PRODUCTION AND DISTRIBUTION OF COD EGGS IN MASSACHUSETTS BAY IN 1924 AND 1925

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INTRODUCTION

PELAGIC EGGS AND LARVÆ

With very few exceptions all marine animals, and in fact almost all plants of the sea as well, spend a large part of their lives in the surface waters. Some forms remain pelagic a very short time, while others drift about for months. The fate of even the invertebrate communities inhabiting our coastal waters lies solely in the success or failure of their pelagic young to maintain themselves in the plankton. There must be ample food available, and the winds and tides must remain favorable at least until they reach the stage when benthonic life begins.

In regions where a definite drift flows constantly in one direction the communities would soon become exhausted were there not a constant supply of individuals from other sources. The fact that some groups of benthonic animals are not found in certain regions does not imply necessarily that conditions there are unfavorable for their growth. It is likely that currents would carry the young away before they could attach and the neighboring communities are not situated in such a way that they can serve as sources of supply.

In protected areas where no dominant drift occurs it is possible that young pelagic forms oscillate back and forth on the rising and falling tides, later descending to the bottom in approximately the same place from whence they originated. However, if we exclude such exceptional cases as inclosed bays and harbors, it is highly improbable that a single one of the individuals seeking the bottom along our coast succeeds in locating itself within miles of its point of origin.

The importance of drifts in governing animal distribution is by no means confined to invertebrate bottom forms. The relative importance of fish-spawning grounds as production centers is to a large degree dependent upon ocean currents. When one considers that for weeks and even months the helpless eggs and fry drift about at the mercy of the winds and tides, battered by storms and surrounded by enemies, it is not surprising that so small a percentage ever lives to reach maturity. Bigelow (1926, p. 69), in discussing drifts, states: "Outside the outer headlands, however, the journeyings of floating fish eggs are, generally speaking, so considerable that they are often measured better by degrees of latitude and longitude than by miles." Off the northern coast of Norway, Hjort (1914) found that young cod fry sometimes were carried for hundreds of miles. He also found that the actual quantity of eggs produced often is not in itself a factor sufficient to determine the numerical value of a year class. A rich spawning year may yield a very disappointing year class, while a large year class may have its origin in a very poor spawning year. This has been observed repeatedly in Lofoten.

However, it has also been found that the abundance of any age group probably is determined by conditions in the very early stages. As early as 1914 Hjort (1914, p. 204) stated: "The rich year classes thus appear to make their presence 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 lifetime of the individual." Again, in discussing which stage of development forms the most critical period, he added: "Such data as are available, however, appear to indicate the very earliest larval and young-fry stages as most important."

In studying the distribution of fish eggs and larvæ it is necessary to distinguish between those species that collect on definite grounds to spawn and such pelagic forms as the mackerel, which appear to spawn over extended areas, irrespective of depth or bottom. The different starting points of the eggs must be taken into consideration in interpreting movements in the latter species. The gadoids (cod, haddock, and pollock), which have limited spawning areas, may be included as one group, although they are not particularly favorable for a group study, having different spawning areas as well as somewhat different breeding seasons. For that reason only the cod (*Gadus callarias*) will be considered in the present paper.

The breeding areas of the cod may be divided into two groups—the inshore grounds and the offshore grounds. Among the latter may be mentioned Nantucket Shoals, Georges Bank, Western Bank, and the Grand Bank. Ipswich Bay and the spawning area off Plymouth are perhaps the most important of the inshore grounds on the New England coast.

The present paper is concerned with the results of an investigation to determine the importance of Massachusetts Bay as a production center for cod and also its part in the natural economy of the region. It had been suggested that the southwest current or drift along the Maine coast carries eggs and early fry into Massachusetts Bay, which, protected by the arm of Cape Cod, serves as a nursery not only for those entering from the east but also for large numbers spawned in the bay itself, where the young cod find ample food and are protected from storms and winds until large enough to take care of themselves. It had even been suggested that this area might form an important source of supply for the codfish of the whole coast of New England.

PREVIOUS EVIDENCE OF COASTAL DRIFT IN THE GULF OF MAINE

That a definite southerly drift or set exists along the whole western margin of the Gulf of Maine is indisputable. Since earliest times fishermen have known of the "so'west current" and utilized it in navigation. At times its inner margin is defined clearly by slicks or, on calm days, by a line of seaweed and other floating débris.

Drift-bottle and current experiments by Mavor (1920 and 1922), Bigelow (1927), and Dawson (1905) have shown not only the direction of the drift but also have contributed considerable information on its rate of movement. (See fig. 1.) Mavor found that the set in summer and autumn averaged about 4 miles per day, and Bigelow (1926) suggests that in spring it is probably higher than that. To the drift-bottle evidence may be added the very extensive data on the general circulation obtained by the latter author from current measurements, temperature and salinity distribution, and dynamics, all of which substantiate the existence of a definite counterclockwise set around the gulf.

Earlier observations on egg and larval-fish distribution also indicate a movement from the northeast to the southwest. Based on evidence accumulated in the Gulf of Maine since 1912, Bigelow (1926, p. 75) concluded: "Thus fish eggs and larvæ, and for that matter every member of the plankton, animal or vegetable, tend to follow the same peripheral migration zone as do the immigrants that enter the eastern side of the gulf in the upper 50 meters." Also, "At the times when the dominant drift of the surface water follows the coast line closest, south toward Cape Ann, Massachusetts Bay probably acts to some extent as a catch basin for all sorts of flotsam from the north, living, of course, as well as dead, as it did for certain of Mavor's drift bottles. The chart (fig. 2) suggests that larvæ that pass Cape Ann tend to be caught up in the backwater of the bay, to remain there until they abandon the pelagic life for the bottom. Thus it is probable that the rich fish fauna of the bay and its adjacent waters is regularly recruited from the north and east."

The scarcity of eggs reported by Bigelow in the Gulf of Maine east of Mount Desert and the increasing numbers toward the west, combined with the fact that one of the most important of the inshore spawning grounds (Ipswich Bay) is situated just north of Cape Ann, seemed to be assurance in itself of an ample supply of developing eggs and pelagic fry, even if no breeding grounds had existed within the confines of Massachusetts Bay itself; but catches extending over a long period of years from the grounds off Plymouth have shown that this bay harbors one of the largest of the inshore breeding centers and one that supplies a large percentage of the eggs hatched each year at Gloucester. Between November 24, 1911, and January 3, 1912, 67,032,000 cod eggs were collected from Plymouth by the Gloucester hatchery; and in 1925–26 these same grounds were one of the principal contributors to the 1,219,468,000 cod

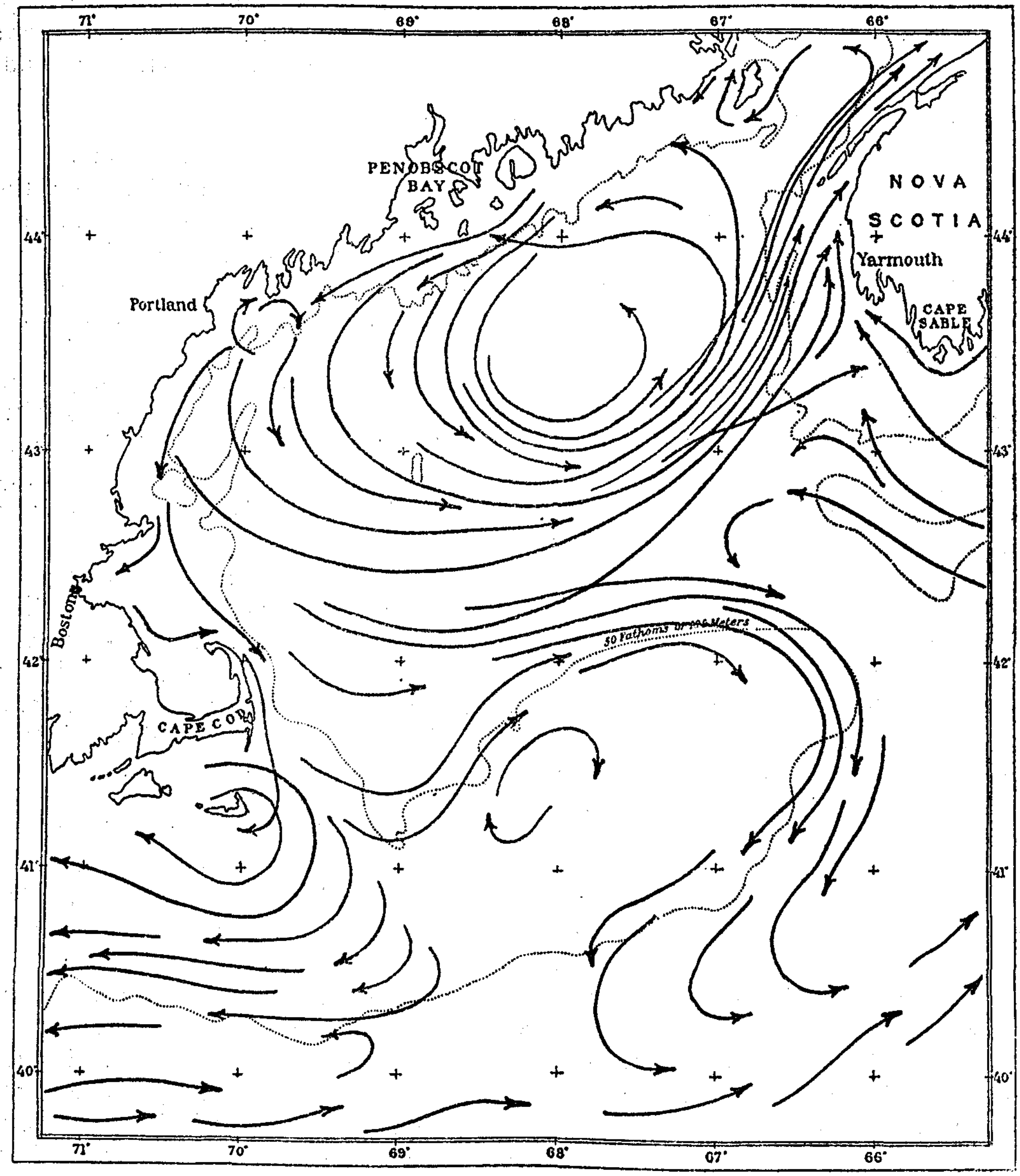

FIG. 1.—Dominant circulation of water in the Gulf of Maine. (After Bigelow.)

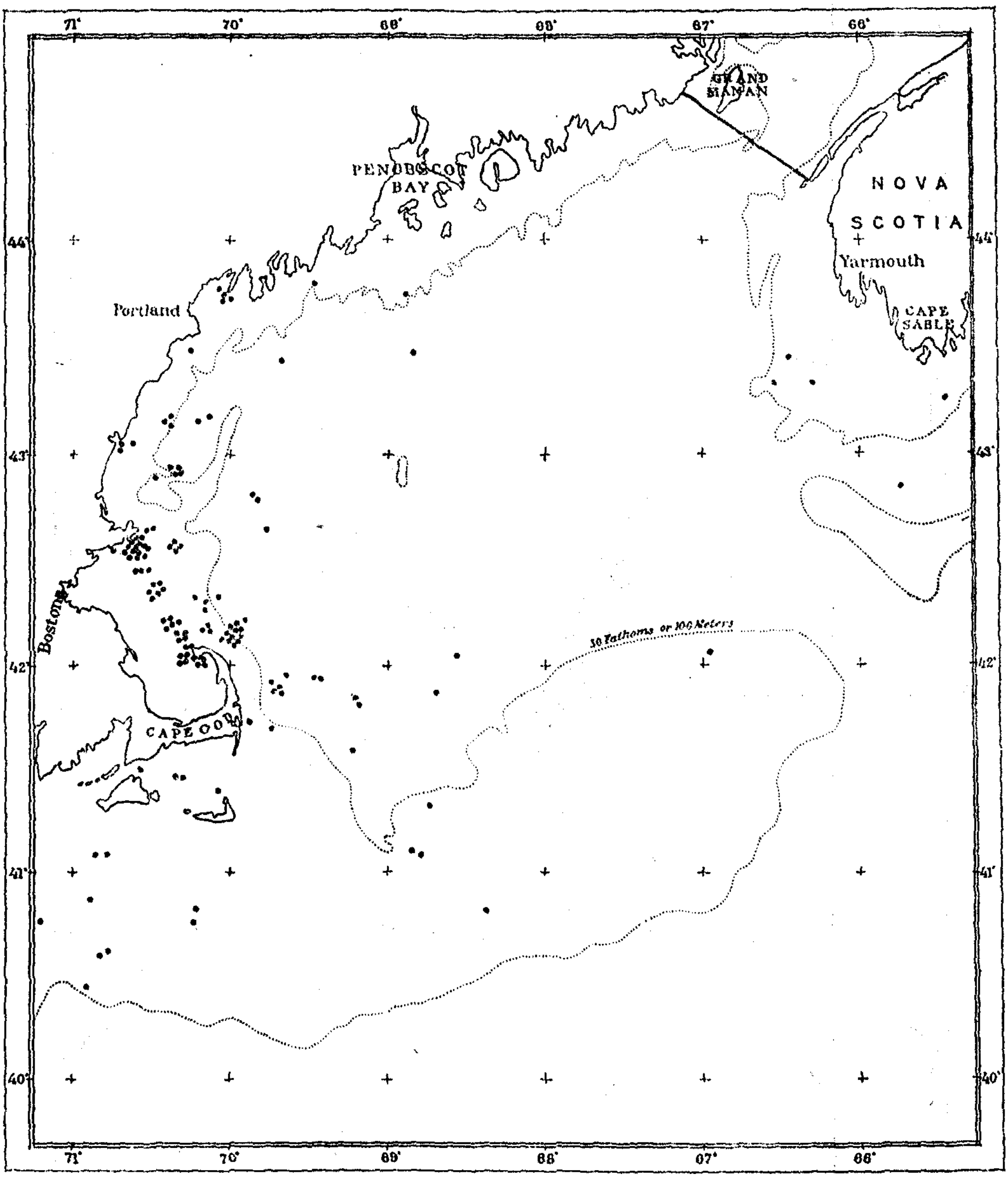

FIG. 2.—Locality records for flounder (pleuronectid) and gadoid larvæ (a dot for each record of each species), to illustrate the probable drift of buoyant fish eggs and larval fishes. (After Bigelow.)

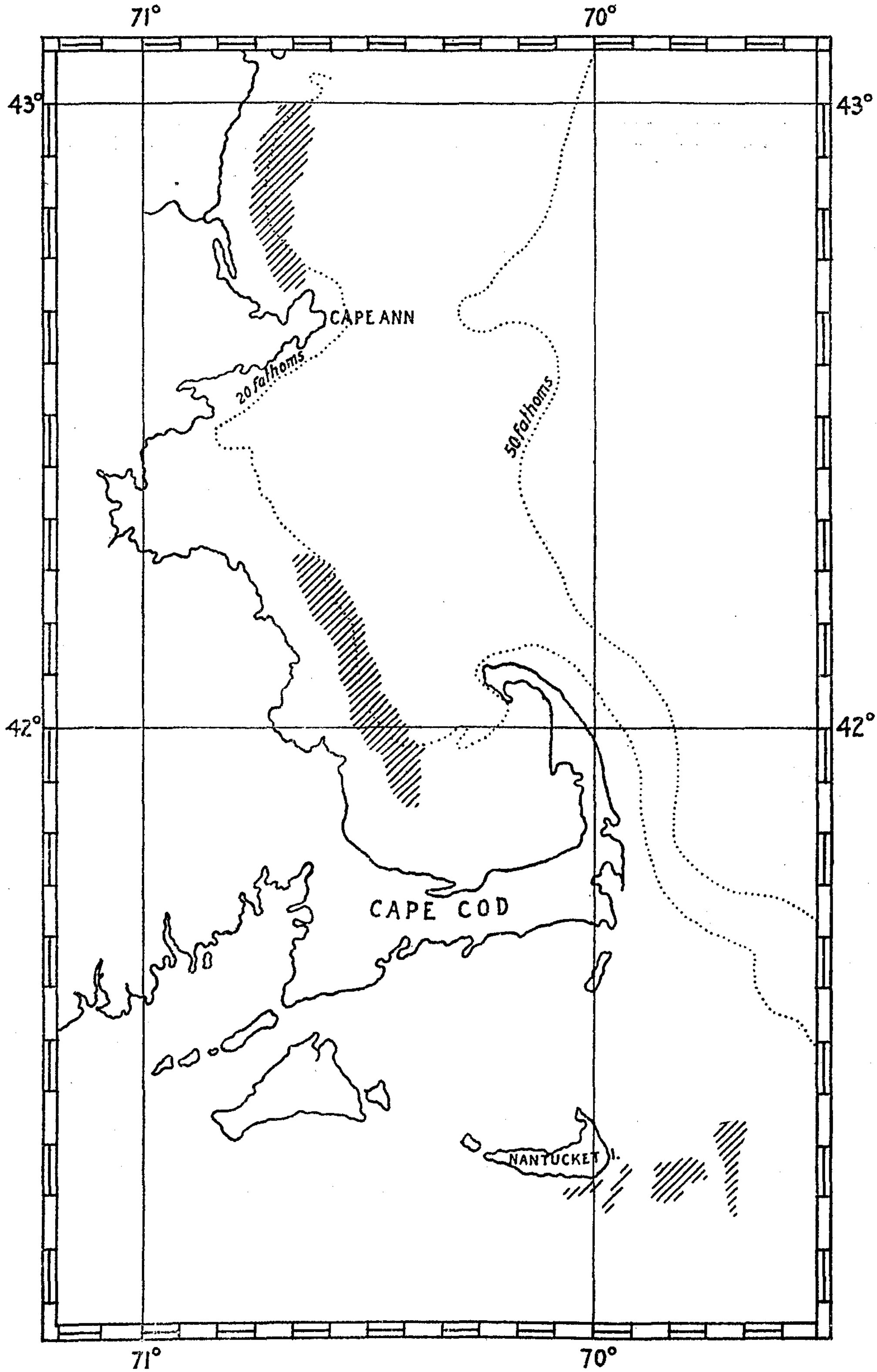

FIG. 3.—Chief spawning grounds of cod in the western side of the Gulf of Maine. (After Bigelow.)

eggs obtained by the same hatchery. In addition to this, 430,648,000 pollock eggs also were obtained, 90 per cent of which were derived from gill nets operating around Plymouth and Duxbury. Therefore there was every reason to believe that we would find Massachusetts Bay a haven for an immense number of eggs and fry and a nursery containing young cod in all stages of development. It was expected, too, that this locality would prove favorable for a study of the early life history of this species, its rate of larval development, vertical movements, food during this period, enemies, and the gradual changes in the feeding habits and migrations during the first year of its existence. This investigation was also to form the first of a series of investigations to determine the relative importance of the various fishing banks as production centers.

PROGRAM AND METHODS

SPAWNING AREAS EXAMINED

The area selected for study (fig. 3) comprises the two most important inshore spawning grounds on the New England Coast—Massachusetts Bay and the adjacent grounds to the north (Ipswich Bay). In many respects the conditions are very much alike in the two localities, both being in very shoal water and limited to small and very well defined areas. Off Plymouth the grounds run parallel with the coast, 3 to 10 miles from shore, and reach from abreast of Sandwich to Minot's Light. Roughly, the Ipswich grounds extend from the Isle of Shoals to Cape Ann, chiefly within 4 to 6 miles of land. (Bigelow and Welsh, 1925.) The Massachusetts Bay grounds range from 22 to 46 meters in depth and the Ipswich grounds 9 to 46 meters. Although ripe cod may be found in either of these localities from September to May, the height of the spawning season is reached at different times.

SPAWNING SEASON

The local fishermen say that the cod strike in the shallow water off Plymouth about November 1 and, according to Bigelow and Welsh (1925), reach the height of their spawning season from December through January, when the water ranges from 2.2 to 5.5° C. Hatching records and the abundance of eggs in collections from these grounds in 1925 indicate that spawning fish were plentiful throughout the winter and spring. Until March 20, the Gloucester station received 25,000,000 to 30,000,000 cod eggs daily from the Plymouth grounds.

In Ipswich Bay the height of the cod-spawning season is reached in March, much later than south of Cape Ann, although a few small breeding areas of lesser importance along the north side of Massachusetts Bay, particularly in the vicinity of Pig Rock, off Gloucester, form a haven for spring breeders. Here the season is said to coincide with that at Ipswich, spawning taking place throughout the coldest part of the year, when the temperature ranges from 0.56 to 3.05° C.

COD AND HADDOCK EGGS

As haddock eggs in their early stages are indistinguishable from cod eggs, distribution charts must be interpreted in the light of our knowledge of the probable points of origin and the direction of the drift. Were there no drift, it would be possible to determine the relative percentage of cod and haddock eggs containing late embryos and then assume that the earlier stages were present in the same propor-

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tions. The difference in the location of the breeding centers of the two species, however, makes this impossible, for, as will be shown, the drift that carries cod eggs out along the south side of Massachusetts Bay brings haddock eggs in from the north and east. As the spawning center of the haddock is in the outer part of the bay, the percentage of cod eggs in early cleavage about Plymouth would be expected to far exceed the haddock, which probably would be in later stages when they reached that point. Similarly, the percentage of haddock eggs containing early embryos should outnumber the cod. Table 5 shows the abundance of eggs in the bay on April 21, at the height of the haddock season. A single surface haul with a foot net at station 18A yielded 8,148 eggs. No such quantities of cod eggs ever were found either at Plymouth or Ipswich.

ITINERARY

Fourteen cruises in all were made and 38 stations visited from December 3, 1924, to June 17, 1925. (See Table 1.)

Starting from Minot's Light, off Boston Harbor (station 17), the stations extended completely around the arm of Cape Cod as far as Provincetown, and from there across the bay to Boston, with three stations on Stellwagen Bank. (Fig. 4.) Later stations were added over the deeper parts in the center of Massachusetts Bay (stations 18, 18A, and 19), a line run along the north shore (stations 29 to 38), and a line across the entrance from Cape Ann to a point off Highland Light (stations 30 to 34).

TABLE 1.—*"Fish Hawk" stations, November 12, 1924, to June 17, 1925, Massachusetts Bay*

Station	Latitude (north)			Longitude (west)			Station	Latitude (north)			Longitude (west)		
	°	′	″	°	′	″		°	′	″	°	′	″
1	42	01		70	34		15	42	09	30	70	38	15
2	42	12		70	23	30	16	42	14		70	41	
3	42	09	30	70	19	30	17	42	18	15	70	44	
4	42	06		70	17		18	42	18	30	70	32	30
5	42	01		70	12		18A	42	16	54	70	30	30
6	41	55	30	70	9	30	19	42	22		70	38	
6A	41	56	00	70	18	30	29	42	38	00	70	33	30
7	41	49	15	70	11	30	30	42	38	00	70	25	15
8	41	49		70	24	30	31	42	30	30	70	20	30
9	41	53	15	70	27		32	42	23	30	70	15	30
10	41	58		70	30	15	33	42	15	30	70	10	30
11	41	59	30	70	31	30	34	42	07	45	70	06	30
11A	42	00	00	70	32	15	35	42	34	30	70	38	00
12	42	01	15	70	33		36	42	30	15	70	43	15
13	42	03		70	34	30	37	42	28	00	70	48	00
13A	42	02	30	70	34	00	38	42	24	15	70	52	15
14	42	05		70	35								

TABLE 2.—*"Fish Hawk" stations, November 12, 1924, to June 17, 1925, Ipswich Bay*

Station	Latitude (north)			Longitude (west)			Station	Latitude (north)			Longitude (west)		
	°	′	″	°	′	″		°	′	″	°	′	″
20	42	44	00	70	36	45	25	42	52	00	70	40	00
21	42	46	00	70	40		26	42	53	30	70	43	00
22	42	47	45	70	43	30	27	42	54	30	70	40	00
23	42	49	30	70	40	00	28	42	56	00	70	41	45
24	42	50	30	70	43	30							

It was originally planned to cover the area every week during the spawning season, and between December 3 and December 23, 1924, four trips were made. How-

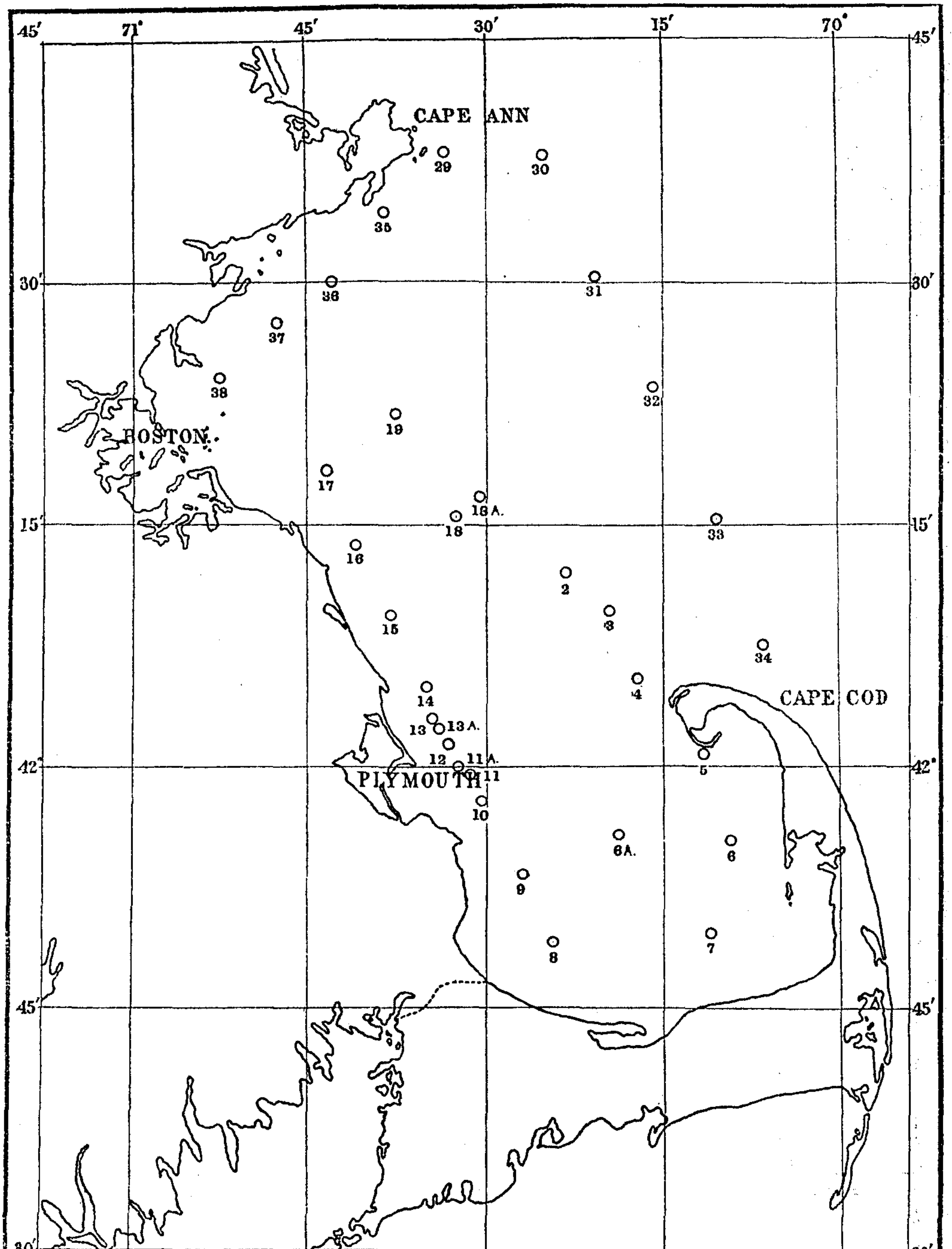

FIG. 4.—*Fish Hawk* stations in Massachusetts Bay, 1924–25

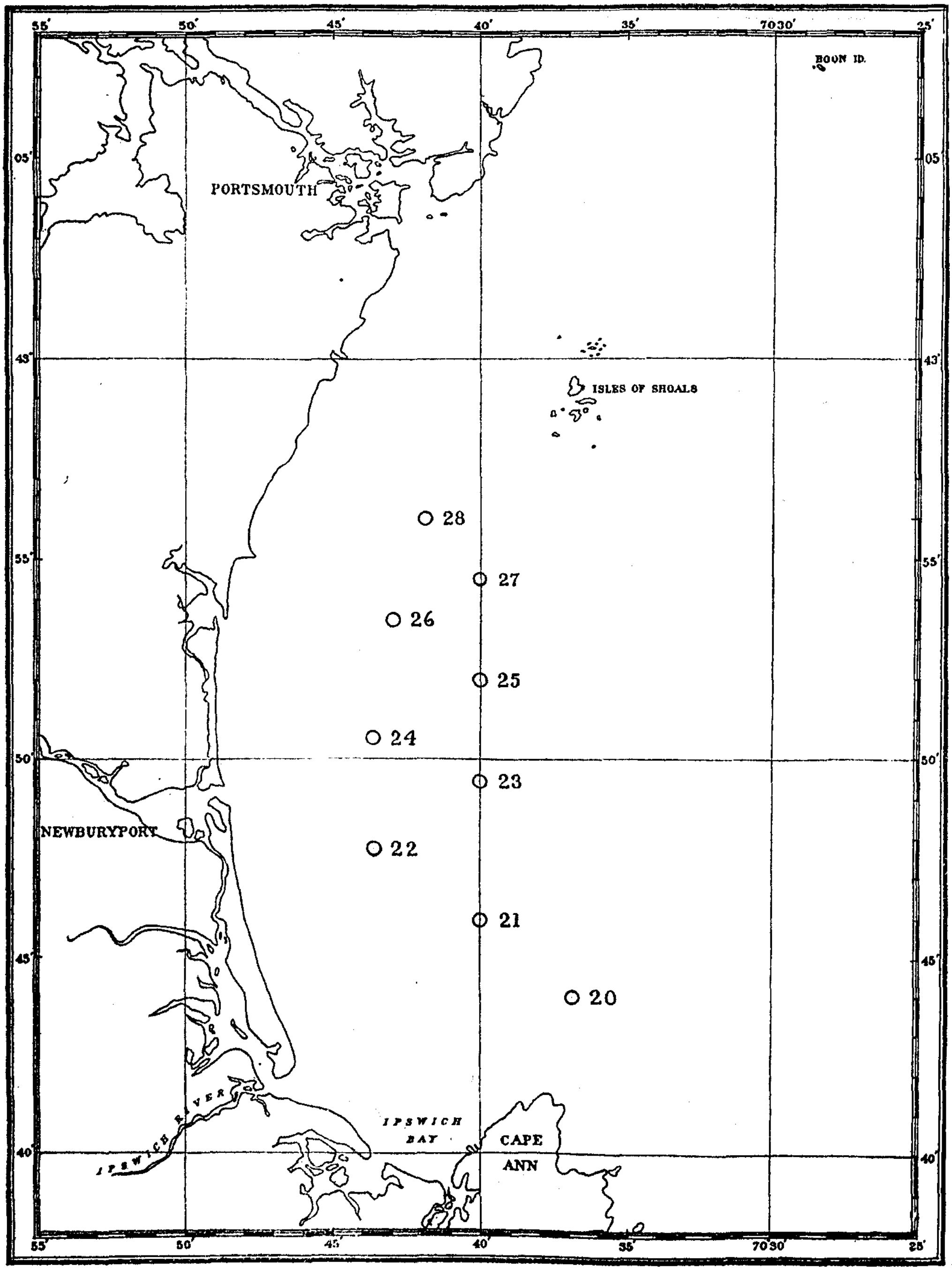

FIG. 5.—*Fish Hawk* stations in Ipswich Bay, 1924–25.

ever, due to the need of increasing the number of stations (thus prolonging the cruises), and to the frequent delays that were inevitable during the severe winter season, the interval between trips was increased later to two weeks.

Cruise	Date	Cruise	Date
1	Dec. 3, 1924.	8	Mar. 10, 1925.
2	Dec. 9–11, 1924.	9	Mar. 12, 1925.
3	Dec. 16–17, 1924.	10	Mar. 25, 1925.
4	Dec. 22–23, 1924.	11	Apr. 7–8, 1925.
5	Jan. 6–7, 1925.	12	Apr. 21–23, 1925.
6	Feb. 6–7, 1925.	13	May 20–22, 1925.
7	Feb. 24–28, 1925.	14	June 16–17, 1925.

EQUIPMENT AND METHODS

The collections made at each station consisted of a vertical haul, two 20-minute surface hauls (one coarse and one fine net), and a 20-minute haul near the bottom with a coarse net. In order to facilitate the work, advantage was taken of the very extensive data on temperature and salinity variations in the Gulf of Maine previously obtained by Doctor Bigelow, and only such physical observations were made as were necessary to interpret the existing conditions and to serve as a basis for comparison with previous years (see Table 15). These consisted of temperature readings from various levels and, at times, salinity determinations. Most of the latter were computed by Richard Parmenter from hydrometer readings. Greene-Bigelow water bottles, with reversing deep-sea thermometers (Richter and Schmidt-Vossberg), were used.

Vertical hauls were made with a Michael Sars meter net, the upper 1½ meters (nearest the large opening) being of No. 00 silk bolting cloth and the lower three meters of No. 2 silk. The fine surface net of No. 20 silk was 1 foot in diameter at the opening and 3 feet long. Michael Sars meter nets of the same type as the vertical nets were used for surface and bottom towing.

Drift bottles were set out at various places in order to supplement the evidence of water movement indicated by the cod eggs. (Figs. 14 and 15.)

Between November 12, 1924, and June 17, 1925, more than 650 net collections were made and the distribution of the eggs was plotted by trips. Considerable error, no doubt, has entered into the results, but this is unavoidable in work of this type, where so many hauls and such large quantities of eggs are involved. The use of horizontal nets for quantitative work may be criticized, but, as has been pointed out often (Bigelow, 1917; Fish, 1925, etc.), unless the desired species are present in extremely large numbers, the catches with a vertical haul are too small to be of any value; and even when abundant, they are so unequally distributed usually that the results are more likely to be misleading than helpful. Again, conclusions based entirely on surface hauls might prove equally erroneous if the eggs were concentrated at the lower levels. Had there been ample time and funds, more accurate figures might have been obtained, and the difficulties arising from "streaky distribution" overcome to some extent by greatly increasing the number of stations and plotting results based on vertical hauls alone. This was not possible at the time, however; therefore the sum of the yields of one vertical haul and one 20-minute surface haul from each station has been used in preparing charts on the

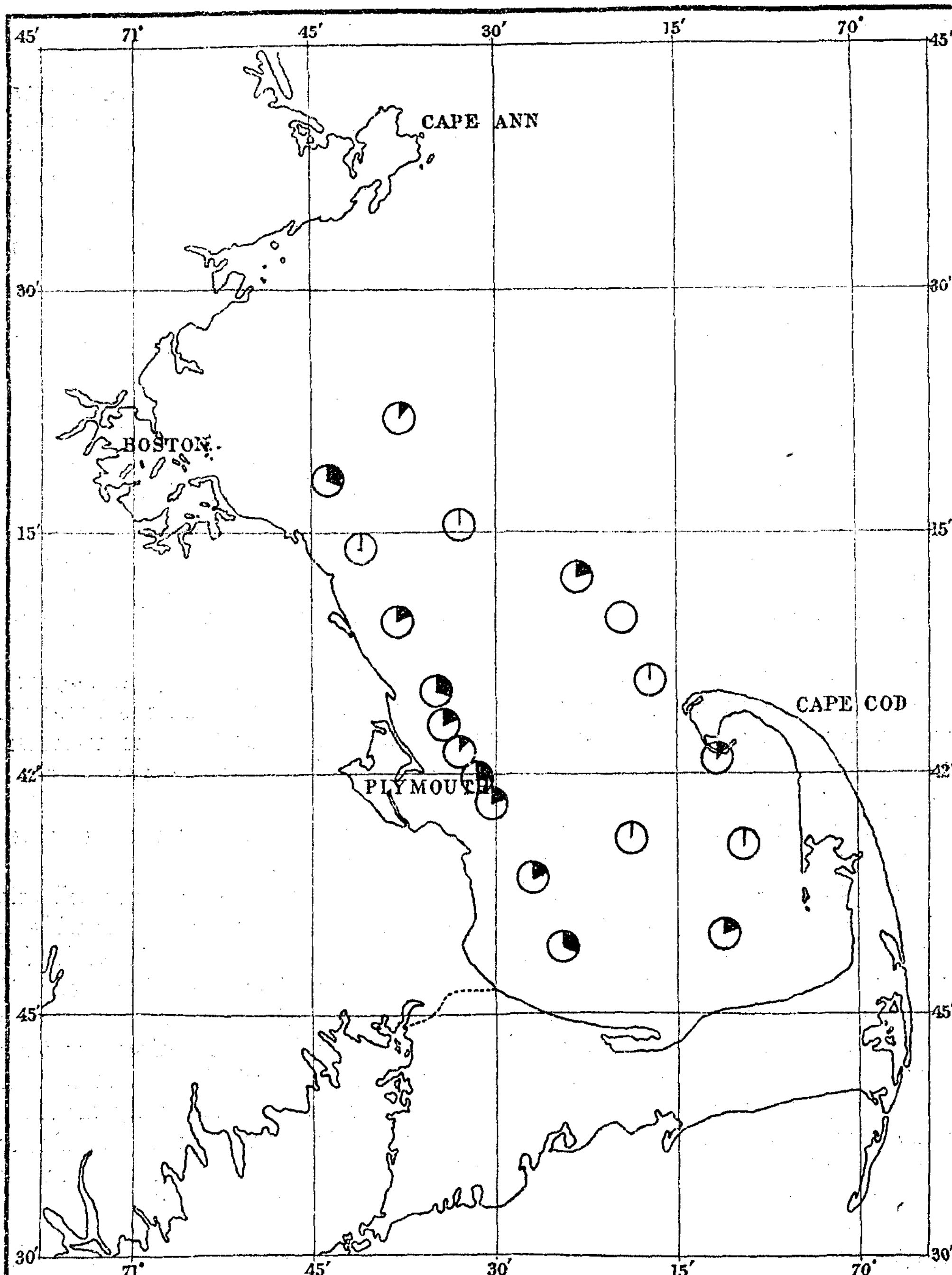

FIG. 6.—Percentage of cod eggs in early cleavage stages during cruises 1 to 8, inclusive. Black sector indicates percentage in early cleavage

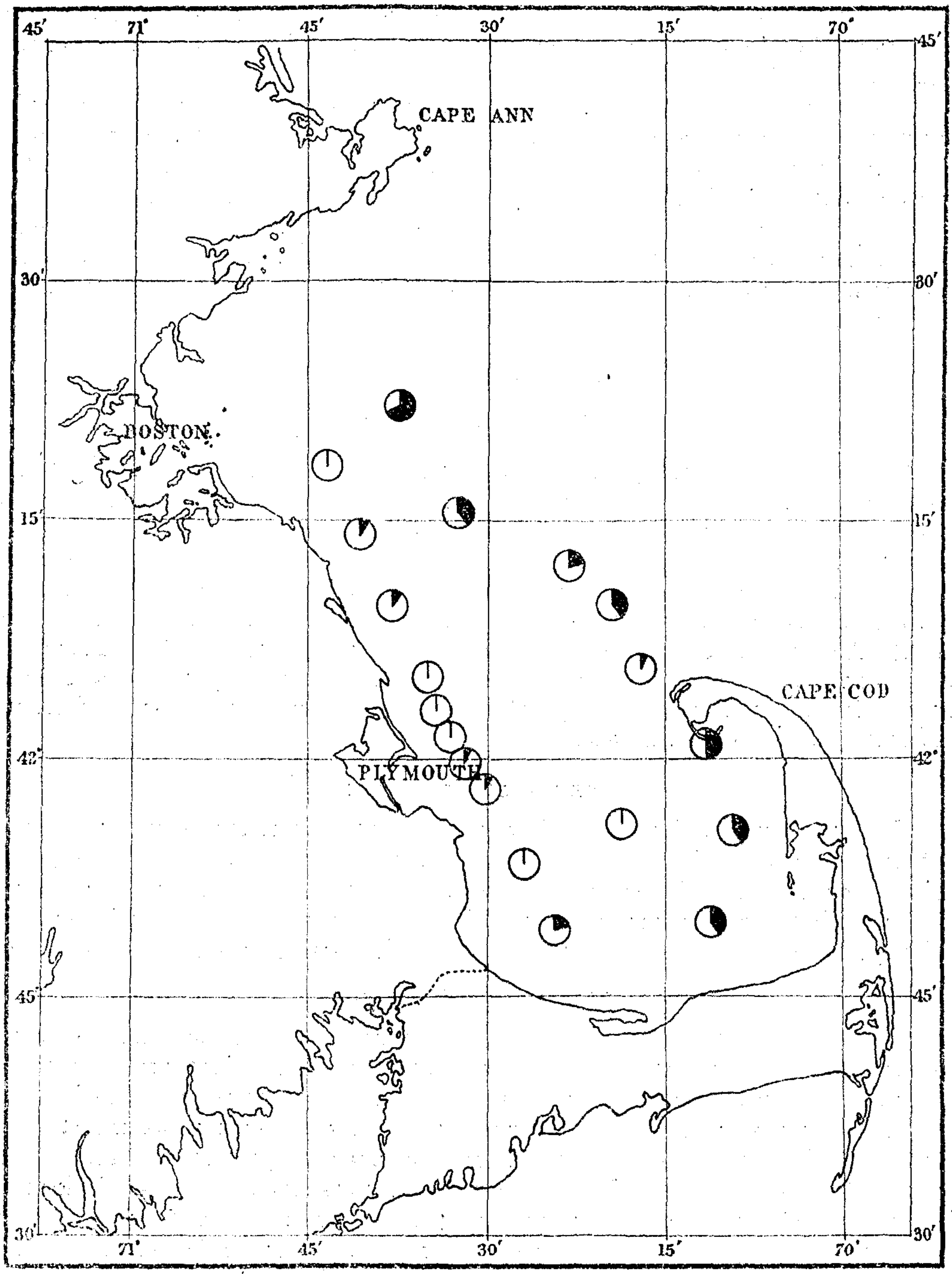

FIG. 7.—Percentage of cod eggs containing late embryos during cruises 1 to 8, inclusive. Black sector indicates percentage of late embryos

distribution of the pelagic eggs. The slight variation in the depth of the vertical hauls (a matter of a few meters at most) becomes insignificant when included with a 20-minute horizontal haul.

In examining the eggs the following stages were distinguished and recorded: Early cleavage, late cleavage, early embryo, and late embryo. Later, in preparing the charts, only the early-cleavage and the late-embryo records were used.[1] This extreme contrast facilitated the plotting and also simplified the results.

In making composite charts to show the general movements of the eggs the first eight cruises and the last four have been combined in two groups. This was done in order that the first group would not be complicated by the great influx of haddock eggs from the northeast in the late spring.

SUMMARY OF OBSERVATIONS

GENERAL CONDITIONS

The problem, as already stated, involved a determination of the value of Massachusetts Bay as a production center for cod and also as a nursery for the large number of eggs and larvæ that we had reason to believe were being transported in continually as contributions from the spawning grounds to the north and east. It is known that of the millions of eggs liberated on cod banks, probably few escape fertilization, and also that under normal conditions these eggs tend to float near the surface. (Prince, 1909.) Ample stations were selected to allow for a determination of the distribution of eggs and larvæ within the bay at any one time. By preparing charts on the distribution of eggs in various stages of development it was hoped that the directions and rate of dispersal would be shown.

THE ABSENCE OF FRY

On the 14 trips hundreds of hauls were made and thousands of eggs were obtained, but not one larval cod appeared. It was evident that the eggs were disappearing before they hatched. To ascertain whether they were concentrated at some particular depth, hauls were made at all levels but without success. No cod fry appeared although larval pollock and later larval haddock were fairly numerous sometimes.

DEFINITE DRIFT OF EGGS

Charts based on the distribution of eggs almost without exception indicated a concentration of early stages over the spawning grounds and of later stages along the lower arm of Massachusetts Bay, and particularly in the outer parts. (See figs. 6 and 7.) Thus, on the first 8 cruises, 88.7 per cent of the eggs taken at station 11 (in the heart of the Plymouth grounds) were in early-cleavage stages and only 11.3 per cent contained embryos. These figures become even more significant when divided into four groups, 30.8 per cent of the eggs being in early cleavage, 57.9 per cent in late cleavage, 7.9 per cent containing early embryos, and 3.4 per cent late embryos. Contrasted with this, station 3 (at the outer entrance to the bay) yielded not one egg in early cleavage, but 40 per cent were late embryos.

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[1] These two stages in the present paper are distinguished as follows: Early cleavage extends from fertilization to a point where the exact cleavage stage can not be distinguished easily (32 to 64 cell stage). In late embryos the chromatophores are arranged in groups and give the characteristic banded appearance.

LOCAL PRODUCTION IN MASSACHUSETTS BAY

The Plymouth grounds could easily be established as the production center for locally spawned eggs throughout the season of 1924–25; and even during the great influx of haddock and cod eggs from the east in the late spring (fig. 8), as will be described later, the charts show unmistakable evidence of local production.

Figures 6 and 7 indicate the distribution of eggs in early-cleavage and late-embryo stages, based on the results of the first eight cruises. In Figure 6, extending all along the western shore from station 17 to station 8, the large percentages of eggs in early cleavage indicate the production area. By comparing this figure with Figure 7, it will be seen that elsewhere in Massachusetts Bay later stages dominate.

Production on the Plymouth grounds is illustrated further by the following table, showing the number of eggs taken on each cruise at station 15, on the northern part of the grounds, and the increased numbers that had accumulated by the time the drift reached station 10, on the southern part. The percentage of eggs in cleavage stages is included to show that locally spawned eggs were being dealt with and not immigrants from some distant source.

TABLE 3

Cruise	Station 15		Station 10	
	Total number of eggs taken	Percentage in early cleavage	Total number of eggs taken	Percentage in early cleavage
1	9	77.8	28	40.9
2	2	100.0	14	56.0
3	17	58.8	519	53.2
4	30	100.0	26	92.4
5	24	75.0	298	93.0
6	0	0.0	17	11.7
7	15	53.3	265	63.5
8	9	100.0	243	80.3

EXTENT OF THE SPAWNING SEASON ON THE PLYMOUTH GROUNDS

The collections also afford considerable information on the duration of the spawning season on the Plymouth grounds in 1924–25. Before starting the regular cruises with the *Fish Hawk*, two visits were made to these grounds, the first on November 12. Spawning had already begun at that time, although the temperature of the water had dropped to only 10.1° C. A 20-minute haul with a foot net (No. 0 silk) yielded 53 eggs, all in early-cleavage stages. These can safely be called cod, both because of the abundance of ripe cod present and also because haddock spawning had not begun. Of 11 adult cod, ranging from 5 to 50 pounds, taken at random from a trawl at this time, 6 were females and 5 were males. One female was still green, one nearly ripe, two ripe, and two nearly spent. Of the males, one was green and four were ripe. On November 20 a second haul on the same grounds yielded 65 cod eggs, all, with the exception of one (an early embryo), in cleavage stages. Some idea of the length of the season may be obtained from the following table, giving the average number of eggs in cleavage stages per station on the Plymouth grounds:

TABLE 4

Trip	Date, 1924-25	Average number of eggs	Trip	Date, 1924-25	Average number of eggs
1	Dec. 3	26	7	Feb. 24-25	71
2	Dec. 9-11	46	8	Mar. 10	70
3	Dec. 16-17	57	11	Apr. 7-8	304
4	Dec. 22-23	24	12	Apr. 21	167
5	Jan. 6-8	72	13	May 20-22	10
6	Feb. 6-7	8			

This table shows clearly the increase in production as the spawning season progressed and also the destruction of eggs by the storms that occurred at the time of the fourth and sixth cruises. (See p. 286.) Up to the time of cruise 8, for reasons given on page 274, it is safe to assume that most of these were cod.

Omitting for the moment the small returns on December 22 and February 6, which obviously represent artificial results (p. 286) and give no indication of the true production that took place at the time, the figures on the Plymouth grounds show that spawning had already begun on November 12, increased through December, and reached its height in January, February, and early March, although, as will be shown later, considerable spawning, no doubt, took place throughout April. Taken alone, this table gives no indication of the end of the breeding season at Plymouth, for in late March and early April the great influx of haddock and cod eggs from the east (fig. 8) complicated the results and made it impossible to distinguish locally spawned eggs from the immigrants.

Extending the area to cover all of Massachusetts Bay and computing the average number of eggs per station, it is seen that the conditions at Plymouth reflect very well the general conditions for the whole bay, as would be expected if that locality forms the source of supply.

TABLE 5

Trip	Number of stations	Total number of eggs	Average number of eggs per station	Mean surface temperature (° C.)	Mean bottom temperature (° C.)	Date
MASSACHUSETTS BAY						
1	9	222	25	6.14	6.13	Dec. 3.
2	15	445	30	6.20	6.25	Dec. 9-11.
3	14	797	57	5.02	5.46	Dec. 16-17.
4	13	250	19	4.30	4.75	Dec. 22-23.
5	14	699	50	2.54	2.60	Jan. 6-8.
6	15	236	16	.75	.95	Feb. 6-7.
7	7	1,083	155	1.65	1.68	Feb. 24-25.
8	6	305	51	2.00	1.89	Mar. 10.
11	14	1,962	140	4.59	3.40	Apr. 7-8.
12	20	20,761	1,038	5.27	4.02	Apr. 21.
13	20	4,542	239	8.89	4.57	May 20-22.
IPSWICH BAY						
9	5	319	64	3.54	2.50	Mar. 12
10	8	940	117	3.54	2.72	Mar. 25.
11	4	508	127	4.61	2.64	Apr. 7.

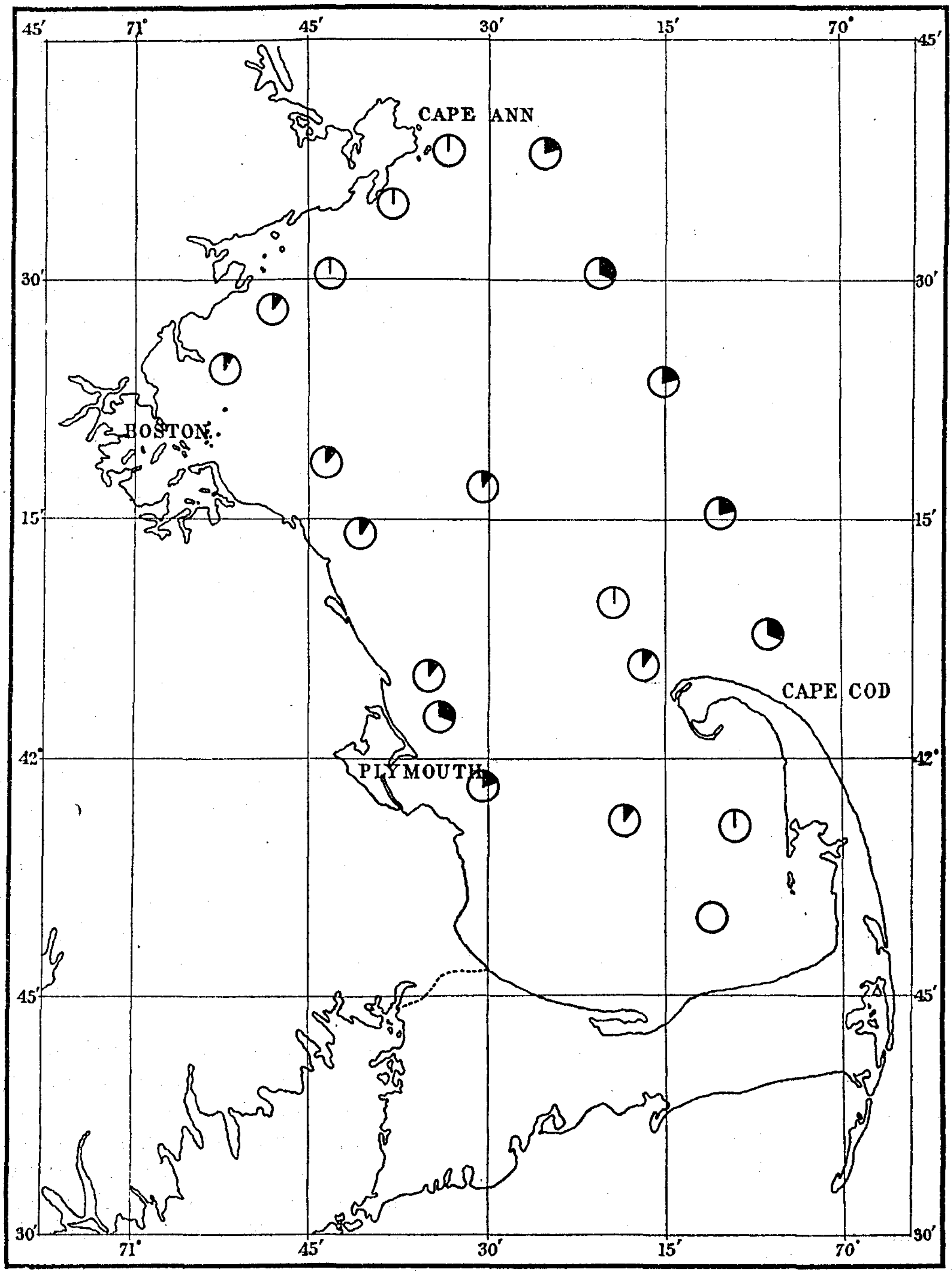

FIG. 8.—Percentage of eggs in early cleavage stages during cruises 9 to 12, inclusive. Black sector indicates percentage in early cleavage

Here, again, the destructive effects of storms (p. 268) are evidenced by the small returns from trips 4 and 6. The increase through December and January, reaching its peak in late February about the time of the seventh cruise (February 24–25), and then the decline until overcome by the invasion from the east, corresponds very well in the two tables. In each the influx became evident on cruise 11.

In comparing these two tables it will be noticed that, although the number of eggs taken in Massachusetts Bay on the twelfth cruise (April 21) was more than four times that taken on any of the other cruises, the actual number of eggs in cleavage stages on the Plymouth grounds had declined to approximately one-half that of the trip in the previous month. The influx of eggs from the outer waters was supplemented to some extent, no doubt, by locally spawned eggs even on April 21, but by May 20–22 local spawning had virtually ceased. This point is very well brought out also by a comparison of Figures 8 and 11. The former, based on the results of trips 9 to 12, shows the quantities of newly spawned eggs in the outer waters but at the same time indicates clearly that considerable production was still taking place on the Plymouth grounds. Figure 11, giving the quantitative distribution of eggs a month later, shows that by May 20, 1925, production on these grounds had virtually ceased, and the large numbers recorded for this cruise (Table 5) are seen to be concentrated in the outer parts of the bay and along the northern side.

The large number of eggs entering from the east was probably the result partly of contributions from the Ipswich grounds and partly of haddock eggs drifting in from the northern part of Stellwagen Banks (favorite spawning grounds for that species) or from the waters east of Cape Ann; for, as already stated, haddock do not spawn in abundance in the inner parts of the bay and few, if any, on the grounds off Plymouth. (Bigelow and Welsh, 1925.)

According to Bigelow and Welsh (1925), the height of the cod spawning season at Plymouth is reached during the period of falling temperature, the bulk of the eggs being liberated before the winter minimum is reached. In 1924–25 the height of the season apparently was reached in February and extended through the coldest part of the year, when the mean surface temperature ranged from 2.54° to 0.75° C. In this it agreed with previous observations at Ipswich, where the greatest production is known to take place during the period of minimum temperatures.

DRIFT AS INDICATED BY THE EGGS

The determination of spawning areas by locating the centers of distribution of eggs in early cleavage and then following the general movement from these centers by charting the distribution of eggs in progressively advanced stages of development is not new. In 1914 Hjort reported that cod eggs in early development had been found to be restricted to very limited areas and suggested the possibility that these eggs might serve as a basis for determining the position of the spawning shoals. As early as 1900, however, this same author stated that in European waters cod fry often are carried for hundreds of miles, being distributed over the banks off the northern coast of Norway and especially in the Barents Sea, where they may be taken the following year in fine-meshed nets on the bottom.

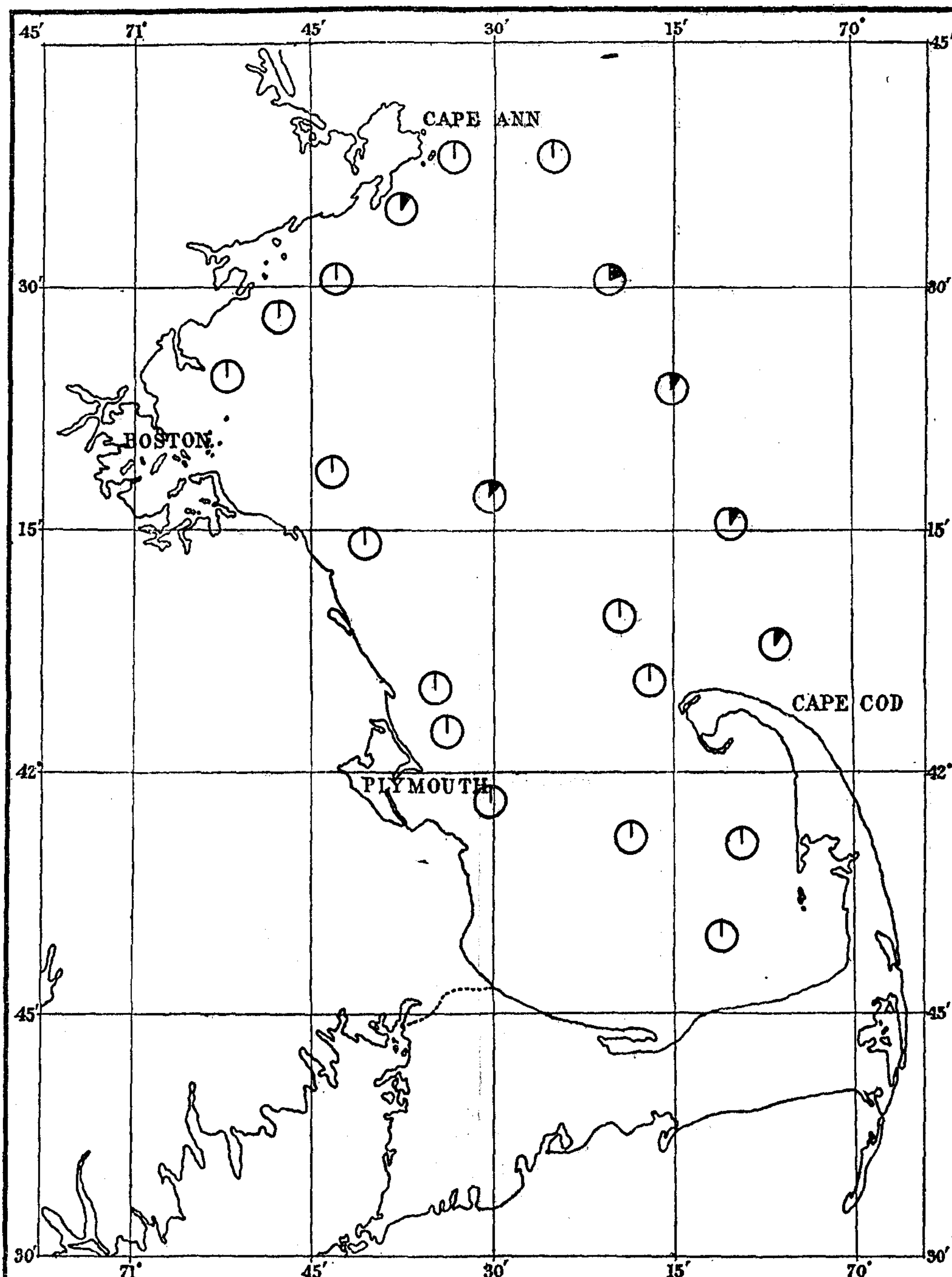

FIG. 9.—Percentage of eggs containing late embryos during cruises 9 to 13

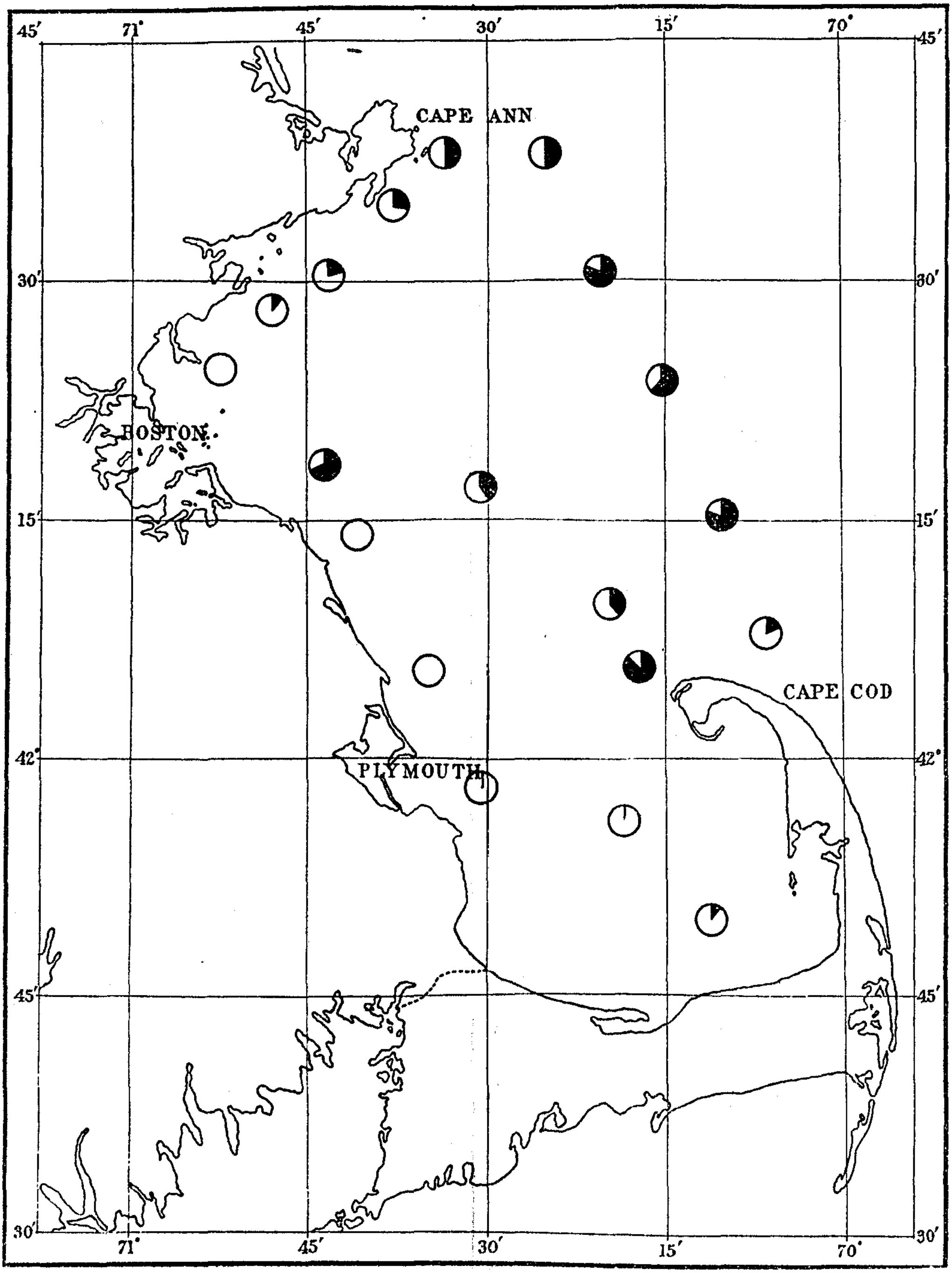

FIG. 10.—Percentage of eggs containing embryos during cruise 13 (May 20-22, 1925). Black sector indicates embryos

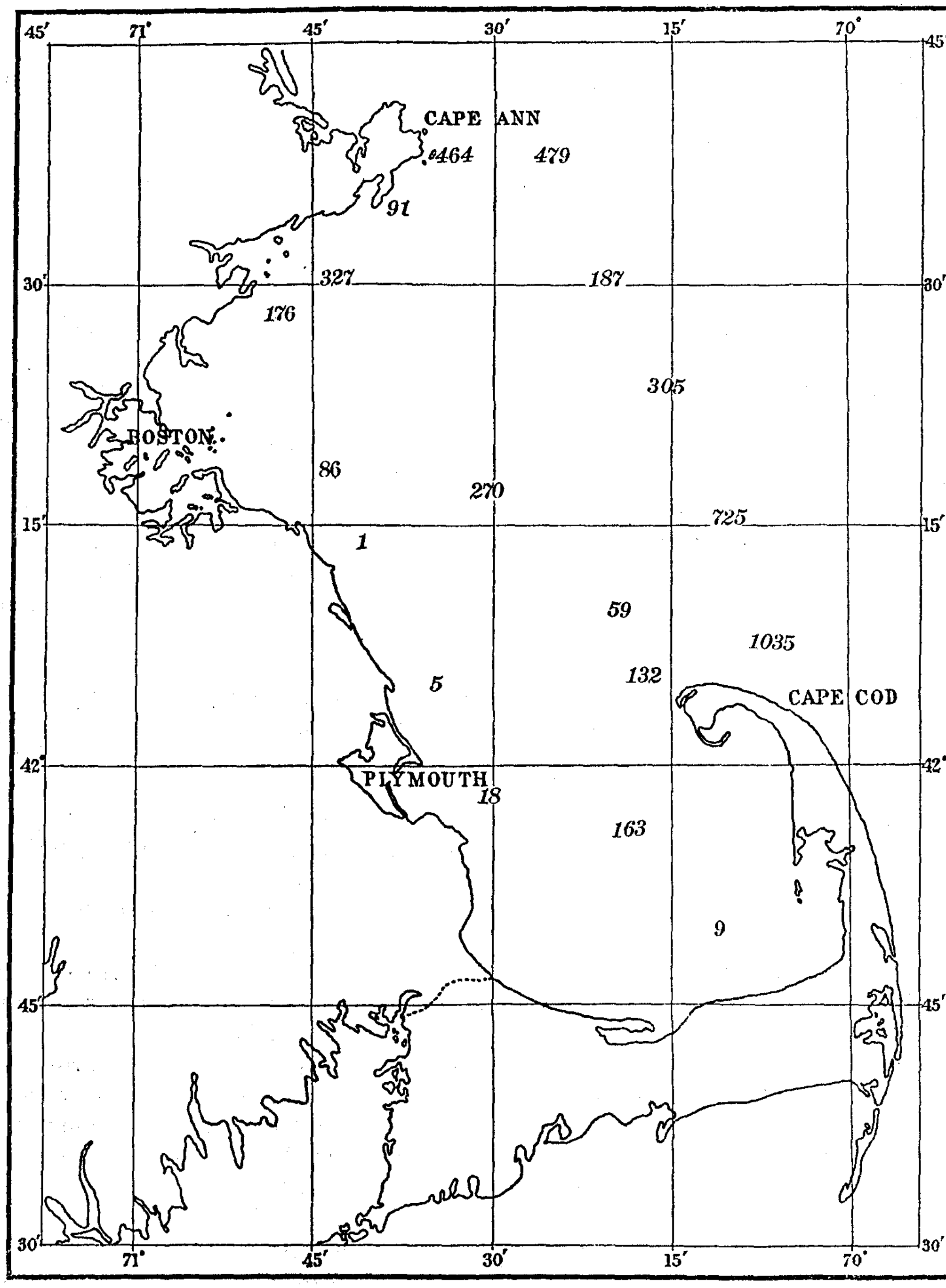

FIG. 11.—Quantitative distribution of eggs in Massachusetts Bay during cruise 13 (May 20-22, 1925), showing influx of cod-haddock eggs from the east

Were there no dominant drift, but only tides and winds, to scatter the eggs, one would find newly spawned eggs and those in early cleavage stages over the spawning grounds and over a large area a mixture of eggs and larvæ in various stages of development. Contrasted with a condition of this sort, in regions subjected to a definite drift flowing in one direction, we should expect to find over the spawning grounds only eggs in the earliest stages of development, provided there were no other complicating influences, such as storms, tidal actions, or neighboring spawning areas nearer the source of the drift. Following the course of the current from the grounds, eggs should be found in progressively later stages of incubation, the distances traveled before hatching depending on two factors—temperature (as this increases or retards the rate of development) and the rate of the drift. In localities where a very rapid drift passes over the grounds the eggs might be carried great distances before hatching, provided the temperature were low enough. For example, eggs incubating in a temperature of 1° C. (February temperature in Massachusetts Bay) and subjected to a drift of 4 miles a day might travel more than 120 miles before hatching, and the fry then might drift for two to two and a half months. Those fry might then seek the bottom 420 miles from the spawning grounds. This, of course, is merely a hypothetical case, but it illustrates a possible occurrence. Consequently it was expected that conditions in Massachusetts Bay would be complicated, for tidal action and contrary winds, often of considerable force, might prove in themselves ample cause for confusion, even though other spawning grounds were not so located as to form an added disturbing influence.

As previously stated, the Plymouth grounds could be established easily as the principal production center for locally spawned eggs throughout the season. In Figure 6 (based on the results of eight trips) the large percentages of eggs in early cleavage stages found along the western shore from station 17 to station 8 indicate clearly the source of production during the winter and early spring. By comparing this figure with Figure 7 it will be seen that few late embryos remained along the western shore, the movement being either south into the arm of Cape Cod (stations 5, 6, 7 and 8) or directly across the bay in an easterly direction (stations 3, 2, 18, and 19). Drift-bottle experiments, which will be explained later, prove that both movements were taking place.

It was also interesting to find that, although storms apparently destroyed large quantities of eggs (see p. 268), the general distribution was not altered seriously. In spite of the particularly bad weather that had prevailed for several days before the fourth trip, Figure 12 shows a concentration of embryos about the Provincetown region and of newly-spawned eggs over the breeding grounds. Probably when the surface becomes disturbed the eggs tend to become distributed throughout the water mass and thus escape being forced along by the wind, like objects that remain at the surface. The distribution of stages during the fourth cruise was normal and quite typical of conditions existing during the winter and early spring.

The influence of haddock eggs first became noticeable on the eleventh cruise (April 7–8), when a considerable increase in the average number of eggs taken in Massachusetts Bay and also a noticeable change in the distribution of eggs in early cleavage were observed. Figure 13, based on the distribution of cleavage stages, shows for the first time large numbers of newly-spawned eggs in the outer parts of the bay. In fact, at stations 31 to 33 all of the eggs taken were in early cleavage,

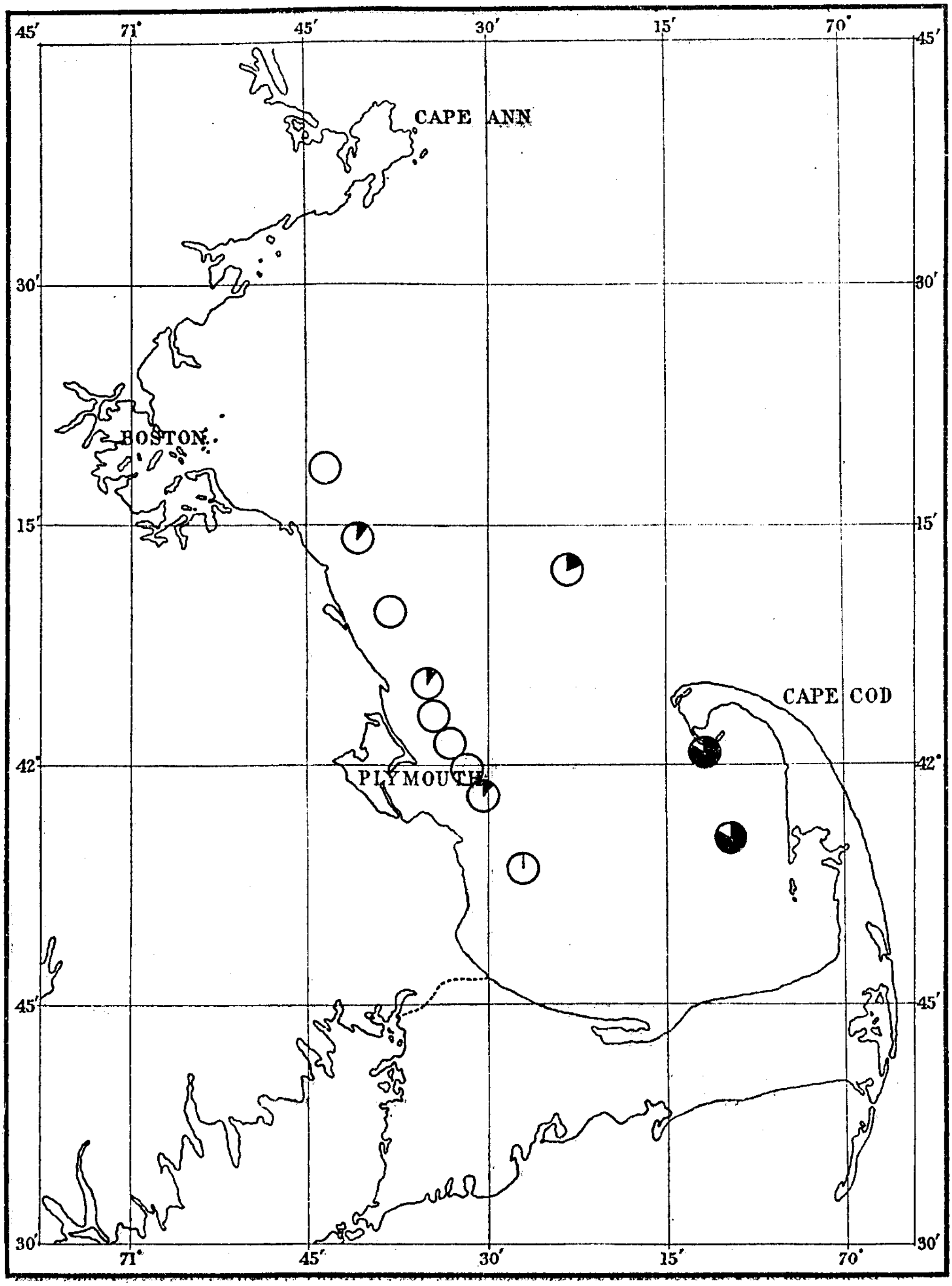

FIG. 12.—Percentage of cod eggs containing embryos during cruise 4 (December 22–23, 1924). Black sector indicates embryos

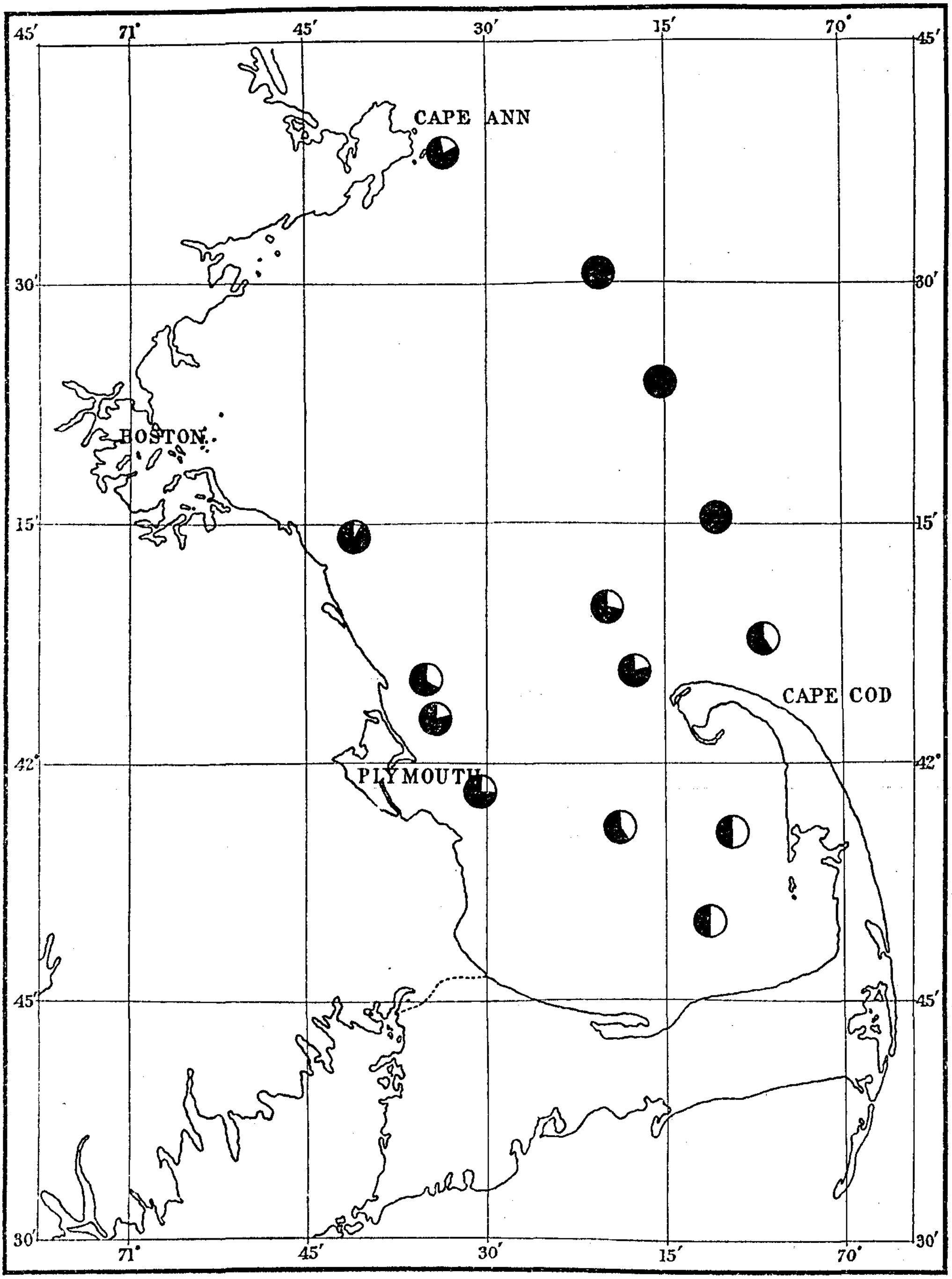

FIG. 13.—Distribution of cod-haddock eggs in cleavage stages during cruise 11 (April 7-8, 1925), showing the spawning center of the haddock in the outer part of the bay. Black sector indicates percentage of eggs in cleavage stages

As haddock do not spawn in the inner parts of the bay, the concentration of early cleavage stages on the Plymouth grounds indicates that considerable cod spawning still was taking place there.

Passing on to the late spring, Figure 8 again shows that spawning (haddock) was taking place along the Stellwagen Banks in the outer part of the bay and that there was still some production at Plymouth as well. There is also some indication that the influx of eggs into Massachusetts Bay from north of Cape Ann had begun, although less than 5 per cent of the eggs taken along the north shore were in cleavage stages.

DRIFT-BOTTLE EXPERIMENTS

For positive evidence of the set, drift bottles were placed in various parts of Massachusetts Bay in February and again in May. On the latter occasion the field was extended to include Ipswich. One hundred and forty-one bottles were set out during the year, and 49, or 34.7 per cent, were recovered.

Of 90 bottles set adrift on February 6 and 7, 18, or 20 per cent, were found within a few days along the inner arm of Cape Cod. (Table 6.) Four circled Cape Cod, one being taken 29 miles east-southeast of Stellwagen Bank,[2] two on the south shore of Nantucket, and one at Fire Island, N. Y. Four turned east, and of these, three appeared in Nova Scotian waters. One had started on a similar course when picked up 28 miles east-southeast of Cape Ann. On June 15, 1926, bottle No. 49 was reported from Lands End, Cornwall, England, where it had been picked up on the beach 494 days after starting its journey. In all, 27, or 30 per cent, of the bottles set adrift on this cruise were recovered.

TABLE 6.—*Record of recoveries. Bottles set adrift on February 6 and 7, 1925, in Massachusetts and Cape Cod Bays*

Bottle No.	Date set adrift	Locality where released: Latitude			Locality where released: Longitude			Date of recovery	Locality where recovered	Interval, days	Probable minimum distance covered, miles
	1925	°	′	″	°	′	″	1925			
25	Feb. 6	42	00	45	70	11	50	Feb. 11	Beach, Provincetown, Mass	5	4
26	do	42	00	45	70	11	50	Feb. 26	Pilgrim Heights, Provincetown	20	4
27	do	42	00	45	70	11	50	Feb. 12	East End Breakwater, Provincetown	6	4
28	do	41	58	12	70	10	48	Feb. 14	Pickett Wharf, Provincetown	8	6.5
29	do	41	58	12	70	10	48	Feb. 11	Provincetown	5	6.5
30	do	41	58	12	70	10	48	do	do	5	6.5
32	do	41	55	30	70	09	30	Feb. 12	Beach at Provincetown	6	9
33	do	41	55	30	70	09	30	Feb. 11	Beach at North Truro, Mass	5	6.5
34	do	41	52	18	70	10	30	do	East Harbor, Provincetown	5	11.5
35	do	41	52	18	70	10	30	do	Provincetown	5	12
36	do	41	52	18	70	10	30	Feb. 12	Smith's bathing beach, Mass	6	12
37	do	41	49	30	70	11	15	Feb. 11	Provincetown Harbor	5	16
38	do	41	49	30	70	11	15	Feb. 14	Beach at Provincetown	8	16
39	do	41	49	30	70	11	15	Feb. 12	Provincetown Harbor	6	16
40	do	41	52	27	70	15	24	Feb. 17	North Truro Beach	11	12
42	do	41	52	27	70	15	24	Feb. 22	Bay Shore, North Truro	16	11
43	do	41	56	00	70	18	30	Feb. 23	Beach Point, Provincetown Harbor	17	12
44	d	41	56	00	70	18	30	Feb. 18	Provincetown	12	12
22	do	42	03	18	70	14	42	July 4	Fire Island Coast Guard Station, N. Y	149	220
15	do	42	12	00	70	23	30	June 14	Near U. S. Naval Radio Station, Nantucket, Mass	128	88
74	Feb. 7	42	07	18	70	36	36	Feb. 16	29 miles east-southeast from Eastern Point, Stellwagen Bank.	9	49
78	do	42	09	30	70	38	15	June 30	2 miles east of Surfside, south shore, Nantucket	143	80
4	Feb. 6	42	19	00	70	36	05	Aug. 27	Meteghan, Digby County, Nova Scotia	202	237
82	Feb. 7	42	14	00	70	41	00	Aug. 5	2¼ miles south by west of Cape Sable, Shelburne County, Nova Scotia.	179	233
85	do	42	16	06	70	42	30	July 2	Cove near Freeport, Digby County, Nova Scotia	145	abt. 250
89	do	42	18	15	70	44	00	Feb. 17	28 miles east-southeast from Thatchers Island, Mass	10	38
								1926			
49	do	41	53	15	70	27	00	June 15	Beach at Lands End, Cornwall, England	494	----------

[2] There is some uncertainty about the location where this bottle was found.

Forty bottles were set out on May 20, 21, and 22, and 18, or 45 per cent, were returned (Table 7). The courses taken at this time differed considerably from those of February. Bottles placed along the north shore of Massachusetts Bay were carried either directly in by the tide or west with the set. Those from stations 17, 18A, and 32 moved south and grounded along the inner arm of the cape or on the outer tip about Race Point, but one of the bottles placed in Cape Cod [3] beached along the inner arm. Two (Nos. 114 and 117) circled westward and were picked up drifting off Plymouth. Two others (Nos. 112 and 113) from station 6A passed Race Point, but one grounded within a short distance on the outer side. The other joined the bottles from stations 34 and 14 and circled Cape Cod. Only in the latter group did the courses coincide with the movements of the bottles set out in February. Apparently none of the bottles liberated in Massachusetts Bay at this time moved east to Nova Scotian waters.

TABLE 7.—*Record of recoveries. Bottles set adrift on May 20, 21, and 22, 1925, in Massachusetts Bay*

Bottle No.	Date of release	Locality where released: Latitude			Locality where released: Longitude			Date of recovery	Locality where recovered	Interval, days
	1925	°	′	″	°	′	″	1925		
103	May 20	42	18	15	70	44	00	June 6	Dennisport, Mass	17
106	do	42	16	54	70	30	30	May 26	3 miles northwest of Race Point Light, Cape Cod	6
108	do	42	05	00	70	35	00	May 30	1¼ miles north of Pamet River, Coast Guard station, Cape Cod.	10
109	do	42	05	00	70	35	00	May 25	Coast Guard station, Provincetown, Mass	5
112	do	41	56	00	70	18	30	June 1	Race Point Coast Guard Station, Cape Cod	12
113	do	41	56	00	70	18	30	July 24	South Beach, Edgartown, Mass	65
114	do	41	49	30	70	11	15	May 29	6 miles east of Garnet Light, Plymouth, Mass	9
115	do	41	49	30	70	11	15	May 26	South Truro, Mass	6
117	do	41	55	30	70	11	15	May 31	5 miles west of Race Point	11
118	May 21	42	05	30	70	17	00	July 12	Nauset Beach, near Coast Guard station, Eastham, Mass	52
120	do	42	09	30	70	19	30	June 12	75 miles southeast and south from Cape Cod Light	22
126	do	42	23	30	70	15	30	May 27	1¼ miles west of Race Point Coast Guard Station	6
127	do	42	23	30	70	15	30	do	2 miles off Peaked Hill bar, Cape Cod	6
136	May 22	42	30	15	70	43	15	July 15	Marblehead Neck, Mass	54
137	do	42	30	15	70	43	15	June 1	Pea Island, Nahant, Mass	10
139	do	42	28	00	70	48	00	May 31	¼ mile east of Tinkers Island, Marblehead	9
140	do	42	24	15	70	52	15	May 27	Lynn Beach, Mass	5
141	do	42	24	15	70	52	15	May 28	Long Island, Boston Harbor, Mass	6

CURRENT MOVEMENTS IN FEBRUARY

Using the bottle drift of February, 1925, as the basis for determining the movements of cod eggs in early spring, it is possible to divide Massachusetts Bay into two general regions—southern and northern.

1. The southern region lies in Cape Cod Bay and comprises the area east of a line extending from Race Point, on the tip of Cape Cod, to the canal. From within this zone no bottles are known to have escaped the bay; all those reported fetched up along the inner arm or entered Provincetown Harbor. Stations 5, 6, 6A, and the drift-bottle stations between these points were included in the region.

2. The northern region consists of that part of Massachusetts Bay lying north and west of the southern area. All recovered bottles placed within this area in February drifted in an easterly direction out of the bay. This region may, in turn, itself be divided into two parts, for after passing beyond the tip of Cape Cod, the current divides into two branches, one branch turning west along the outer side of the cape, the other east to continue the anticlockwise drift around the Gulf of Maine.

[3] Portion of Massachusetts Bay bounded by Cape Cod.

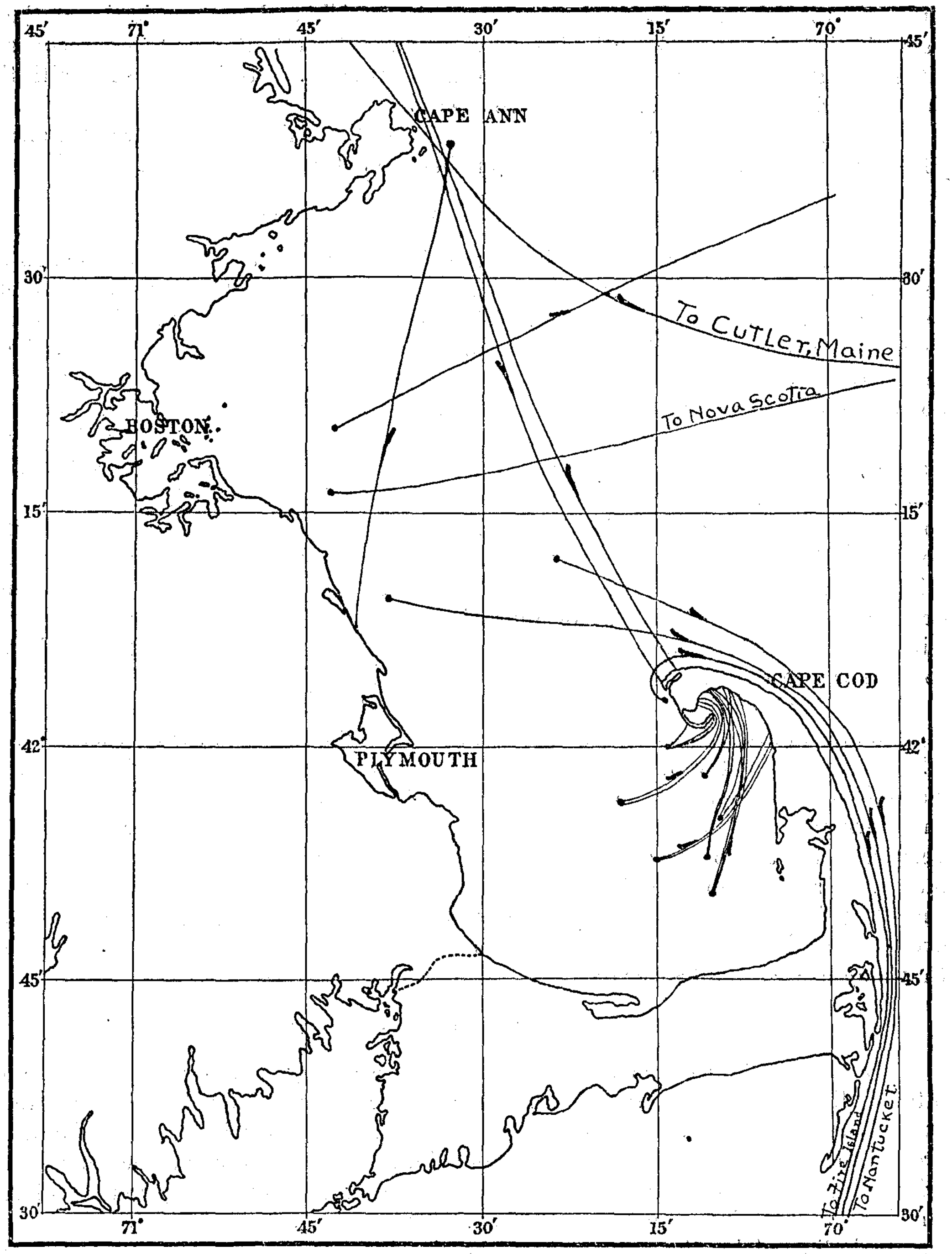

FIG. 14.—Assumed drifts of recovered bottles set out in Massachusetts Bay, February 6–7, and in Ipswich Bay, April 7, 1925, place of release

A line extending east from a point midway between stations 15 and 16 (about latitudes 42° 10′ N.) would divide these two branches. All bottles set out in the southern part of this region turned south after leaving Massachusetts Bay and were recovered either along the outer side of Cape Cod or at Nantucket. Stations 9 to 15, with the inserted drift-bottle stations, are in this section.

Bottles in the northern part turned to the east. This area includes stations 2, 16 to 19, and inserted drift-bottle stations between stations 16 and 19.

RATE OF DRIFT IN FEBRUARY, 1925

The bottle records also throw important light upon the rate of drift. Taken by sections, the February records indicate that the average rate of drift in the southern region was 1.5 nautical miles per day. This slow-moving drift about the inner arm of Cape Cod represents a minor lateral branch of the main current. In the northern region the average rate of the set leaving Massachusetts Bay, as shown by the two bottles found drifting, was 4.4 miles per day. Bottle No. 74, set out in the northern section, had taken the easterly course and averaged 5.4 miles per day for nine days. Bottle No. 89, from the southern part of this region, drifted in the opposite direction at a rate of 3.5 miles per day. Either these two branches later slackened their speed considerably, the route was circuitous, or the bottles remained for some time before being found, because the three that reached Nova Scotia show an average of only 1.36 miles per day and the two grounding at Nantucket, 0.62 mile per day. The average drift out of Massachusetts Bay of approximately 4.5 miles per day agrees very well with Mavor's (1922) records for 1919, when 11 bottles traveled from the Bay of Fundy to Massachusetts Bay at an average rate of at least 4 miles per day.

Applying the drift-bottle data to egg movements, it will be seen that the spawning grounds in Massachusetts Bay are included almost entirely in the northern region. This suggests that the bulk of the eggs produced during the winter and early spring would follow the course of the drift bottles directly out of the bay. Those taken along the inner arm in Cape Cod Bay (figs. 7 and 12) probably represent the output of a very small fraction of the grounds—the southern extremity. The drift-bottle experiments, therefore, indicate that during the height of the season (January and February) by far the greater part of the eggs produced on the Plymouth grounds do not even circle the bay before entering the coastal waters but drift directly out at a rate that may exceed 4 miles per day.

DRIFT-BOTTLE RESULTS IN MAY

By May, 1925, the general set in Massachusetts Bay had become considerably altered (fig. 15). The increased amount of water entering from the Gulf of Maine caused the direction of the set to change, so that, instead of turning west and following around the shore line of the bay, it was forced directly across the entrance in a southerly direction. During the winter and early spring the entering current probably circles around the inner margin of the bay. The general sweep of the drift in May is clearly indicated by the movement of bottles from stations 18A and 32 (fig. 15). In February these bottles would have been directly in the path of the easterly drift, but now they were carried south to the tip of Cape Cod, where two grounded. A third barely missed the cape and was found drifting 2 miles off Peaked Hill Bar.

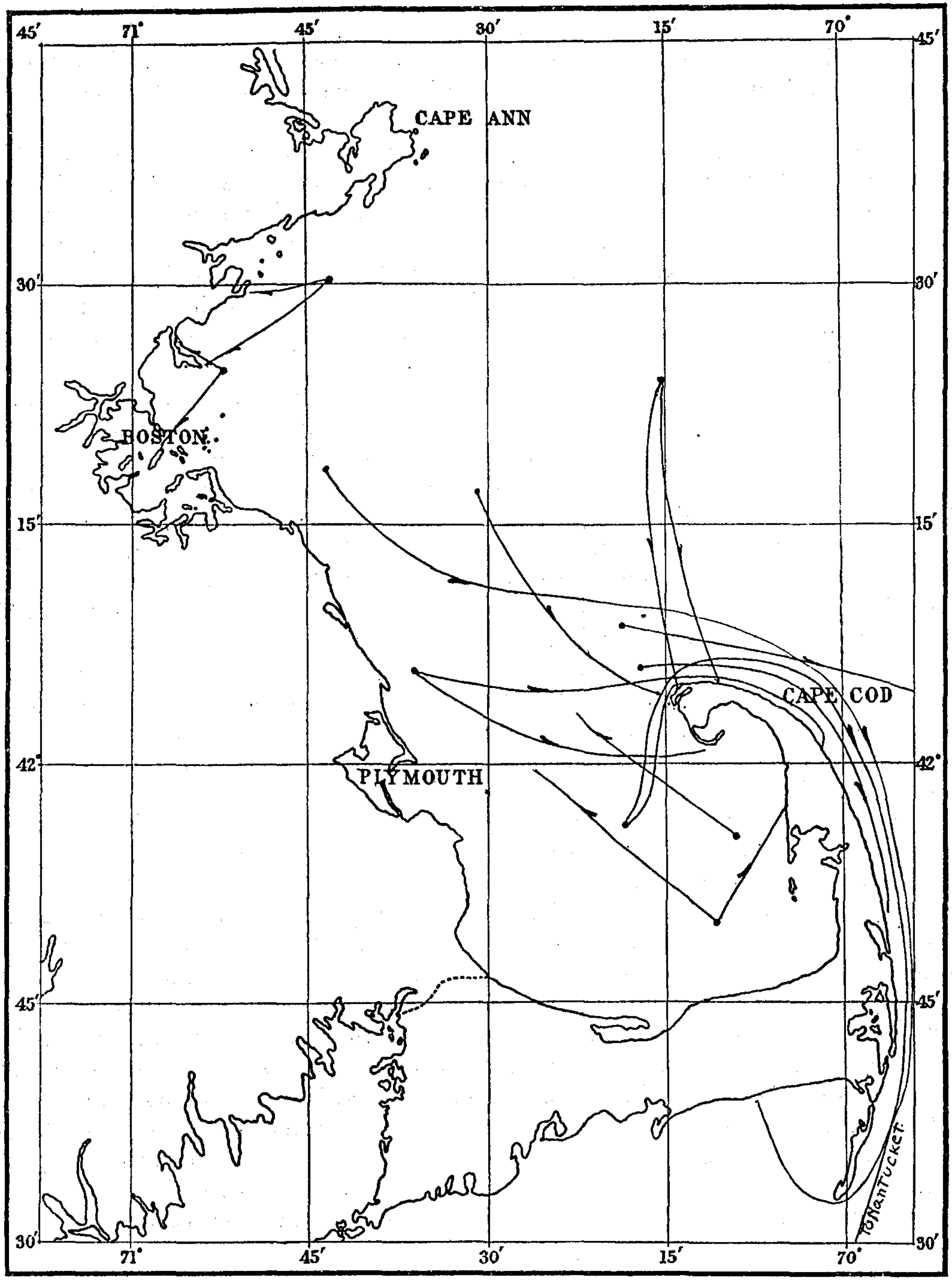

FIG. 15.—Assumed drifts of representative bottles set out in Massachusetts Bay, May 20–22, 1925, place of release

Mavor's bottles in 1919 showed a similar movement across the entrance of the bay, three passing the tip and stranding along the outer side of the cape. However, although the main body of the water mass escapes Massachusetts Bay, bottles placed on the north side indicate that a definite drift passes in along the shore. This set was noted previously in April by the course of bottle No. 99 from Ipswich Bay to the Brant Rock.

There is considerable uncertainty about the movements of the drift in Cape Cod Bay in May. In February the presence of a uniform anticlockwise set was evidenced clearly by the fact that all recovered bottles not grounding along the way passed directly into Provincetown Harbor. However, none of those set out in May reached Provincetown; in fact, but one stranded in the bay. Figure 15 gives the possible movements of bottles at this time. It will be seen that, although the general movements of all bottles placed in Cape Cod Bay were northerly, the exact courses are rather confusing.

One would hardly expect that bottle No. 117 would require 11 days to travel 12 miles and bottle No. 114, placed out on the same day, 9 days to travel 18 miles. The fact that these two bottles passed to the west, directly across the path of two others set out at virtually the same time and which rounded the cape in the opposite direction, is further evidence of the complexity of the set in Cape Cod Bay at this time. Again, in view of the courses taken by the two bottles from station 14 and those from stations 6 and 7, the course of bottle No. 103 to Dennisport Beach is not clear. Therefore, after the beginning of the spring floods, it is not possible to retain the regions into which the bay was divided on the basis of February returns.

Bottles placed in Cape Cod Bay in May drifted in a northerly direction and joined the easterly set out of Massachusetts Bay. Thus, at this time the eggs from all the grounds would drift out. The two sections of the northern region, in turn, could not be distinguished because the movement of all bottles leaving the bay was southerly. That a branch later may pass to the east is illustrated by subsequent observations. As far as is known, none of the bottles set out in May, 1925, by the *Fish Hawk* took this course; but part of a line placed in Cape Cod Bay on April 19, 1926 (Bigelow, 1927), were recovered in Nova Scotian waters and part at Nantucket. This indicates that, even though the dominant drift across the mouth of Massachusetts Bay at this time is southerly, eggs spawned on the Ipswich and Plymouth grounds in the late spring may be transported to either Georges Banks or Nantucket Shoals.

In discussing the results of the April, 1926, series, Bigelow (1927) speaks of a "strong or general tendency southward, across the mouth of Massachusetts Bay and so down past Cape Cod, recalling the drifts of bottles from Ipswich Bay and out of Massachusetts Bay the spring before. All that is needed to make the parallel between the two years complete is Nova Scotian returns for the series of 1926." However, no matter how the currents set in Cape Cod Bay in the late spring, the conditions are equally unfavorable for retaining cod eggs; for, as indicated by the five recovered bottles set out in this region, all not destroyed are carried out.

RATE OF DRIFT IN MAY

Four bottles set adrift on the May cruise were recovered before grounding. The average rate of Nos. 126, 127, and 106 (the courses of which are obvious) was 3 miles per day. The rate of No. 109 from station 14 was 3.4 miles, while the rate of No. 108, from the same station, was 2.9 miles. It is hardly justifiable to give the average rate of all bottles for this cruise, because the courses taken by those within Cape Cod Bay are not definitely known, and such bottles as Nos. 112 and 118 evidently had been on the beach for some time.

The returns from the bottles placed along the north shore of the bay (stations 36 to 38) proved rather surprising. The general courses taken agreed with expectations, being carried either directly inshore by the tide or drifting westward with the set of the current. (Nos. 136 to 141.) However, it was not expected that the rates would be so slow. It is hardly probable that they could have grounded at such widely separated places and, after lying on the shore for several days, all be found within such a short period. No. 136 evidently had been ashore for some time when recovered, but the other four bottles set out on May 22 were recovered on May 27, 28, 31, and June 1. The average rate of Nos. 137 and 141, which were carried west, was 0.92 mile per day. Bottle No. 120, found drifting 75 miles off Highland Light, had traveled a minimum distance of 91 miles at a rate of 4.1 miles per day.

To summarize the evidence shown by bottle movements in Massachusetts Bay, the greater part of the cod eggs spawned in winter and early spring probably move east directly across the bay at a rate of 3 to 4 miles per day. In the late spring the drift certainly is not diminished and, as shown by bottle No. 120, may retain a rate of 4 miles for at least 90 miles.

IPSWICH BAY

The spawning grounds in Ipswich Bay, situated just north of Cape Ann, are in a favorable position to form a source of supply for Massachusetts Bay, for they lie in the path of the westerly drift. Regarding this drift, Bigelow and Welsh (1925, p. 75) state that "fish eggs and larvæ, and for that matter every member of the plankton, animal or vegetable, tend to follow the same peripheral migration zone as do the immigrants that enter the eastern side of the gulf in the upper 50 meters. Only such buoyant eggs as are spawned among the islands, in bays, or close in alongshore (as most of the cunners are) are likely to escape this dominant set."

Three trips were made to the regions lying between the Isle of Shoals and Cape Ann. (Fig. 5.) The data obtained from these few observations are hardly sufficient to explain the conditions existing throughout the season but clearly indicate the movement of the eggs. At the time of the first trip (March 12) considerable spawning was taking place, and an average of 64 cod-haddock eggs was obtained at each of five stations. (See Table 5.) On March 25 the average rose to 117 and on April 7 to 127 eggs per station.

The stations were arranged in two parallel lines (fig. 5), and on every trip the number of eggs taken on the western (inshore) line was by far the greatest, thereby indicating an alongshore and not a seaward drift. The following table, giving the quantitative distribution of eggs on trip 10, illustrates this movement. The two lines were only about 2 miles apart.

TABLE 8

Station	Western line		Station	Eastern line	
	Percentage in cleavage stages	Number of eggs		Percentage in cleavage stages	Number of eggs
28	100	490	27	100	18
26	100	88	25	100	39
24	100	154	23	100	2
22	100	142	21	100	5

The general movement of the set is shown further by the distribution of incubation stages. As the table indicates, all of the eggs taken on trip 10 were in cleavage stages. Figure 16 gives the combined results of the three trips to the Ipswich grounds. It will be seen that in Ipswich Bay the cod eggs drift out at even earlier stages than in Massachusetts Bay, for of 1,767 taken north of Cape Ann, only 1 contained a late embryo. This appeared at station 22, the most southerly station on the inner line.

Whither these eggs drift is a question. Appearing during the increased spring set, virtually all of them pass south across the entrance of Massachusetts Bay, and those that do enter probably do not penetrate far but soon are carried out again

TABLE 9.—*Record of recoveries of 11 bottles set adrift on April 7, 1925, in Ipswich Bay*

Released					Recovered		
Bottle No.	Station	Time, a. m.	Latitude (north)	Longitude (west)	Locality	Date	Interval, days
			° ′ ″	° ′ ″			
95	23	3.20	42 49 30	70 40 00	¼ mile west of Race Point, Cape Cod	Apr. 21	14
96	23	3.20	42 49 30	70 40 00	¼ mile southeast of Race Point	Apr. 24	17
97	21	4.30	42 46 00	70 40 00	2 miles off Cutler, Me.	July 21	105
99	29	6.10	42 38 00	70 33 00	2 miles north of Brant Rock Coast Guard Station, Mass.	Apr. 29	22

DRIFT-BOTTLE RECORDS

Eleven bottles were placed in Ipswich Bay on April 7, 1925, and of these, four have been recovered (Table 9). One entered Massachusetts Bay and was found near the Brant Rock Coast Guard Station. Two moved south across the entrance and stranded near Cape Race, and one drifted around the gulf to Cutler, Me., near the western entrance of the Bay of Fundy. The movements of these bottles reflect the nature of the currents at this time. In passing Cape Ann, two were carried in the main set directly across the entrance of Massachusetts Bay to the tip of Cape Cod. Another, passing outside of Cape Cod, followed the counterclockwise set around the Gulf of Maine, probably traveling along the eastern part of Georges Bank. The route taken by bottle No. 99 indicates that a branch of the current, passing Cape Ann, turns west and follows the shore line into Massachusetts Bay. Any statement regarding the migrations of eggs from Ipswich Bay in the spring must, therefore, be merely speculative. However, it is possible that, like the winter and early spring eggs from Plymouth, some of which, after leaving Massachusetts Bay, appear to go east and others west, many of the Ipswich eggs may deflect to the east after passing south of the Cape and, if the movement happens to be seaward (bottle No. 120), supply Georges Bank as well as Nantucket Shoals.

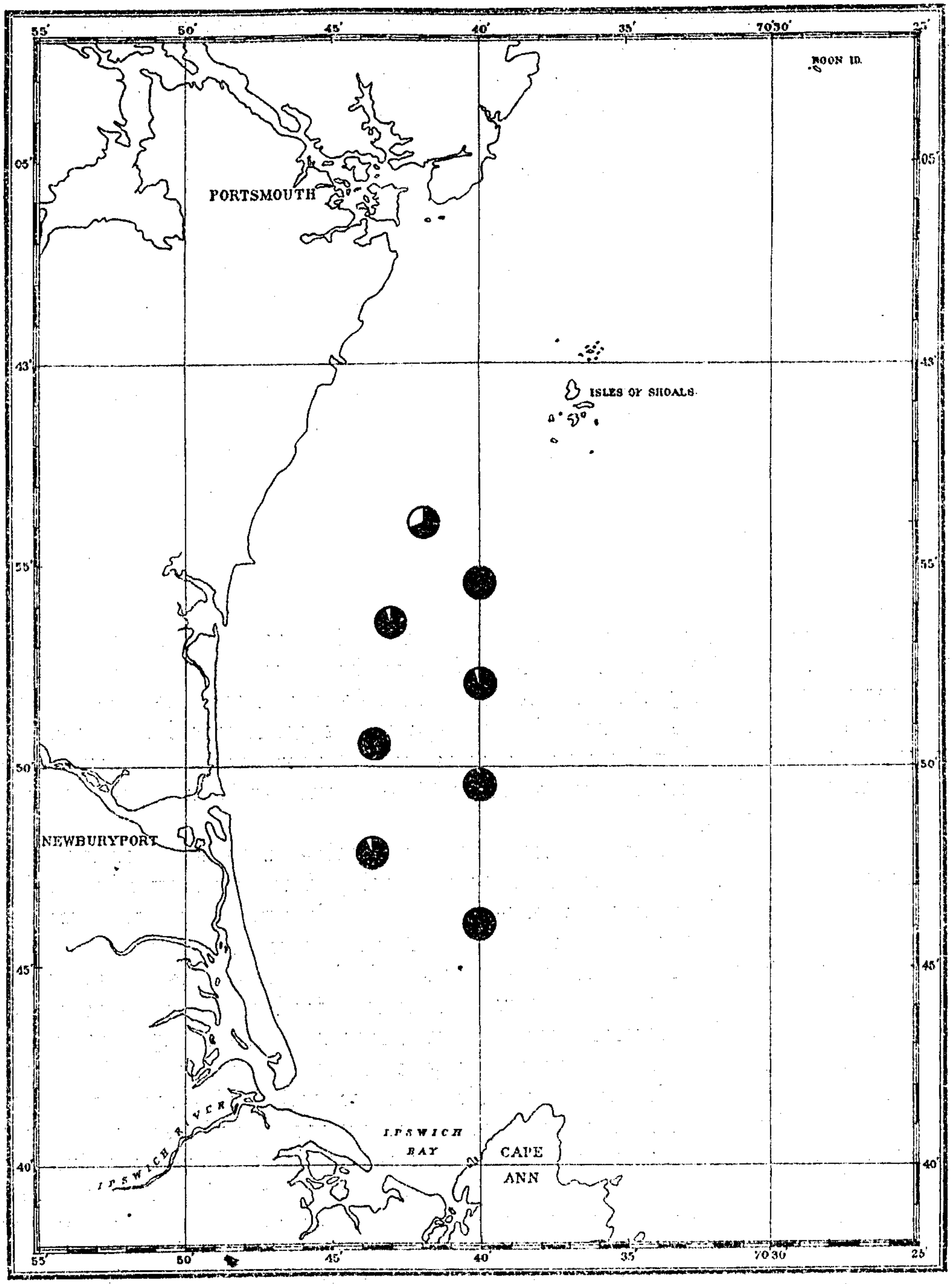

FIG. 16.—Percentage of cod-haddock eggs in cleavage stages in Ipswich Bay during cruises 9 to 12, inclusive. Black secto indicates eggs in cleavage stages

GENERAL DISCUSSION

In attempting to account for the disappearance of cod eggs and the absence of fry in Massachusetts Bay we must take into account the possibility that the eggs perish before hatching. Possibly the absence of fry may be attributed to a combination of two or even more factors. There are several ways in which the eggs and larvæ may be destroyed:

1. *Storms.*—Without doubt storms destroy not only large numbers of pelagic eggs and fry, but immense numbers of other planktonic animals as well. As previously stated, Tables 4 and 5 show clearly the disastrous effects of the storms preceding trips 4 and 6. There can be little question that the decline in the number of cod eggs taken on trip 6, from 697 (the number taken on trip 5) to 236, and the striking reduction in the number of pollock eggs, from 781 on trip 5 to 2 on trip 6, resulted from unfavorable weather. The fact that the sudden drops in numbers in the middle of the season coincided in each case with bad weather and no other apparent change in the physical conditions affords added evidence of destruction by storms. However, storms in themselves are not sufficient to explain how fry can be completely destroyed in a protected area like Massachusetts Bay and yet survive the terrific gales that sweep across such exposed breeding grounds as Georges Banks and the Grand Banks. Were storms the sole destructive agent, at least a small percentage of the large number of late-embryo stages taken in the Provincetown region would be expected to hatch.

2. *Unsuitable physical conditions.*—The possibility that wave action (which in water so shoal would extend from the surface to the bottom) might so disturb the fish that they would stop spawning is not applicable in this case, because, although it might account for the absence of newly spawned eggs, it would not explain the disappearance of later development stages as well. Other physical conditions, such as temperature and density, were normal in 1924–25 and rarely, if ever, approached limits critical to cod eggs.

3. *Food.*—During the late winter and early spring there is a scarcity of zoöplankton in the Gulf of Maine, that present being dominated by adult animals (calanids and Sagittæ) too large to serve as food for early fry. About the time of the spring diatom maximum in March and early April, the reproduction season of the calanids occurs, and by April the water teems with the young. As copepod nauplii form a favorate diet of cod larvæ, there is no lack of food in the late spring. It is reasonable to conclude, therefore, that although food may prove important in some localities, it is obviously not the determining factor in Massachusetts Bay, for the cod-spawning season at Plymouth extends from the period of scanty zoöplankton right through the vernal reproduction period of copepods, and yet no young cod appeared at any time. The eggs vanished just as completely during the time when food was plentiful as when it was scarce. The zoöplankton scarcity in Massachusetts Bay is a short-time one and probably does not affect seriously the natural economy of the region.

4. *Enemies.*—The destruction of fry, and possibly eggs, by enemies in the plankton is probably an important limiting factor. Recent investigators have emphasized the necessity of considering enemies of this sort. Dannevig (1919) found that cod eggs disappear from the spawning grounds in the waters about Lofoten

and Finmark and, although admitting that currents are important as transporting agents, believes that the greatest attention should be paid to the wastage caused by other animals. Bigelow (1926) has also called attention to the importance of enemies in limiting the numbers of fish. In 1925 *Tima formosa*, a large hydromedusa, was everywhere abundant during the height of the cod season at Plymouth, and many of the specimens taken contained one or more young fishes of various species. One was taken with six postlarval herring entangled by its manubrium. As these fish were 40 millimeters in length and capable of rapid movement, the helpless larvæ of such species as the cod must fall an easy prey and be destroyed in large numbers. *Beröe cucumis*, another arch enemy of young fish, also was abundant. There can be little doubt that enemies of this type could destroy large quantities of fish fry; but here, again, contradictory evidence is encountered, for larvæ of pollock were at times rather numerous, even about Plymouth, although this species spawns in very limited numbers in the inner parts of the bay. Were enemies the controlling factor, larval cod could hardly be completely destroyed at all times while specimens of such a closely related species survive in abundance. The following is a record of pollock larvæ taken on the Plymouth grounds on trip 1.

Station	Pollock larvæ
8	35
9	29
10	68
11	42
12	2
17	5

Other species of larval fishes, particularly sand eels, also were abundant at times. On trips 5 to 12 sand eels swarmed along the inner arm of Massachusetts Bay. At station 22 (trip 9) 375 appeared in a single haul. The distribution of this species is not exactly comparable to that of the cod and pollock, because, having demersal eggs, the young hatch and enter the surface waters in precisely the same spot where the eggs were deposited; but it is mentioned to show another species, the young of which escapes annihilation by enemies.

5. Drift.—The evidence of drift is overwhelming. In several other localities investigators have found that ocean currents play an important part in the distribution of cod eggs. Schmidt (1909) studied the drift of eggs about Iceland; Hjort (1914) and Damas (1909) reported similar migrations off Norway, and Petersen (1892) in Danish waters. Dannevig (1919) found that cod eggs disappear with greatest rapidity in the outer waters off Lofoten and Finmarken. An interesting account of the movements of eggs in English waters also has been published by Graham (1925).

In Massachusetts Bay both the drift bottles and the charts on egg distribution show very well the general movement of the circulatory drift in the bay.

Special attention was devoted to the incubation period of cod eggs as affected by fluctuating water temperature and the consequent variations in the interval during which they would drift before hatching. These data were then applied with the rates, as indicated by bottle drifts, to determine the probable distance that eggs leaving Massachusetts Bay would be carried before hatching.

The following table gives the incubation periods of eight collections of cod eggs at the Woods Hole hatchery, the first seven of which were subjected to the normal winter cooling of the water:[4]

TABLE 10

Date received	Number of eggs received	Number good after 24 hours	Date hatched	Number of eggs hatched	Incubation period, days	Average temperature, ° C.
Nov. 10, 1925	426,000	289,000	Nov. 22, 1925	184,000	13	8.5
Nov. 11, 1925	994,000	910,000	do	794,000	12	8.56
Nov. 21, 1925	11,361,000	10,092,000	Dec. 4, 1925	9,176,000	14	6.8
Nov 23, 1925	15,414,000	14,235,000	Dec. 6, 1925	12,387,000	14	6.67
Nov 28, 1925	11,598,000	10,593,000	Dec. 11, 1925	8,573,000	14	6.0
Dec. 9, 1925	6,114,000	5,684,000	Dec. 28, 1925	4,947,000	20	2.83
Dec. 15, 1925	3,553,000	3,290,000	Jan. 5, 1926	2,553,000	22	1.56
Jan. 1, 1926	3,532,000	3,225,000	Jan. 19, 1926	1,613,000	19	3.33

These data were prepared to serve as a comparison with the records of other observers made on eggs maintained at constant temperatures. The collection received on January 1, 1926, after the water had been raised artificially to a constant temperature of 3.33° C., is included as a check and compares very well with the following records of Ryder, Hensen, Earll, Bigelow, and Welsh.

TABLE 11

Incubation period, days	Temperature, ° C.	Authority	Incubation period, days	Temperature, ° C.	Authority
10-11	8.33	Bigelow and Welsh.	20	3.00	Hensen.
13	7.22	Earll.	20-23	3.33-3.89	Bigelow and Welsh.
13	7.50	Hensen.	21	3.33	U. S. Fisheries Manual.
14	6.11	U. S. Fisheries Manual.	24	2.20	Hensen.
14-15	6.11	Bigelow and Welsh.	34	.50	Do.
16	5.00	Hensen.	40 or more	.00	Bigelow and Welsh.
20	3.33	Ryder.	50	−1.20	Hensen.

By comparing Tables 10 and 11 it will be seen that, in determining the length of an incubation period during the fall cooling of the water, the average temperature may be used. Thus, on November 21 eggs hatched in 14 days at an average temperature of 6.8° C., which compares very well with the records of Bigelow and Welsh and the United States Fisheries Manual for eggs maintained at a constant temperature of 6.11° C. Again, on December 9, eggs hatched in 20 days at an average temperature of 2.83° C. as compared to 3° C. given by Hensen for a similar period. In the light of these data it was possible to determine the approximate incubation period at the time of each cruise. Using the range indicated by the mean surface and bottom temperatures, the following results were obtained:

TABLE 12

Trip	Mean surface temperature, ° C.	Mean bottom temperature, ° C.	Approximate incubation period, days	Date 1924-25
1	6.14	6.13	14-15	Dec. 3.
2	6.20	6.25	14-15	Dec. 9-11.
3	5.02	5.46	15	Dec. 16-17.
4	4.30	4.75	16-17	Dec. 22-23.
5	2.54	2.60	22	Jan. 6-8.
6	.75	.95	30	Feb. 6-7.
7	1.65	1.68	26-28	Feb. 24-25.
8	2.00	1.89	24-25	Mar. 10.
11	4.59	3.40	17-20	Apr. 7-8.
12	5.27	4.02	14½-17	Apr. 21.
13	8.89	4.57	9-17	May 20-22.

[4] Eggs obtained from tank fishes.

During the early part of the spawning season at Plymouth, and again near the end of the season, the eggs drift for 14 to 17 days. However, in the coldest months (February, in 1925) the drift may range from 24 to 30 days. Taking 4 miles per day as the average rate at which eggs are carried out of the bay, in December they might travel 56 to 68 miles before hatching; in February they would travel 104 to 120 miles, and it must be remembered that after leaving the egg young cod drift from two to two and one-half months before seeking the bottom. It is quite probable, therefore, that each year fry produced in Massachusetts Bay and the inshore waters north of Cape Ann may be distributed over almost all of the offshore banks. In fact, it is conceivable that some circle the gulf and are carried in on the east side by the same drift that carries the eggs out on the west. Nantucket Shoals, Georges Banks, and the grounds in the Gulf of Maine may all benefit by this dispersal, but to what extent is a question.

It is possible that the presence of the young cod that each year enter the shore waters about Woods Hole in company with large numbers of pollock may be explainable on this basis. Pollock, as far as is known, do not spawn south of the cape, but the extensive breeding grounds on Stellwagen Banks lie in the path of the southerly set, and the eggs could easily be carried south to Vineyard Sound. It is also possible that of the small cod, 3 to 4 inches in length, found in abundance on Georges Bank, in August, 1926, some originated in the inshore waters. Until this work has been extended to cover the outer waters, these suggestions must remain mere possibilities.

We can speak with more confidence about conditions in the inshore waters. There is reason to believe that the cod stock of the coastal belt of the Gulf of Maine is not self-supporting, so that were it not for constant immigration from the outer waters the supply would be exhausted. It is possible that the same drift that carries the eggs out of Massachusetts Bay may carry young fish in from the offshore banks. The large numbers of young cod, 12 to 14 inches in length, found at certain places along the coast of Maine suggest this.

How important Massachusetts Bay is as a production center has not yet been determined. Its value as a nursery is no greater than that of any other equal sector of the coastal belt, but as a source of supply for offshore banks it may prove of significance. To estimate this, it will be necessary to trace the courses of the eggs from the bay, determining where they hatch, the food and enemies of the fry, and their fate. Although it has not been possible, on these 13 cruises, to find solutions to all of the problems involved in a determination of the value of Massachusetts Bay as a production center, it is hoped that it will form the beginning of a much more extended investigation of (1) the outer banks and (2) the fate of the eggs that pass beyond the confines of the bay.

In discussing the cod Professor Baird long ago stated that deep-sea fisheries depleted in any particular locality will not be restored; no fish will come from surrounding localities to take the vacant place (Prince, 1909). The second statement has been borne out to some extent by recent cod-tagging experiments, which indicate that in places schools of cod are confined to certain definite areas and do not migrate up and down the coast in a haphazard manner. However, whether or not the depleted areas would be restored will depend not necessarily on immigration by adults, but upon the ultimate goal of the millions of tiny eggs and fry that drift out of such areas as Massachusetts Bay. If such a drift should bring larvæ to a depleted area, restoration of the cod stock there might be rapid. For example, although the adult cod from the region of Nantucket Shoals apparently do not migrate north of Cape Cod, many of them may have originated from eggs transported from the Gulf of Maine. Therefore, if Prince (1909) were correct in his view that the restoration would be a matter of a long time, it would be necessary to assume that of the millions of fry that Hjort (1914) found to be carried sometimes for hundreds of miles, being sown over the coastal banks, few, if any, survive, and such a condition is inconceivable.

SUMMARY

1. Cod spawn at a wide range of temperature in Massachusetts Bay. Considerable spawning was taking place on November 12, 1924, at a time when the surface temperature had fallen to only 10.1° C. At Plymouth the height of production continued through the coldest season (0° C. or even lower in places). In Norway it has been found that spawning cod are limited strictly to a water layer between 4° C. and 6° C.[5] Spawning in the bay continued throughout April, but apparently had ceased by May 20, 1925. These grounds could be established easily as the production center for locally spawned eggs throughout the season.

2. The results indicate clearly that a very definite and constant counterclockwise drift carries cod eggs spawned in Massachusetts Bay out before they hatch. Throughout the breeding season eggs were found in abundance, particularly about the Plymouth grounds, but the collections of 14 cruises failed to yield a single young cod.

Some of the drift bottles set out to indicate the rate and direction of the drift fetched up on the inner arm of Cape Cod. Those escaping Massachusetts Bay divided into two branches, one of which completed the circle about the margin of the Gulf of Maine and appeared on the Nova Scotia coast. Those turning south passed into the region about Nantucket. One apparently drifted farther to the eastward and was carried in the Gulf Stream to Lands End, Cornwall, England, where it was recovered more than a year later.

Investigations carried on in Ipswich Bay (an important adjacent spawning ground to the north) yielded similar results, showing that here the eggs are carried east or south beyond Cape Ann at even earlier stages than in Massachusetts Bay.

There is evidence that some of the eggs entering Massachusetts Bay from the east in the late spring hatch before leaving the bay, but this is of minor importance, for the fry drift for two to two and one-half months, and the same current that carries them in from the east transports them out again on the south. They are merely transients.

We must therefore conclude that local production in Massachusetts Bay does not maintain the inshore stock, and were it not for constant immigration from the outer waters the supply would be exhausted. As a nursery, its value can be no greater than that of any other equal sector of the coastal belt, but as a source of supply for offshore banks it may prove of significance. This will depend upon the ultimate destination of the eggs passing beyond Cape Cod. It is probable that Nantucket Shoals, Georges Banks, and the grounds in the Gulf of Maine may all benefit by this dispersal.

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[5] Procès-Verbaux, Conseil Permanent International pour l'Exploration de la Mer, Vol. XXXVIII, September, 1925, p. 82.

SIZE OF COD EGGS

In the course of the investigation many interesting observations were made on allied problems, which, for the most part, will have to be treated separately later. However, because of its possible application in future surveys of this type, it may be well to include a brief report on the effect of temperature on the size of cod eggs.

In making a study of production centers where the local stock is supplemented each year by contributions in the form of eggs and pelagic fry from other sources it will be highly desirable if one can determine in any one area the quantity of eggs supplied from other spawning centers and their relative importance compared with local production. If the temperature at the time of fertilization affects the size of cod eggs, and if the physical conditions in two spawning centers are sufficiently different, then it is quite probable that locally spawned eggs in one of these two areas may be distinguished by measurement from immigrants from the other. For example, on the Grand Banks the cod spawn in summer at a time when the temperature of the shallow banks water has risen considerably above that of the Labrador current. If eggs produced farther north and carried south to the banks can be distinguished, through their size, it may throw important light on the problem of whether the cod stock of the Grand Banks is self-supporting or, if not, to what extent it is dependent upon contributions from other sources.

I first noticed the variation in cod eggs collected in the region of the Grand Banks on June 5 to 17, 1924. There was a very striking difference between those from the warm, shallow water over the bank and those from the cold Arctic current. The average size of the banks eggs, based on measurements of about 500 eggs, was 1.28 millimeters, while at station 3, in the Labrador current, the average was 1.42 millimeters. The following table gives the results for each station:

TABLE 13

Date, 1924	Station	Average	Smallest	Largest	Number measured
		Millimeters	*Millimeters*	*Millimeters*	
June 5	1	1.31	1.10	1.38	240
June 7	2	1.27	1.17	1.32	5
Do	3	1.42	1.35	1.55	16
June 12	4	1.27	1.20	1.50	9
June 13	5	1.24	1.20	1.27	7
June 15	6	1.28	1.15	1.40	65
June 16	7	1.29	1.17	1.40	107
June 17	8	1.30	1.19	1.40	56

The eggs were found to average between 1.2 millimeters and 1.3 millimeters everywhere except at No. 3, the most northerly station (approximately 390 miles north of the tip of the Grand Banks), where the surprising average of 1.42 millimeters was found, no eggs being less than 1.35 millimeters. The total absence of cleavage stages at this station (the earliest eggs having the embryo well developed) indicates that they may have been carried for a long distance and belong to an entirely different race of fish, although I do not think the latter condition probable. The rate of flow of the Labrador current at this point, the low temperature, and the number of planktonic forms occurring here and at no other station, tend to substantiate the former possibility. *Metridia longa* and *Calanus hyperboreas*, true arctic forms, were very abundant at station 3, but totally absent elsewhere. A similar variation was found in Massachusetts Bay eggs at various seasons. The average size increased during the cold winter months and declined as the water warmed in the spring.

TABLE 14.—*Cod eggs from Massachusetts Bay*

Date	Average size of 50 eggs	Date	Average size of 50 eggs
	Millimeters		*Millimeters*
Dec. 11, 1924	1.458	Mar. 10, 1925	1.501
Dec. 17, 1924	1.495	Apr. 8, 1925	1.513
Jan. 7, 1925	1.494	May 20, 1925	1.488
Feb. 6, 1925	1.529	June 5, 1926	1.425

Basing conclusions on these collections alone, it was natural to conclude that temperature has a very decided effect on the size of cod eggs, causing them to average larger during the colder periods and decrease in size as the water becomes warmer. Thus, in Massachusetts Bay eggs averaged smallest in December and May and largest in February. In the region of the Labrador current the largest average was found at the northernmost station and the smallest at the more southerly ones, where the summer warming of the water had become noticeable.

In order to determine whether the variations are explainable on the basis of temperature alone, experiments were carried on at Gloucester and on the Boars Head fishing grounds in April, 1926. Eggs and sperm from two fish (*Gadus callarias*) were fertilized in two jars of water, one maintained at 0° C. and the other at 8° C. The water in both jars had been taken from the surface at one spot on the fishing grounds. In general, the results appear significant, 50 eggs fertilized at 0° C. averaging 1.447 millimeters (1.45, 1.44, 1.45, 1.44, and 1.45 millimeters averages in groups of 10) and 50 at 8° C. averaging 1.4106 millimeters (1.41, 1.39, 1.41, 1.43, and 1.41 millimeters). The unfertilized eggs remaining at the bottom of the jars showed the same relationship to temperature, but in each case the average size was somewhat greater than in the developing eggs.

Ehrenbaum found that in the North Sea cod eggs averaged 1.46 millimeters in January and 1.30 millimeters in April. Fifty cod eggs from the Gloucester hatchery averaged 1.497 millimeters on March 25, 1925; of these, 4 per cent were 1.35 millimeters; 14 per cent, 1.40 millimeters; 16 per cent, 1.45 millimeters; 38 per cent, 1.50 millimeters; 10 per cent, 1.55 millimeters; 14 per cent, 1.60 millimeters; and 4 per cent, 1.65 millimeters. Welsh found that artificially fertilized eggs in the Gulf of Maine averaged 1.46 millimeters, but no date is given.

Where water temperatures are more or less even over large areas, cod eggs at two or more spawning centers may average the same in size. In such cases it would not be possible, of course, to make distinctions on the grounds themselves, and any estimates would have to be based on the abundance of eggs traversing a known course from one spawning center to another.

TABLE 15.—*Hydrographic data, Massachusetts Bay and Ipswich Bay. Tables of temperature and salinity*

Cruise, date, and station	Depth, meters	Temperature, °C.
First cruise, 1924		
Dec. 3:		
Sta. 8	0	6.85
	23	6.80
Sta. 9	0	6.93
	33	6.40
Sta. 10	0	6.74
	33	6.80
Sta. 11	0	6.84
	35	6.85
Sta. 12	0	6.51
	27	6.40
Sta. 13	0	5.83
	20	5.80
Sta. 14	0	5.13
	18	4.90
Sta. 15	0	4.82
	20	4.80
Sta. 16	0	5.62
	24	5.80
Sta. 17	0	6.83
	38	6.90
Second cruise, 1924		
Dec. 11:		
Sta. 2	0	6.75
	33	6.79
	66	6.85
Sta. 3	0	6.50
	13	7.50
	26	6.55
Sta. 4	0	6.70
	31	6.42
	62	6.90
Sta. 5	0	5.30
	20	5.43
	40	5.30
Dec. 9:		
Sta. 7	0	6.30
	6	6.32
	12	6.30
Sta. 9	0	6.30
	14	6.73
	28	6.10
Sta. 10	0	6.90
	18	6.93
	36	7.10
Sta. 11	0	6.80
	18	6.82
	36	6.70
Sta. 12	0	6.90
	14	6.42
	28	--------
Sta. 13	0	5.85
	17	5.73
	34	5.50
Sta. 14	0	5.90
	13	5.87
	26	5.80
Sta. 15	0	4.95
	12	4.93
	24	4.90
Sta. 16	0	5.65
	12	5.62
	24	6.10
Sta. 17	0	6.50
	18	6.42
	36	6.50
Third cruise, 1924		
Dec. 16:		
Sta. 2	0	5.95
	28	5.97
	56	5.95
Sta. 5	0	4.60
	21	4.93
	42	4.25
Sta. 6	0	5.20
	13	5.34
	26	4.70
Sta. 7	0	4.25
	7	4.43
	14	4.34
Sta. 9	0	4.90
	17	4.93
	34	4.40
Dec. 17:		
Sta. 10	0	5.40
	18	5.47
	36	5.90
Sta. 11	0	5.40
	18	5.93
	36	6.10
Sta. 12	0	5.60
	13	5.62
	26	6.05
Sta. 13	0	5.80
	12	5.83
	24	5.05
Sta. 14	0	4.60
	11	4.51
	22	4.20
Sta. 15	0	4.25
	10	4.25
	20	4.25
Sta. 16	0	3.80
	13	4.50
	26	4.80
Dec. 16:		
Sta. 17	0	5.15
	16	5.34
	32	5.20
Sta. 18	0	5.40
	30	5.49
	60	5.45
Fourth cruise, 1924		
Dec. 22:		
Sta. 2	0	4.90
	32	4.62
	64	4.90
Sta. 5	0	4.50
	20	4.95
	41	4.50
Sta. 6	0	4.90
	14	4.55
	28	4.80
Sta. 9	0	4.80
	17	4.83
	34	4.80
Sta. 10	0	4.60
	19	4.63
	37	4.80
Dec. 23:		
Sta. 11	0	4.50
	18	4.63
	35	4.60
Sta. 12	0	--------
	16	4.63
	31	3.50
Fourth cruise, 1924—Continued		
Dec. 23:		
Sta. 13	0	2.50
	13	4.54
	25	4.50
Sta. 14	0	4.50
	8	2.56
	16	3.90
Sta. 15	0	3.50
	12	4.54
	24	3.00
Sta. 16	0	4.50
	13	4.54
	25	4.50
Dec. 22:		
Sta. 17	0	4.90
	19	4.53
	35	4.50
Sta. 18	0	4.50
	32	5.03
	64	4.50
Fifth cruise, 1925		
Jan. 6:		
Sta. 2	0	4.05
	32	4.07
	64	4.15
Sta. 4	0	3.65
	29	3.87
	58	4.05
Sta. 5	0	2.80
	19	2.85
	39	2.80
Sta. 6	0	2.45
	12	2.48
	24	2.70
Sta. 7	0	0.36
	6	0.37
	13	0.25
Jan. 7:		
Sta. 9	0	2.15
	16	2.20
	32	2.15
Sta. 10	0	2.25
	19	2.47
	37	2.15
Sta. 11	0	2.00
	18	2.00
	35	1.15
Sta. 12	0	2.15
	13	1.67
	26	1.55
Sta. 13	0	2.00
	13	1.90
	25	1.90
Sta. 14	0	2.15
	13	2.23
	25	2.05
Sta. 15	0	2.05
	10	2.53
	20	2.95
Sta. 16	0	2.70
	10	2.70
	20	2.70
Jan. 6:		
Sta. 18	0	3.50
	32	3.57
	63	4.35
Sta. 19	0	3.95
	29	3.97
	58	4.10

TABLE 15.—*Hydrographic data, Massachusetts Bay and Ipswich Bay. Tables of temperature and salinity*—Continued

Cruise, date, and station	Depth, meters	Temperature, ° C.	Salinity, per mille
Sixth cruise, 1925			
Feb. 6:			
Sta. 2	0	2.00	32.87
	32	1.91	32.90
	63	3.10	32.83
Sta. 4	0	.60	32.51
	30	.60	32.61
	60	1.00	32.74
Sta. 5	0	.60	32.43
	20	−.14	--------
	39	.10	--------
Sta. 6	0	.20	32.23
	8	.81	32.29
	16	.00	32.57
Sta. 6A	0	−.60	32.62
	17	−1.55	32.45
	34	−.40	32.74
Sta. 7	0	−.70	32.35
	6	−.41	32.47
	11	−.60	32.66
Sta. 9	0	1.90	32.70
	15	.59	32.78
	29	.70	33.19
Feb. 7:			
Sta. 10	0	1.00	32.77
	18	.87	32.62
	35	.80	32.79
Sta. 11A	0	1.10	32.67
	18	1.01	32.97
	36	1.20	32.92
Sta. 13A	0	1.20	32.81
	16	1.10	32.94
	32	1.10	33.04
Sta. 14	0	−.10	32.72
	11	−.20	32.98
	22	.20	32.78
Sta. 15	0	.00	32.67
	12	−.50	32.63
	23	2.00	32.91
Sta. 16	0	.00	32.54
	12	−.10	32.92
	24	.50	32.95
Feb. 6:			
Sta. 18A	0	2.00	33.01
	34	1.85	33.08
	68	2.00	32.90
Sta. 19	0	2.60	33.13
	35	2.06	33.26
	70	2.60	33.18
Seventh cruise, 1925			
Feb. 24:			
Sta. 2	0	2.10	32.75
	32	1.83	32.71
	64	1.90	33.07
Sta. 5	0	2.30	32.29
	22	1.88	32.61
	43	2.34	32.99
Sta. 7	0	1.60	32.25
	6	1.48	32.35
	12	1.39	32.34
Feb. 28:			
Sta. 10	0	1.10	--------
	19	1.43	--------
	36	1.40	--------
Sta. 13A	0	1.21	--------
	15	1.13	--------
	30	1.21	--------
Sta. 15	0	1.21	--------
	12	1.21	--------
	22	1.30	--------
Feb. 24:			
Sta. 18A	0	2.00	33.14
	35	1.70	32.51
	70	2.20	33.10

Cruise, date, and station	Depth, meters	Temperature, ° C.	Salinity, per mille
Eighth cruise, 1925			
Mar. 10:			
Sta. 2	0	2.40	32.94
	33	2.14	32.98
	65	2.05	33.12
Sta. 10	0	2.00	32.66
	17	1.63	32.61
	33	2.17	32.52
Sta. 13A	0	1.70	32.61
	13	1.64	--------
	25	1.45	32.36
Sta. 15	0	2.00	32.43
	11	1.67	32.47
	21	1.95	32.58
Sta. 18A	0	1.90	32.90
	38	1.88	32.91
	76	1.85	33.01
Ninth cruise, 1925			
Mar. 12:			
Sta. 20	0	3.50	31.47
	32	2.60	32.94
	64	2.70	33.11
Sta. 21	0	3.60	30.71
	21	2.81	33.08
	41	2.45	33.19
Sta. 22	0	3.80	32.41?
	15	2.46	32.86
	30	2.44	32.94
Sta. 25	0	3.60	31.47
	25	2.40	32.47
	49	2.44	33.02
Sta. 26	0	3.70	31.03
	17	2.36	32.81
	33	2.40	32.94
Sta. 28	0	3.10	32.10
	22	2.60	32.70
	43	2.60	33.21
Tenth cruise, 1925			
Mar. 25:			
Sta. 21	0	3.80	--------
	32	2.71	--------
	64	2.82	--------
Sta. 22	0	3.60	--------
	20	2.72	--------
	39	2.48	--------
Sta. 23	0	3.70	--------
	40	--------	--------
	79	2.89	--------
Sta. 24	0	3.60	--------
	16	2.73	--------
	33	2.57	--------
Sta. 25	0	3.80	--------
	38	2.63	--------
	75	2.90	--------
Sta. 26	0	3.40	--------
	12	3.27	--------
	24	2.64	--------
Sta. 27	0	3.35	--------
	38	2.63	--------
	76	2.85	--------
Sta. 28	0	3.60	--------
	18	2.83	--------
	37	2.59	--------
Eleventh cruise, 1925			
Apr. 7:			
Sta. 3	0	4.10	--------
	30	4.08	--------
	60	3.40	--------
Sta. 4	0	4.40	--------
	30	4.20	--------
	60	3.58	--------

Cruise, date, and station	Depth, meters	Temperature, ° C.	Salinity, per mille
Eleventh cruise, 1925—Contd.			
Apr. 8:			
Sta. 6	0	4.90	--------
	13	4.86	--------
	26	5.14	--------
Sta. 6A	0	4.75	31.86
	22	4.40	--------
	45	2.86	32.§0
Sta. 7	0	5.40	--------
	6	5.25	--------
	12	5.26	--------
Sta. 10	0	4.10	31.18
	20	4.59	--------
	40	2.46	32.26
Sta. 13A	0	5.40	--------
	12	4.63	--------
	24	3.81	--------
Sta. 14	0	5.10	--------
	10	5.22	--------
	20	4.65	--------
Sta. 16	0	5.05	--------
	15	4.93	--------
	30	3.52	--------
Apr. 7:			
Sta 21	0	4.90	28.75
	20	2.62	--------
	39	2.61	31.80
Sta. 23	0	4.60	--------
	37	2.43	--------
	75	2.48	--------
Sta. 25	0	4.75	--------
	33	2.87	--------
	65	2.78	--------
Sta. 28	0	4.20	29.02
	26	2.57	--------
	51	2.61	33.15
Sta. 29	0	4.55	--------
	20	2.83	--------
	39	2.81	--------
Sta. 30	0	4.30	--------
	42	3.13	--------
	84	3.11	--------
Sta. 31	0	4.05	32.02
	57	2.86	--------
	112	2.90	82.59
Sta. 32	0	4.40	--------
	30	3.33	--------
	60	2.72	--------
Sta. 33	0	4.60	31.91
	40	3.69	--------
	80	2.91	33.18
Sta. 34	0	4.40	32.01
	22	2.94	--------
	44	3.12	32.68
Twelfth cruise, 1925			
Apr. 22:			
Sta. 3	0	5.50	31.71
	17	5.49	31.62
	33	3.79	32.50
Sta. 4	0	6.00	31.87
	27	5.20	31.76
	55	4.18	32.32
Sta. 6	0	6.80	32.01
	15	4.63	31.67
	30	3.79	32.21
Sta. 6A	0	6.60	31.75
	17	5.77	31.43
	35	4.98	31.71
Apr. 23:			
Sta. 7	0	6.30	31.55
	6	--------	--------
	12	6.48	31.42
Sta. 10	0	5.60	31.60
	22	5.54	31.44
	44	4.87	31.66

TABLE 15.—*Hydrographic data, Massachusetts Bay and Ipswich Bay. Tables of temperature and salinity*—Continued

Cruise, date, and station	Depth, meters	Temperature, ° C.	Salinity, per mille
Twelfth cruise, 1925—Contd.			
Apr. 23.			
Sta. 14	0	5.30	31.90
	10	5.10	31.72
	20	4.60	31.69
Sta. 16	0	5.70	31.55
	12	5.10	31.62
	24	4.58	31.66
Sta. 17	0	5.60	31.63
	17	5.13	31.71
	35	4.60	31.56
Sta. 18A	0	6.40	31.86
	35	4.00	32.00
	70	2.88	32.48
Apr. 22:			
Sta. 29	0	4.20	31.18
	22	4.23	31.04
	44	3.56	32.00
Sta. 30	0	4.00	31.79
	40	3.42	32.38
	80	2.92	32.82
Sta. 31	0	4.40	31.30
	42	2.63	32.47
	84	2.70	32.81
Sta. 32	0	4.30	31.47
	25	4.11	31.66
	50	3.09	32.41
Sta. 33	0	4.40	32.00
	32	4.18	32.57
	64	3.06	32.65
Sta. 34	0	4.50	31.86
	25	4.02	32.01
	50	3.48	32.91
Sta. 35	0	4.40	31.26
	22	4.23	31.66
	44	3.66	31.86
Apr. 21:			
Sta. 36	0	5.20	31.53
	22	4.83	31.72
	44	3.95	31.65
Sta. 37	0	4.20	31.59
	19	4.83	31.75
	38	4.60	32.00
Sta. 38	0	6.00	31.47
	13	4.57	31.40
	26	4.75	32.09
Thirteenth cruise, 1925			
May 21:			
Sta. 3	0	8.50	31.47
	15	8.14	31.36
	30	5.15	31.59
Sta. 4	0	9.80	31.58
	30	3.83	32.36
	60	3.20	32.35
May 20:			
Sta. 6	0	10.20	31.63
	15	9.95	31.65
	30	9.88	31.78
Sta. 6A	0	10.20	31.73
	17	--------	31.44
	34	4.62	31.89
Sta. 7	0	11.00	31.82
	6	10.96	31.69
	12	10.92	31.64
Sta. 10	0	9.00	31.76
Thirteenth cruise, 1925—Continued			
May 20:			
Sta. 10	17	5.14	31.56
	34	3.99	31.92
Sta. 14	0	8.80	31.85
	10	8.84	--------
	20	4.69	31.87
Sta. 16	0	8.40	31.39
	13	8.64?	31.55
	26	8.52	31.89
Sta. 17	0	8.70	31.60
	16	5.00	31.96
	32	3.68	32.20
Sta. 18A	0	8.15	31.50
	40	3.71	32.29
	80	3.08	32.38
May 21:			
Sta. 29	0	7.10	31.44
	32	3.38	32.61
	64	3.21	32.42
Sta. 30	0	9.40	31.11
	25	3.51	32.21
	50	3.80	32.21
Sta. 31	0	9.40	31.27
	81	3.12	--------
	162	3.10	32.59
Sta. 32	0	9.20	31.66
	35	3.40	32.41
	70	3.09	32.56
Sta. 33	0	8.30	31.74
	25	5.04	32.26
	50	3.28	32.52
Sta. 34	0	9.00	31.59
	28	4.30	32.29
	56	3.31	32.36
Sta. 35	0	8.00	31.47
	22	3.78	32.05
	44	3.31	32.74
May 22:			
Sta. 36	0	6.95	31.87
	23	3.99	32.51
	46	3.72	32.47
Sta. 37	0	8.72	31.71
	20	4.39	32.99
	39	3.69	31.89
Sta. 38	0	9.25	31.35
	15	4.33	32.02
	30	3.86	--------
Fourteenth cruise, 1925			
June 17:			
Sta. 3	0	12.13	32.38
	10	12.05	32.38
	20	9.23	32.52
	30	5.06	33.17
Sta. 4	0	14.79	32.30
	10	14.35	32.30
	20	7.47	32.81
	40	3.75	33.23
	60	3.74	33.24
June 16:			
Sta. 6A	0	15.01	31.80
	10	14.91	32.01
	20	8.47	32.38
	34	4.66	32.45
Fourteenth cruise, 1925—Continued			
June 16:			
Sta. 7	0	15.23	32.23
	10	15.20	32.38
Sta. 10	0	14.43	32.16
	10	12.83	32.23
	20	5.98	32.81
	38	5.69	32.95
Sta. 14	0	15.21	32.09
	10	10.66	32.38
	22	7.56	32.66
Sta. 16	0	15.17	32.09
	10	15.14	32.09
	26	6.76	32.66
Sta. 17	0	15.00	32.23
	10	14.32	32.16
	20	7.27	32.66
	37	4.65	32.95
Sta. 18A	0	15.22	32.33
	10	13.88	32.16
	20	6.11	32.95
	40	3.55	33.39
	79	3.23	33.24
June 17:			
Sta. 29	0	12.91	32.09
	10	12.24	32.09
	20	11.87	32.09
	48	5.19	32.88
Sta. 30	0	13.33	32.38
	10	12.08	32.66
	20	6.39	32.95
	40	4.23	33.24
	75	4.04	33.24
Sta. 31	0	12.94	32.66
	10	9.11	32.74
	20	5.45	33.10
	40	4.00	33.17
	94	3.47	33.24
Sta. 32	0	12.43	32.52
	10	9.62	32.59
	20	4.56	33.39
	50	3.97	33.17
Sta. 33	0	12.94	32.59
	10	11.81	32.45
	20	5.20	33.17
	50	4.09	33.17
Sta. 34	0	12.11	32.59
	10	11.06	32.38
	20	5.56	33.03
	56	3.91	33.10
Sta. 35	0	13.16	32.09
	10	12.72	32.16
	20	12.03	32.30
	40	6.14	32.66
Sta. 36	0	13.53	32.23
	10	12.15	32.38
	20	12.06	32.66
	44	4.61	32.88
Sta. 37	0	12.16	32.38
	10	10.24	32.45
	20	9.08	32.66
	42	5.30	32.88
Sta. 38	0	12.76	32.16
	10	9.75	32.52
	20	8.93	32.52
	28	5.02	32.81

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