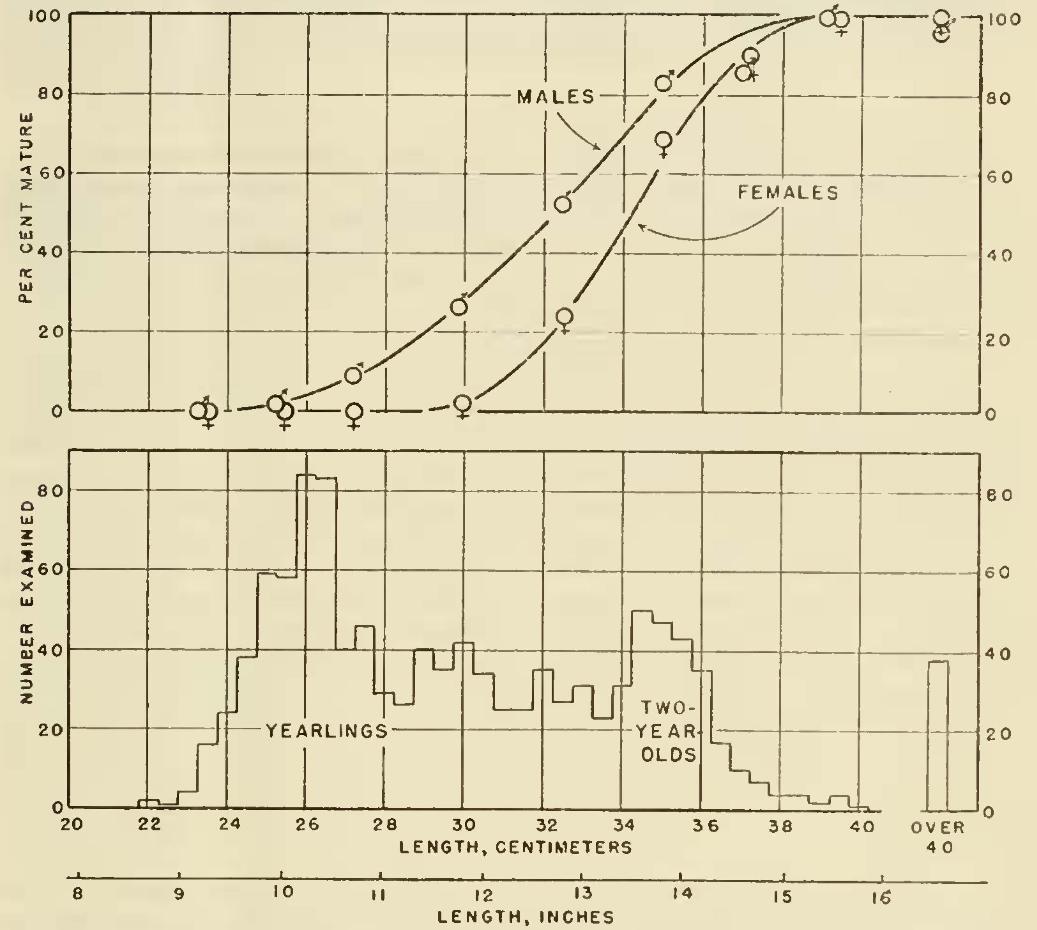

FIGURE 2.—Length and age at which mackerel reach reproductive maturity. The upper panel shows, by 2½ cm. length groups, the percentage of each sex matured. The lower part shows by half cm. length groups, the numbers examined for determination of percentage of maturity.

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.

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[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

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[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.[1]

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 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

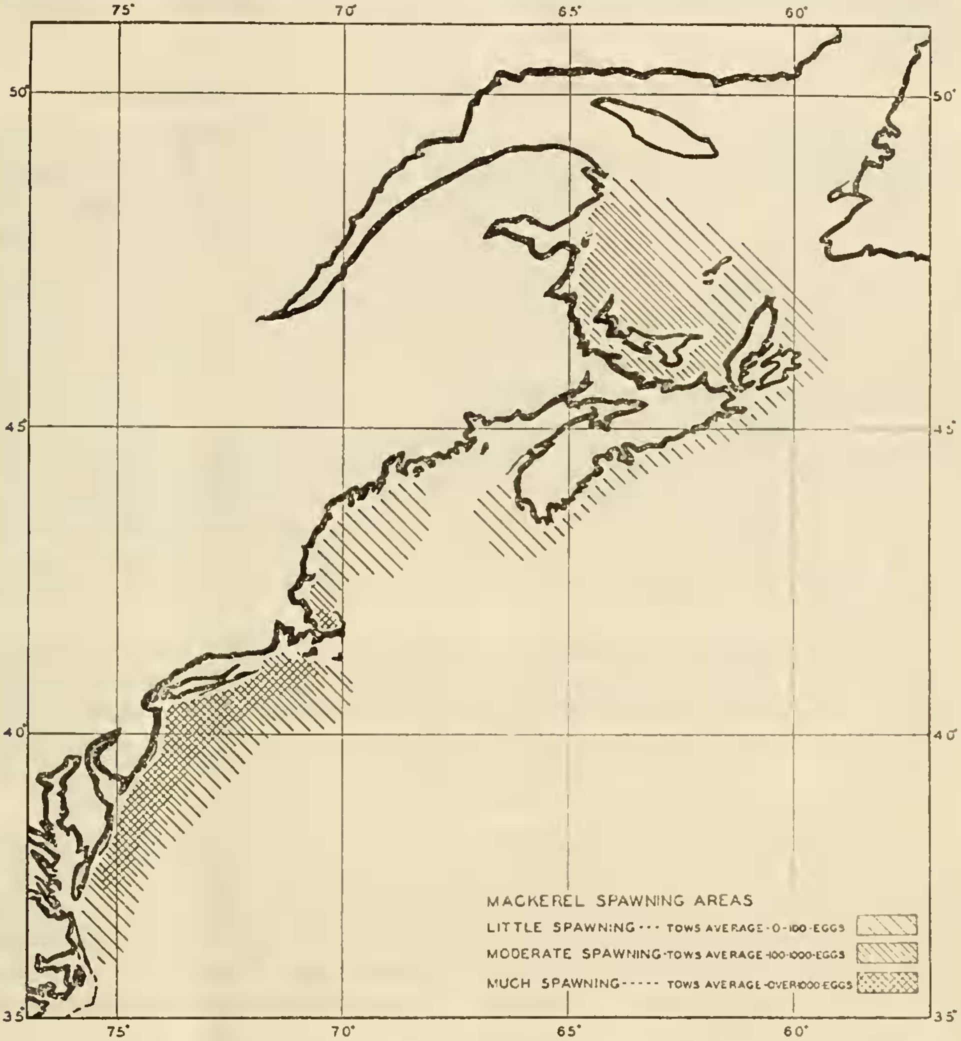

FIGURE 3.—Relative intensity of mackerel spawning in various regions along the Atlantic coast of North America, as indicated by the average number of eggs caught in plankton nets.

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

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[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	[3] 22,850	[3] 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.

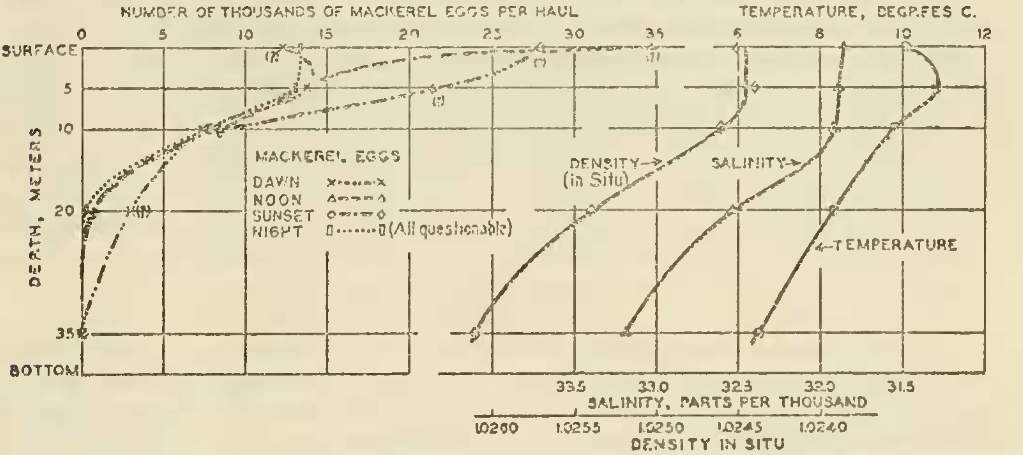

FIGURE 4.—Vertical distribution of mackerel eggs in relation to temperatures, salinity, and density of water. Observations were adjusted to the basis of standard speed of towing, except those indicated as questionable.

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

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[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

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[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.

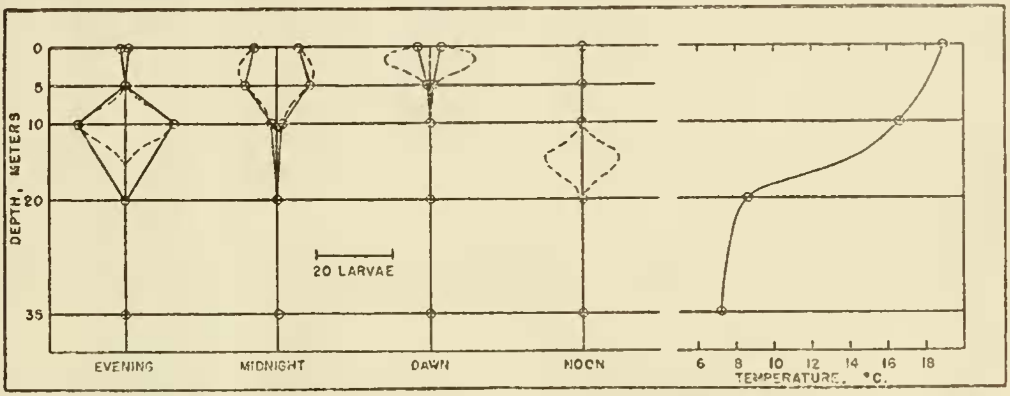

FIGURE 5.—Vertical distribution of mackerel larvae at several points of time in the diurnal cycle in relation to temperature. The solid lines connect observational points. The broken lines indicate the probable vertical position of the bulk of the population of larvae.

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 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.

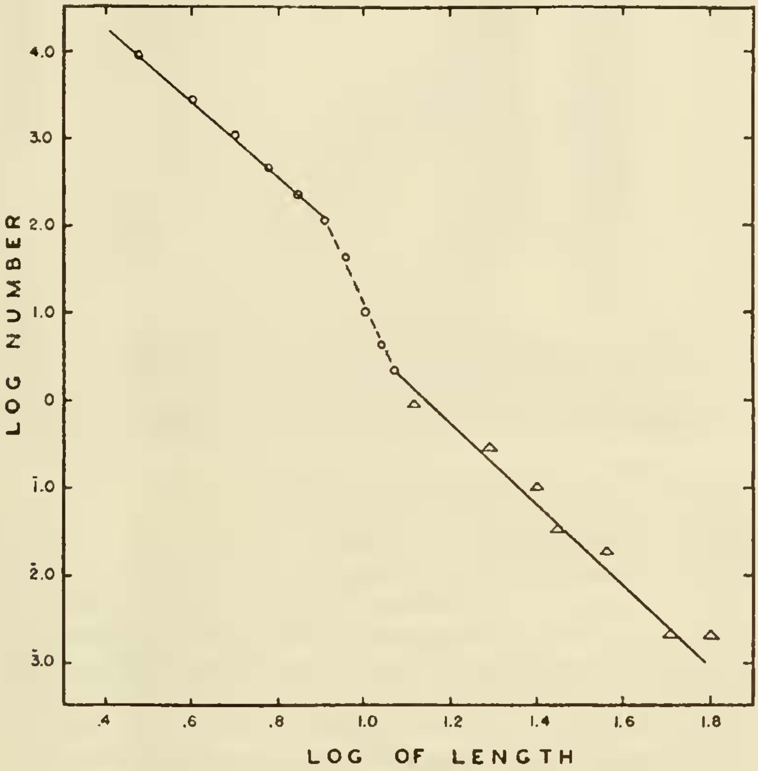

FIGURE 6.—Frequency distribution of lengths of larvae plotted logarithmically.

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	−1.56	−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 homologous modes, and that the straight lines fitted to the respective series correctly describe the larval and post-larval growth in 1932.

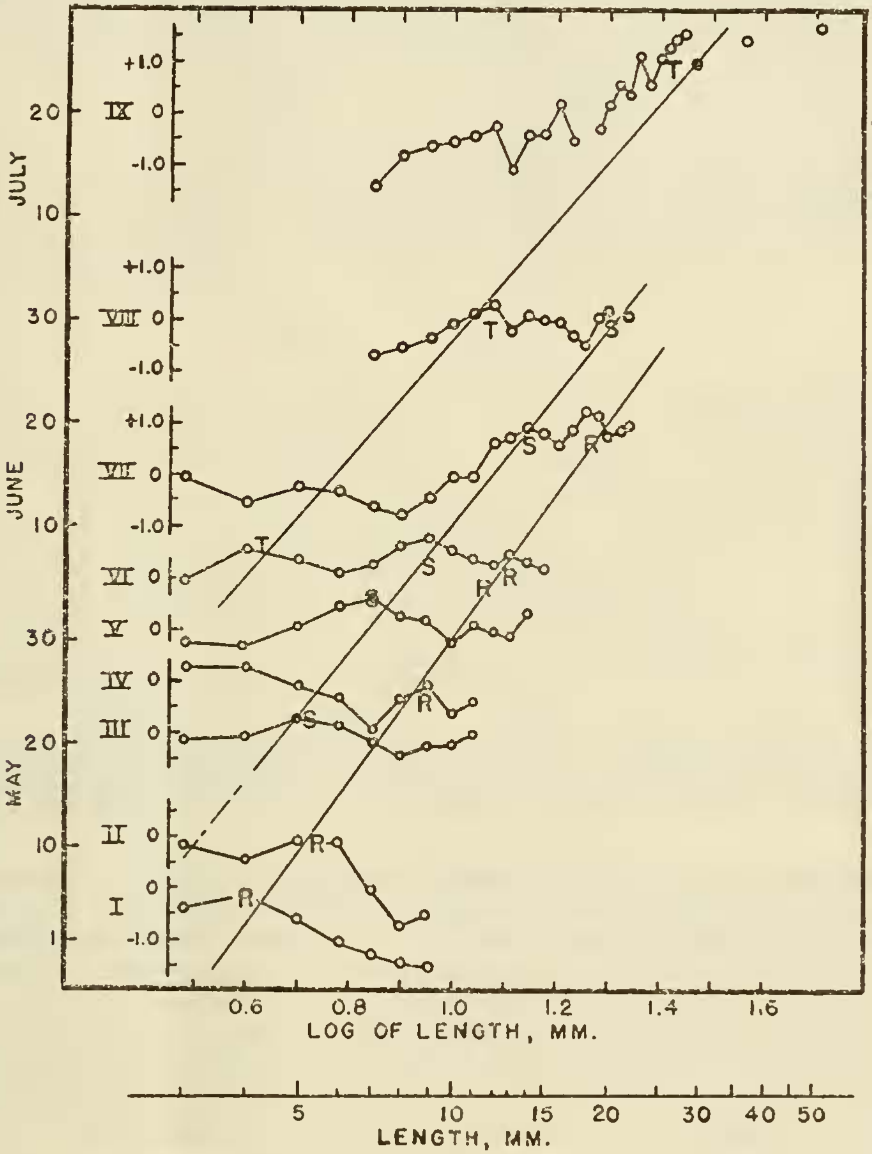

FIGURE 7.—Growth of mackerel larvae and post-larvae as indicated by the progress of modes in the deviations of numbers of specimens in each size-class taken on individual cruises from the average number taken on all cruises. The letters R, S, and T mark the positions of homologous modes referred to the 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.

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[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.

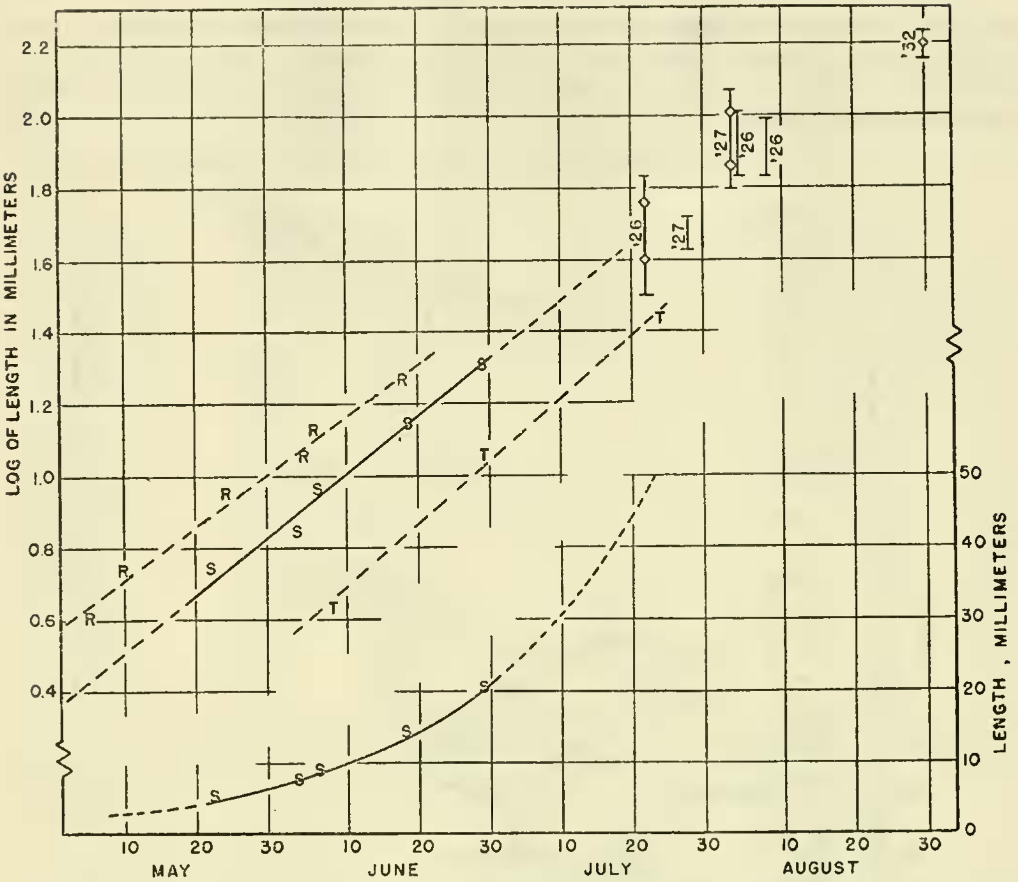

FIGURE 8.—Growth of mackerel larvae and post-larvae derived from the progression of modes of figure 7. The vertical lines at the upper right represent the range of sizes and position of modes (diamonds) of young mackerel collected by dip net from pound nets in the vicinity of Woods Hole, Mass., in the 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. Since the data on these need to be formalized for comparison with the mackerel, each will be presented in turn.

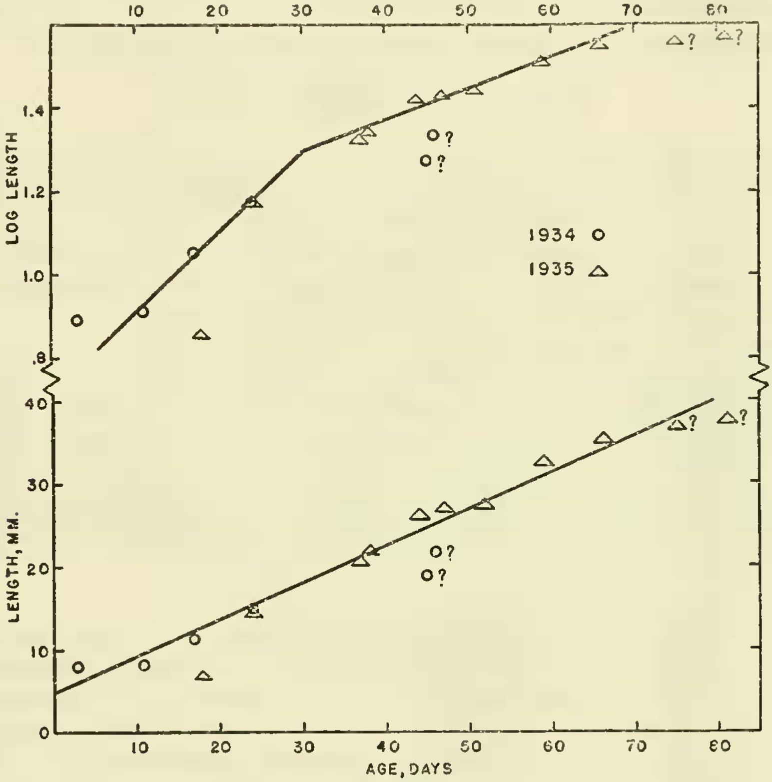

FIGURE 9.—Growth of pre-metamorphosis herring on the Clyde Sea area, after Marshall, Nicholls, and Orr, plotted logarithmically (upper part) and arithmetically (lower part).

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 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]

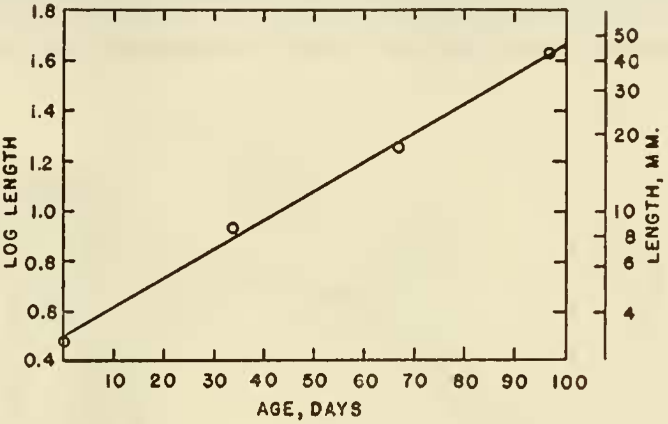

FIGURE 10.—Growth of haddock during early life. Data from Walford, 1938.

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.

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[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.

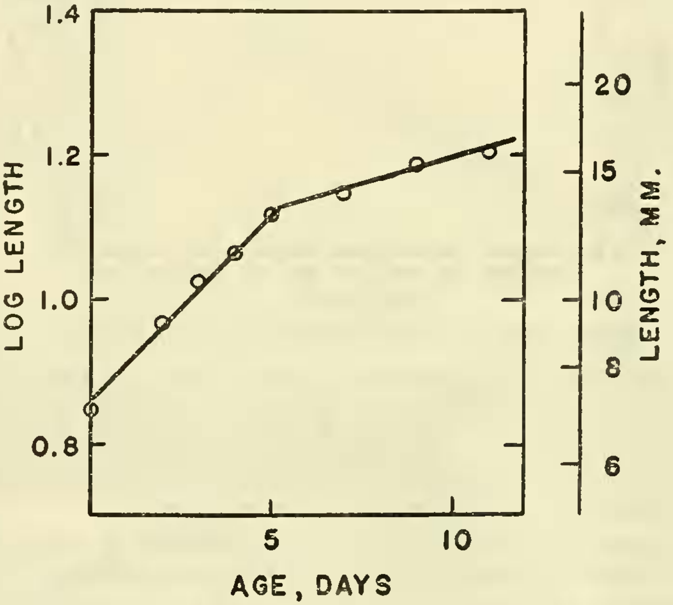


FIGURE 11.—Growth of northern pike during early life. Data from Embody, 1910.

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 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.

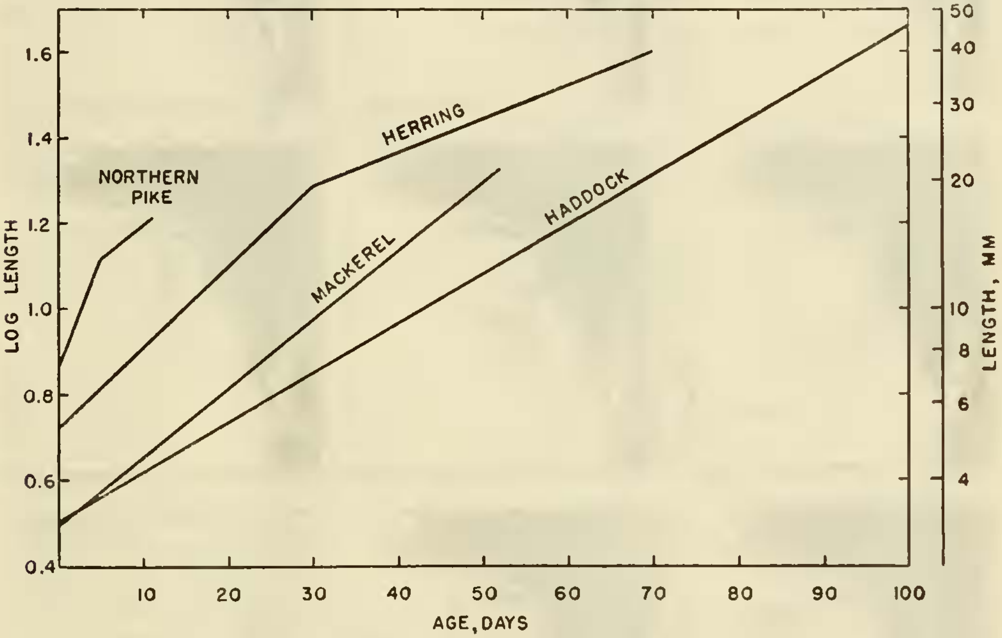
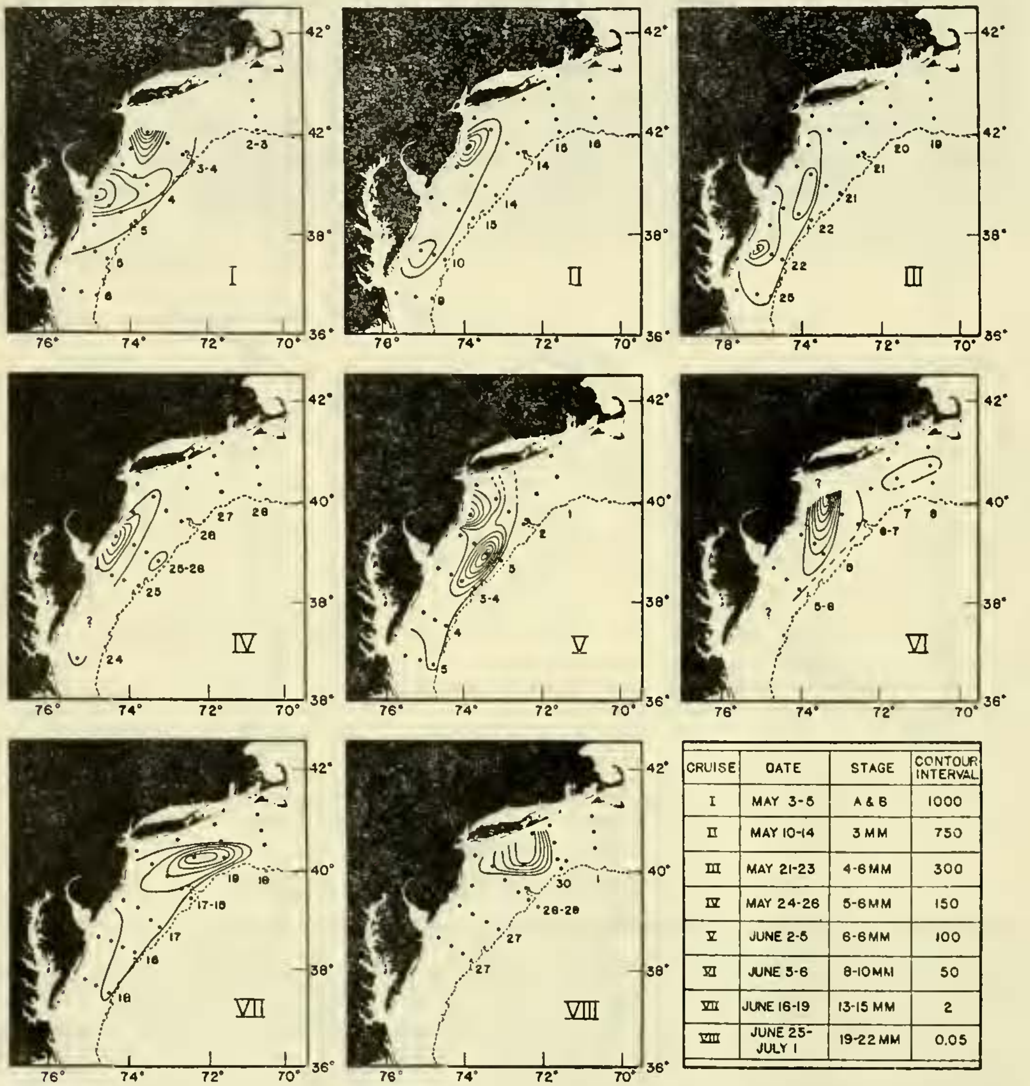


FIGURE 12.—Growth of northern pike, herring, mackerel, and haddock.

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 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).



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	6-6 MM	100
VI	JUNE 5-6	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.

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[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.

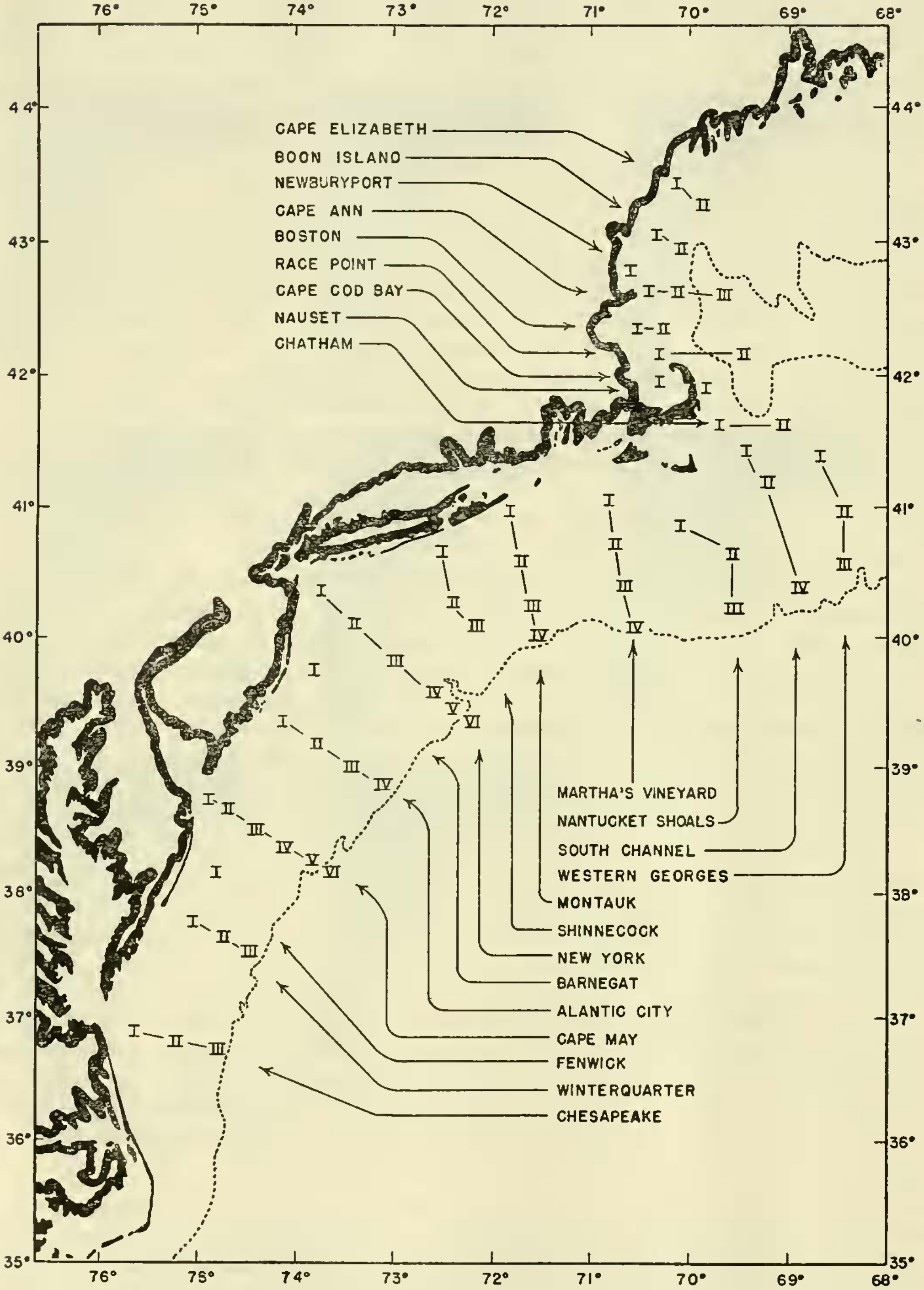

FIGURE 14.—Location of stations occupied during the 9 cruises of 1932.

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 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

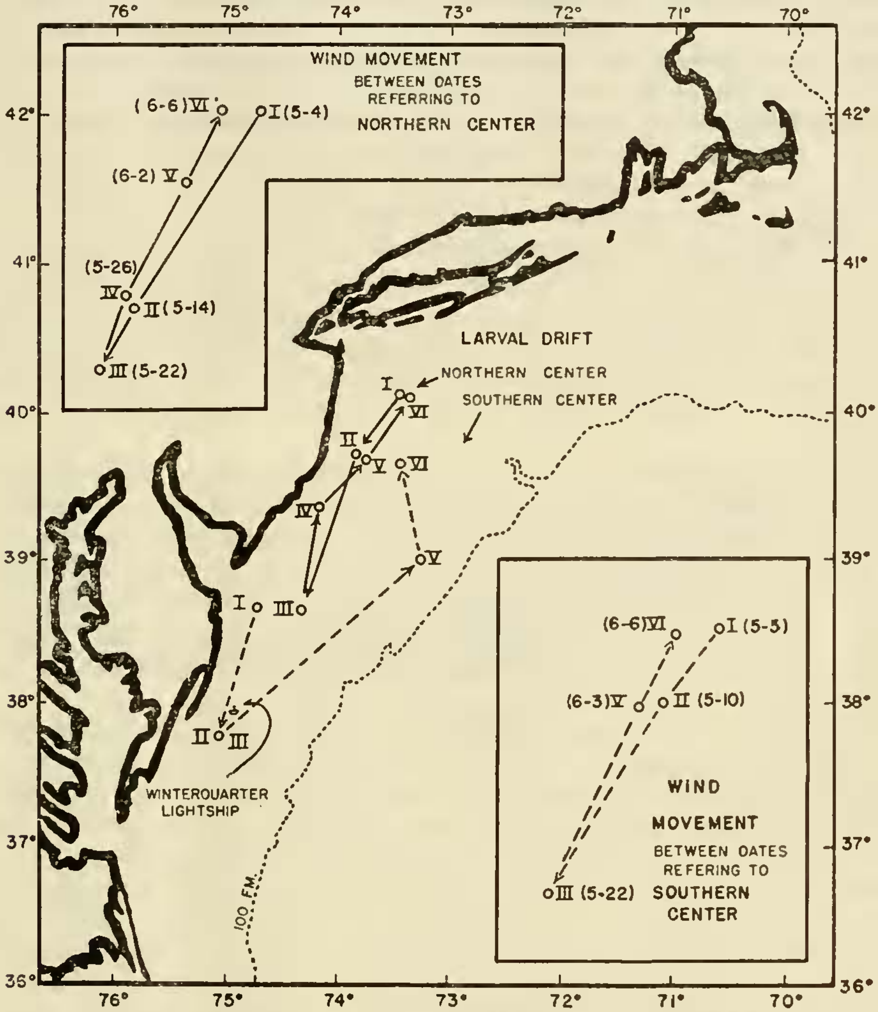

FIGURE 15.—Drift of the 2 centers of distribution of the S group compared with wind movements, as recorded at Winterquarter Lightship.

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[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

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[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 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.

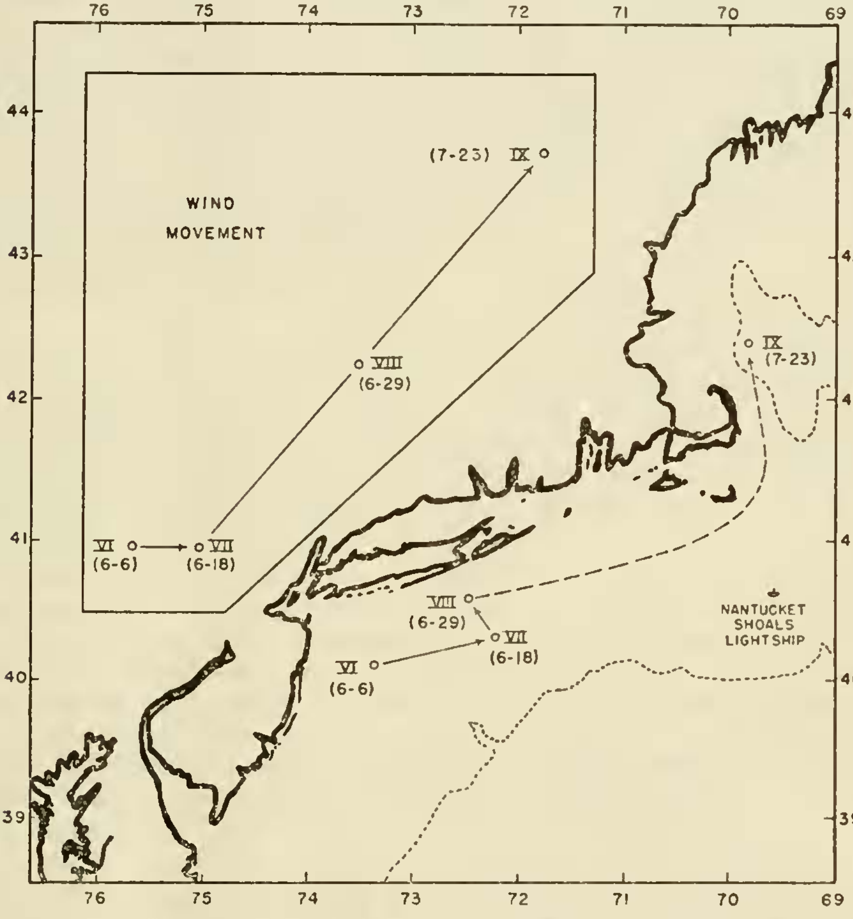

FIGURE 16.—Drift of post-larvae of the S group compared with wind movement, as recorded at Nantucket Shoals Lightship.

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 [3]	Frequencies		Survival per million newly spawned eggs			
					Logarithmic values		Arithmetic values	
			Average per cruise [3]	Average per cruise adjusted for duration of category [4]	Empirical [5]	Computed [6]	Empirical	Computed [6]
Egg stages:	*Days*	*Days*	*Number*	*Number*	*Log*	*Log*	*Number*	*Number*
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

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[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 I, Winterquarter I, 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 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

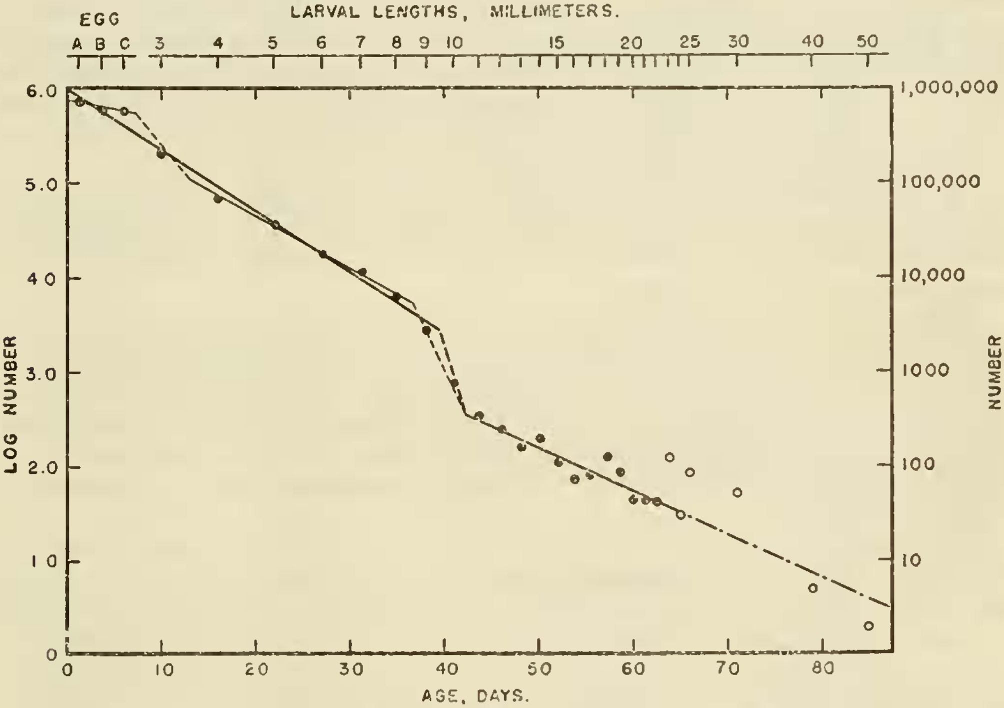

FIGURE 17.—Survival of young stages of mackerel in 1932. Solid dots represent the means of three or four cruises each. Open circles represent the less reliable values based on only one cruise. The heavy lines represent a simple interpretation of survival rates, and the fine lines, a more complex alternative 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.

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.

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[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

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

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[21] Buchanan-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		
9,500	6.71	6.71
9,000	13.82	7.11
8,500	21.32	7.50
8,000	29.28	7.96
7,500	37.77	8.49
7,000	46.85	9.08
6,500	56.59	9.74
6,000	67.12	10.53
5,500	78.57	11.45
5,000	91.14	12.57
4,500	105.02	13.88
4,000	120.55	15.53
3,500	138.12	17.57
3,000	158.38	20.26
2,500	182.40	24.02
2,000	211.74	29.34
1,500	249.57	37.83
1,000	302.93	53.36
500	394.12	91.19
475	400.83	6.71
450	407.94	7.11
425	415.44	7.50
400	423.40	7.96
375	431.89	8.49
350	440.97	9.08
325	450.71	9.74
300	461.24	10.53
275	472.69	11.45
250	485.26	12.57
225	499.14	13.88
200	514.67	15.53
175	532.24	17.57
150	552.50	20.26
125	576.52	24.02
100	605.86	29.34
75	643.69	37.83
50	697.05	53.36
25	788.24	91.19
20	817.58	29.34
15	855.41	37.83
10	908.77	53.36
5	999.96	91.19

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

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

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

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

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[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

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[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 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.

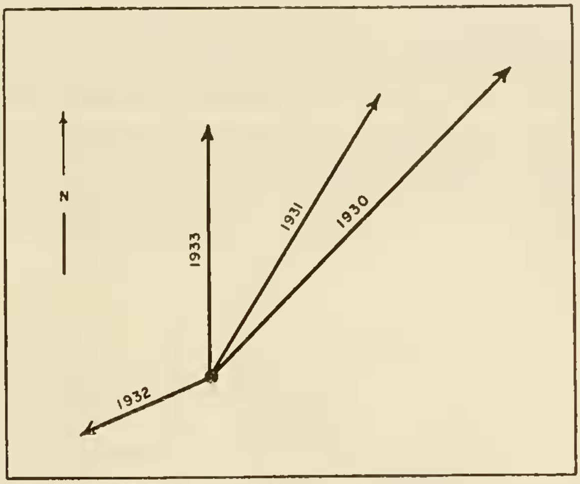

FIGURE 18.—Resultants of wind movement, as recorded at Winterquarter Lightship during May of each year 1930–1933.

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

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[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 16 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	678	.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	1.16	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	.97	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	890	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	21429	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	1.31	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	254	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	1,010	406	1.23	0	102	.07
Barnegat: I	21419	do	7	20	940	325	1.31	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	065	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	.16
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	402	.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	32	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] 445	.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	6	--------	--------	--------	--------	--------	--------	--------
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: [2]										
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:[3]										
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 larvae (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	0	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	37	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	.06	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	34.21	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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