May or the first half of June, for salinities as high as 34.5 to 35 per mille were confined to the channel and to the neighboring part of the basin during the last half of that month, with bottom values of 33.8 to 33.9 per mille in the inner branches of the latter—western as well as eastern. A considerable indraft of slope water certainly

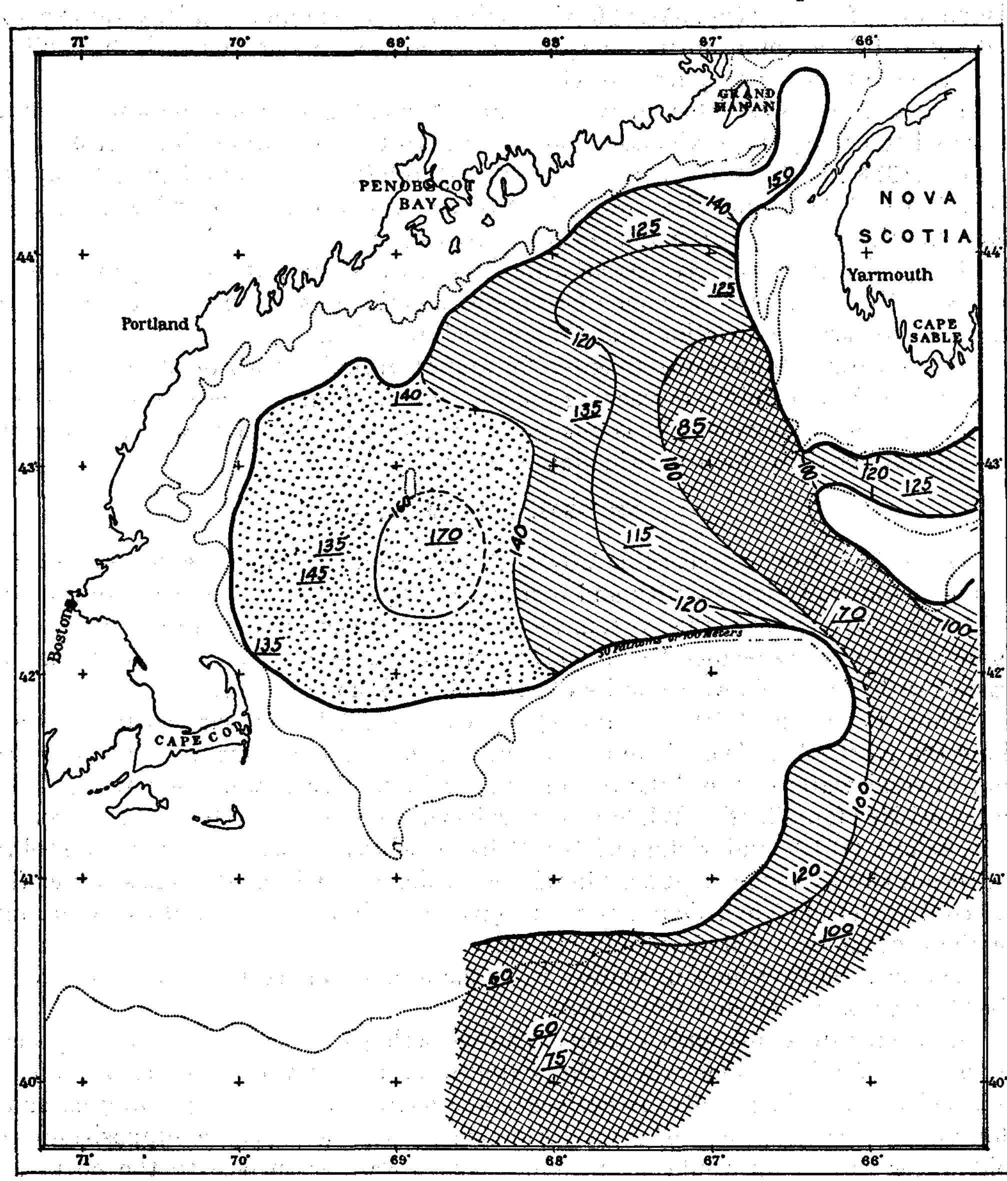

FIG. 172.—Depth of the density surface (isopycnobath) for 1.027; March, 1920. Corrected for compression

took place shortly thereafter, however, spreading inward over both arms of the basin, where the salinity of the bottom water had again risen above 34 per mille by the end of the summer in a layer of considerable thickness (p. 786).

With 10 of our 14 August stations as deep as 180 meters (100 fathoms), or deeper, also showing bottom values higher than 34 per mille in 1912, 1913, and 1914, this indraft is evidently characteristic of June or July. No doubt, however, it varies from year to year, both in its seasonal schedule and in its volume and velocity, and the distribution of density (pp. 958, 960) shows that in some summers, at least (as exemplified by 1914), a counterdrift develops through the channel, out of the gulf, in July, though perhaps only for a brief period.

In a summer when this inflowing bottom current is active, slope water may be expected to occupy approximately the area shown in the contour chart for July and August, 1914 (fig. 152), its boundaries, as in March less extensive than in April, 1920 (figs. 100 and 118), including only the two arms of the trough and the region of their junction instead of the whole central part of the gulf basin.

By good fortune our records afford charts of the slope water at its maximum for the respective months [48]—the one representing a period of active inflow, the other the tendency toward equalization that follows such a period.

Slope water is thus shown to enter the gulf from midsummer on through autumn and winter—but certainly in varying pulses—and to slacken or cease during the late spring and early summer. It is not possible to outline its fluctuations in the gulf more definitely than this from the data gathered so far.

ABYSSAL UPWELLINGS

Upwellings from the oceanic abyss, if such occur, would be a second possible source of water of high salinity and moderate temperature for the deeps of the Gulf of Maine. Upwelling of this sort, in fact, has often been invoked to explain the low temperature of the so-called "cold wall" (referred to here as "slope water"), as contrasted with the tropic water on its offshore side (Buchan, 1896).

Thus, Pettersson (1907 and 1907a), for example, definitely classed the cold wall along the North American littoral as an updrift over the continental slope from the cold abyssal water of the Atlantic, having for its motive power the sinking of cold water off Newfoundland. While this view has not found a very favorable reception, both Schott (1912) and Krümmel (1911) have believed that more or less upwelling does occur along our coasts, at least in winter; while A. H. Clark (1914) has argued that the cold water off Nova Scotia must receive something from the abyss to account for the geographical distribution of crinoids.

The criteria by which upwelling from the oceanic abyss would be made recognizable may be stated in a few words.

In temperate zones surface temperature is perhaps the best index of this process in summer, for in regions where the water wells up actively seasonal warming is retarded, causing abnormally low surface temperature. Unless the upwelling extended along the whole east coast of North America (a most improbable supposition) any cold water welling up would be surrounded by a warmer surface to the north and south of it as well as on its offshore side, as is the case off California (McEwen, 1912) and off the northwest coast of Africa (Schott, 1902, pl. 8). At the same time there would be a continuity in salinity between this cold water near the surface and the

[48] 1920 was a salt March, compared with 1921; 1914 a salt summer, compared with 1913.

deep stratum that served as the source for the updraft, as demonstrated by the distribution of salinity off the coast of Morocco (Schott, 1912, pl. 33). Off the northeastern American seaboard abyssal water would also be betrayed by its precise combination of salinity and temperature, for while only moderately cold (about 4°), the salinity of the Atlantic abyss is much higher (34.9 to 35 per mille) than that of any water on the continental shelf of like temperature.

The observations taken in 1912, on our first cruise, were enough to prove that the inner part of the Gulf of Maine received little if anything from this abyssal source, its salinity being too low and its mean temperature too high.

The rapid warming of the superficial stratum, which takes place all along our seaboard in spring from Nova Scotia to Chesapeake Bay (except in limited areas of active tidal stirring), is, of itself, incompatible with any widespread upwelling of abyssal water, unless this be confined to the deeper strata. So, also, is the wide variation in surface temperature from season to season; for any considerable updraft from the abyss would necessarily check vernal warming and so narrow the seasonal range of temperature. The profiles which the *Grampus*, *Acadia* (Bjerkan, 1919), and *Albatross* have run across the continental shelf between Chesapeake Bay and the Laurentian Channel have produced a large body of evidence to the same general effect; particularly welcome because upwelling had been postulated more on theoretic grounds than from first-hand observation, previous knowledge of subsurface salinity on the continental shelf between Cape Sable and Chesapeake Bay being virtually *nil*. None of these temperature profiles for the summers of 1913, 1914, 1915, and 1916 (Bigelow, 1915 to 1922) yield any evidence that abyssal water ever tends up the slope, much less reaches the continental shelf at that season. To the west of Cape Sable, in fact, the coldest water in on the shelf has been separated from the low temperatures of the water of the deeps by a somewhat warmer zone washing the edge of the continent bottom at intermediate depths in most cases (p. 617). The corresponding salinities have been no more compatible with upwelling either at the time of observation or shortly previous, the coldest water on the shelf being in every case much less saline (below 33.5 per mille) than the level of equally low temperature outside the edge of the continent (34.9 per mille, or higher, at all seasons).

As I have discussed this question in detail in earlier publications (1915, p. 258; 1922, p. 166), I need only add here that none of the observations taken by the *Bache* off Chesapeake Bay in January, 1914 (Bigelow, 1917a), by the *Grampus* between Marthas Vineyard and Chesapeake Bay in November, 1916 (Bigelow, 1922), or by the *Albatross* off the Gulf of Maine in the spring of 1920, show any more evidence of abyssal water reaching the continental shelf than did the earlier observations.

The only route we need consider, then, by which abyssal water might, perhaps, enter the Gulf of Maine, is the Eastern Channel; but the precise combination of temperatures and salinities recorded in its trough for the months of March, April, June, and July (6.07° to 7.2° and 34.6 to 35.03 per mille), combined with the general distribution of salinity and temperature within the gulf, points to quite a different source (the slope water) for the intermittent current that drifts inward over the bottom of the channel, as is discussed above (p. 842).

The distribution of density must, in fact, strongly resist any force, such as offshore winds driving the surface water out to sea, which would tend to draw abyssal water upward over the continental slope abreast the Gulf of Maine; for in every case we have found a decidedly stable state of equilibrium prevailing there. In fact, most of our cross sections of the outer part of the continental shelf abreast the gulf and to the eastward show a general dynamic tendency of quite a different sort—namely, one leading to the development of a drift of the inner slope water toward the west (p. 847), while a counter drift of the outer slope water (or "inner edge of the Gulf Stream") toward the east has often been recorded.

In short, continued observation has not adduced any evidence that water from the ocean deeps ever wells far enough up the continental slope to reach the Eastern Channel, much less to overflow the offshore rim of the gulf.

This conclusion does not imply that upwelling may not take place over the lower part of the continental slope from the Atlantic abyss. On the contrary, much evidence has accumulated to the effect that some such process is of wide occurrence along the lower part of the slope, below, say, the 500 to 1,000 meter level, westward and southward from Georges Bank. Perhaps the clearest evidence of this is afforded by a profile run from Chesapeake Bay to Bermuda by the *Bache* in January and February, 1914, when the uniform abyssal water (about 4° in temperature and 34.9 to 35 per mille in salinity) was banked up against the slope to within 1,100 to 1,200 meters (Bigelow, 1917a, figs. 11 and 12). This also appears on a profile run by the *Dana* from Bermuda to Norfolk, Va., in May, 1922 (Nielsen, 1925, fig. 4). But no direct evidence has yet come to hand that water from this deep source ever reaches the continental shelf of eastern North America in volume sufficient to affect the temperature or salinity of the coast waters.[49]

In denying the occurrence of abyssal upwelling as a cause of low temperature in the Gulf of Maine, I do not refer to upwelling from shallow water along shore—a common event, which often exerts an immediate effect on the temperature and salinity of the surface water in the vicinity in spring and summer, as described in an earlier chapter (p. 550).

RECAPITULATION

The Gulf of Maine incloses a sector of the typical coastwise water of the northwestern Atlantic, receiving its most important accessions periodically from the following sources: Slope water of high salinity (close to 35 per mille) and close to 6°–8° in temperature flows intermittently into the gulf as a bottom current, as it does also into the Gulf of St. Lawrence and into other smaller depressions on the continental shelf. There is strong evidence that the slope water that reaches the Gulf of Maine has its source along the Nova Scotian slope to the eastward. The cold Nova Scotian current brings a large volume of water of low salinity into the gulf from the eastward, past Cape Sable, in spring, as a surface drift; but this current slackens or ceases altogether at other times of year. The gulf also receives a surface drift from the offing of Cape Sable, into the composition of which cold banks water from the east, slope water from the Scotian eddy, and tropic water all enter in proportions that can not yet be stated.

[49] For further discussion of this subject as it concerns the Gulf of Maine, see Bigelow, 1915, p. 255, and 1917, p. 239.

At most times there is no dominant drift into the gulf across Georges Bank, but on rare occasions overflows of tropic water take place at the surface, probably via that route.

The discharges of various rivers, added to rainfall, contribute annually to the gulf sufficient fresh water to form a layer half a fathom thick over its inner parts out to Georges Bank. The gulf also receives annually a blanket of rain water about a foot in thickness, in excess of the amount withdrawn by evaporation.

The gulf discharges water as a surface current around Nantucket Shoals to the westward; to some extent around the eastern end of Georges Bank,[50] and so out through the Eastern Channel.

It is not likely that the gulf ever receives water from the oceanic abyss, by upwelling, or directly from the Labrador current.

CIRCULATION IN THE GULF OF MAINE

Study of the circulation that dominates any part of the sea can be attacked in two different ways: (1) Directly, by observation with current meters or drift bottles, by ships' log books, and by interpreting the distribution of salinity and temperature, or (2) indirectly, by calculation of the hydrostatic forces tending to set the water in motion. The second method has greatly concerned oceanographers of late, and its value can hardly be overestimated in the study of ocean currents in the open sea; but its application to the Gulf of Maine is complicated by the disturbing factors introduced by the irregular contour of the bottom, the limiting coast line, and the strong tides, which not only produce currents of considerable velocity, but are constantly altering the slope of the surface. It is fortunate, therefore, that the following account can be based on the more direct methods of observation, supported by consideration of hydrodynamic forces as causative agents (p. 930).

TIDAL CURRENTS

No one can sail the Gulf of Maine without soon learning that its tidal currents run so strong that they must always be taken into account in coastwise navigation. Their velocities are so great, in fact, in most parts of the gulf, at the strength of ebb and flood, that for the ordinary observer they entirely obscure any dominant or nontidal drift that may be in progress.

No attempt has been made to add to the knowledge of the tides during our survey; but the following brief statement, condensed from the Coast Pilot, the tide tables and current tables of the Atlantic coast published by the United States Coast and Geodetic Survey (1923 and 1926), from the investigations of the Tidal Survey of Canada (Dawson, 1905 and 1908), and from other scattered sources, may be of interest.[51]

The flood, at its strength, runs northerly, the ebb southerly, along the whole line between Nantucket Shoals and the Northern Channel and likewise in the basin to

[50] For discussion of the discharge from the gulf see p. 974.

[51] In 1912 the *Grampus* recorded the velocity of the current near the mid-period of flood or ebb, hoping to learn the approximation of the direction and velocity at its strength. The value of these measurements is discussed in an earlier report (Bigelow, 1914, p. 83).

the north (Mitchell, 1881; Harris, 1907, pl. 7). This is also the case along the west coast of Nova Scotia on the one side of the gulf and along Cape Cod on the other; but the flood runs westward into Massachusetts Bay, as might be expected from the trend of the coast line, drawing southward around the tip of Cape Cod into Cape Cod Bay. There is also a flood current from the westward into the latter, resulting from a division of the tidal wave as it strikes the shore line at Manomet Head just east of Plymouth.

The promontory of Cape Ann also marks a division in the tidal streams; for to the northward of it the flood, setting westward in toward the land, veers to the north, paralleling the coast as far as Cape Elizabeth; to the eastward of Casco Bay the general direction of the flood at its strength is NNE. toward and through the Grand Manan Channel, complicated, however, by the flood currents setting into the bays and rivers. At the mouth of Casco Bay, for example, the tides flood to the north. In the Bay of Fundy the flood sets generally toward the northeast (i.e., inward).

In a general way the ebb, at its strength, is the reverse of the flood, setting out of the Bay of Fundy in a generally SW. to SSW. direction and around the coast of Nova Scotia to the south and southeast. Along the coast of Maine, from the Grand Manan Channel to Penobscot Bay, the tide ebbs southwesterly; southerly off Casco Bay. In Massachusetts Bay the ebb is generally eastward; southerly along Cape Cod.

Generally speaking, the velocity of the tidal currents is least along the sector of coast bounded by Cape Cod on the south and Casco Bay on the north, where velocities lower than 1 knot have been recorded at most of the observing stations for the flood at its strength. But the tide flows much more strongly (up to 1.8 knot) around the tip of Cape Cod and at the entrance to Boston Harbor. The Bay of Fundy stands at the other extreme, with velocities rising to 2.5 to 3 knots in the Grand Manan Channel; considerably higher even than this near the head of Minas Basin and elsewhere near the head of the bay. The velocity of the tides at strength is about 1 to 1.6 knots along the southern rim of the gulf; 1.5 to 2 knots along the west coast of Nova Scotia and out to the neighboring side of the basin.

The rise and fall of the tide is greater in the Bay of Fundy than anywhere else in the world; on the other hand, the tidal amplitude is certainly small over the offshore banks, though the rise and fall has not been measured there as yet.

The following summary of the rise and fall at representative stations, taken from the tide tables of the Atlantic coast (United States Coast and Geodetic Survey, 1926), will illustrate the transition from the mouth of the gulf inward along its two sides for ordinary tides:

Locality	Rise and fall of tide, in feet	Locality	Rise and fall of tide, in feet
WESTERN SIDE		EASTERN SIDE	
Outer shores of Cape Cod	4.3- 7.1	Shelburne, Nova Scotia	6.5- 7.9
Provincetown	7.5-11.1	Yarmouth, Nova Scotia	16.3-17.7
Gloucester	7.2-10.8	BAY OF FUNDY	
Portland	7.9-11.3	St. John	23.7-25.1
Bar Harbor, Mount Desert	9.2-12.6	Digby	27.2-28.6
Cutler (at western end of Grand Manan Channel)	12.9-16.3	Head of Minas Basin	48.7-50.1

DOMINANT OR NONTIDAL DRIFT

In the preceding summary of the tidal currents, directions and velocities are given for the flood and ebb at their strength. In some localities the direction continues virtually constant throughout ebb or flood, as the case may be. In most parts of the gulf, however, the current is to a greater or less extent a veering one, and there is some difference in velocity between flood and ebb. The resultant of movement by which any particle of water would fail to return at the end of any given tidal period (averaging 12 hours and 25 minutes) to the position from which it started its journey, is the dominant drift. The name "nontidal" is commonly used for this; the other appellation just given is preferable, however, there being some evidence that the dominant drift which we have been able to demonstrate for the Gulf of Maine has its source in the tidal currents.

On the high seas, where tidal currents are weak and the dominant drifts are often stronger, the ocean currents, as we now know them, have been charted chiefly by digestion of the drifts reported in the log books of passing ships. This source of information has failed to demonstrate any dominant set (as distinguished from tidal currents) in the Gulf of Maine, as might be expected where the tides are so strong and the resultant movement, if any, comparatively so weak.

MEASUREMENTS OF CURRENTS

A considerable number of measurements of the tidal currents have been made in the Gulf of Maine by the United States Coast and Geodetic Survey at the following localities: Portland lightship off Cape Elizabeth, near Cashes Ledge, three stations between Cape Ann and Cape Cod at the mouth of Massachusetts Bay, Boston lightship off Cape Cod, many stations at the mouth of Nantucket Sound and in the region of Nantucket Shoals, Nantucket lightship, and at a series of stations situated along the southern rim of the gulf from the South Channel to the offing of Cape Sable.

The Tidal Survey of Canada, under Doctor Dawson's direction, carried out an extended survey of the tidal currents at 19 stations distributed around the Nova Scotian coast from the offing of Shelburne to the Bay of Fundy, and within the latter, in the years 1904 and 1907 (Dawson, 1905 and 1908).

One current station also was occupied off Gloucester by the *Albatross* in March, 1920 (station 20051); and measurements of the velocity and direction of flood or ebb were made by the *Grampus* in the summer of 1912 at several localities in the western side of the gulf.

Thus, the western, southern, and eastern sides of the gulf are so well covered that these measurements could hardly fail to reveal the dominant set (if there be any) for that part of its periphery; but no systematic study has yet been made of the tidal currents along the eastern coast of Maine between Portland and the entrance to the Bay of Fundy.

Before proceeding to analyze these data we may first consider briefly what sort of information they may be expected to yield.

Readings of the current meter (or the simpler method of employing a float) give the rate of the current over a known interval of time and its direction.[52] These, then, are reduced to average velocities and directions for each tidal hour after the time of high water at some neighboring station of reference, and it is in this form that they appear in the current tables published in the United States Coast Pilot (United States Coast and Geodetic Survey, 1911, p. 151) and in the current tables for the Bay of Fundy (Dawson, 1908). In all such tables the direction stated is that toward which the current flows, referred to the true meridian. In other words, a "northeast" current is just the opposite of a "northeast" wind.

To plot the course which an imaginary body, floating in the water, would travel during the period from one high tide to the next, is perhaps the most graphic way to bring out the existence or absence of a dominant drift at any given locality. If the flood and ebb currents are exactly opposite in rate, duration, and direction, such a float would return precisely to its starting point, for there would be no resultant drift. In all probability, however, this would never happen in any part of the Gulf of Maine. If, with ebb and flood opposite in direction throughout their respective duration, one were stronger than the other, a dominant set would result parallel to the direction of the stronger. This condition is to be expected in narrow channels, such as the Grand Manan Channel, and close in along some parts of the coast line; but in most parts of the gulf the direction of the tidal current changes from hour to hour, running in a comparatively constant direction for only a few hours when ebb or flood is at its strength. In some localities the tidal current is perfectly rotary, with its direction veering uniformly throughout the half-tidal day. Such a state, for example, is to be expected about 16 miles to the eastward of Nantucket Shoals light vessel (United States Coast and Geodetic Survey, 1912, p. 10).

In the Gulf of Maine and on its offshore banks tidal currents veer always to the right—i. e., with the hands of the clock—most rapidly, in most cases, at the times of high and low water. Thus, a particle of water or any floating object, such as a buoyant fish egg, drifting during a tidal period, would follow a course varying in different parts of the gulf from a closed circle (bringing it back close to its starting point), through various types of veering spirals, to courses nearly opposite in direction for the two tides but unequal in distance. In most parts of the gulf, therefore, any such floating object would not follow the dominant or nontidal set *directly*, but in a zigzag or spiral course, traveling a much greater distance in the daily tidal components than the distance made good along the azimuth of the nontidal set.

The dominant set that results from a veering current may be deduced in various ways. If calculation be preferred, an approximation is easy with the ordinary navigational traverse tables in precisely the same way the navigator calculates, from his dead reckoning, the distance and course made good for the day.

In most cases a graphic method of summation is to be preferred. The following (now in common use and recently described in detail by Mavor (1922)) is, perhaps,

[52] It should be borne in mind that in tabular statements of currents the words "velocity" and "distance" are not synonymous; for, obviously, if the current is flowing at a rate of 1 mile per hour at one hour, and at 2 miles per hour an hour later, the distance made good during the interval is neither 1 mile nor 2 miles, but the mean of the two. This caution is added because some of the published tables of currents have been ambiguous in this respect.

the most convenient and yields approximations close enough for most purposes: Lay down a meridian, marking it N. and S. Then simply plot, to scale, the average distance and direction of the current for each successive hour, as successive lines, giving to each the correct compass bearing, commencing with high water as the starting point. Then the distance by which the location reached at one high water fails to coincide with the preceding high water, measured by the same scale, gives an approximation to the distance covered by the dominant set in one tidal day. The angle between the line connecting the two and the meridian first laid down gives the approximate direction.[53]

It is obvious that the smaller and more frequent the time intervals for which the mean velocity and direction are determined by the current meter, the closer will be the approximation yielded by this method of graphic summation, or by any other.

The work of the two governmental surveys just mentioned (of Canada and of the United States) has been directed primarily to the study of the tides as these affect navigation. Mitchell (1881), however, showed that resolution of the periodic observations at stations in the South Channel, on Georges Bank, and in the Eastern and Northern Channels demonstrated a dominant or nontidal drift at every station, in some cases of considerable velocity. A nontidal drift has also been published for many stations off Cape Cod and in the region of Nantucket Shoals (United States Coast and Geodetic Survey, 1912, chart to face p. 9), as well as for the vicinity of Cashes Ledge (Harris, 1907), long before the general importance of these drifts in the general circulation of the gulf was appreciated.

Dawson (1905, p. 16), on the other hand, believed that the currents in the eastern side of the gulf were strictly tidal, showing no "general movement of the water in any one direction in this region which is at all well marked." Mavor (1922), however, on submitting Dawson's current tables to the method of graphic summation described above, found that a dominant drift was demonstrable at every station, varying in "distance made good" for a single tidal period from about 1 mile to about 6½ miles. Dominant drifts of greater or less magnitude also result from tidal measurements taken at Portland and Boston lightships by the United States Coast and Geodetic Survey and at our *Albatross* station off Gloucester. The number of current stations is now so considerable that the presence of some such set is certainly characteristic of the parts of the gulf which they cover.

Some resultant drift in one direction or another is, in fact, to be expected anywhere in the open sea, set in motion by the temporary effects of the winds alone, if from no other cause. Whether or not such drifts as are revealed by measurements of the tidal currents can be interpreted as evidence of a dominant movement of the water as a whole depends, therefore, on their relative constancy at given stations and on whether they are consistent in direction, one with another, over considerable areas.

This last criterion can be tested most readily by plotting on a general chart of the area the dominant drifts calculated for the various stations.

The current arrows on such a chart for the Gulf of Maine (fig. 173) show this requirement met to a degree somewhat surprising when we remember that the observations were scattered through a long series of years and that the "sets" at the

[53] It is convenient to use a position plotting sheet, such as can be had from any dealer in navigational supplies.

individual stations varied widely in their duration, some being continued through several successive months and others only for a few days. Even if nothing else whatever were known of the movements of the water in the Gulf of Maine, these arrows

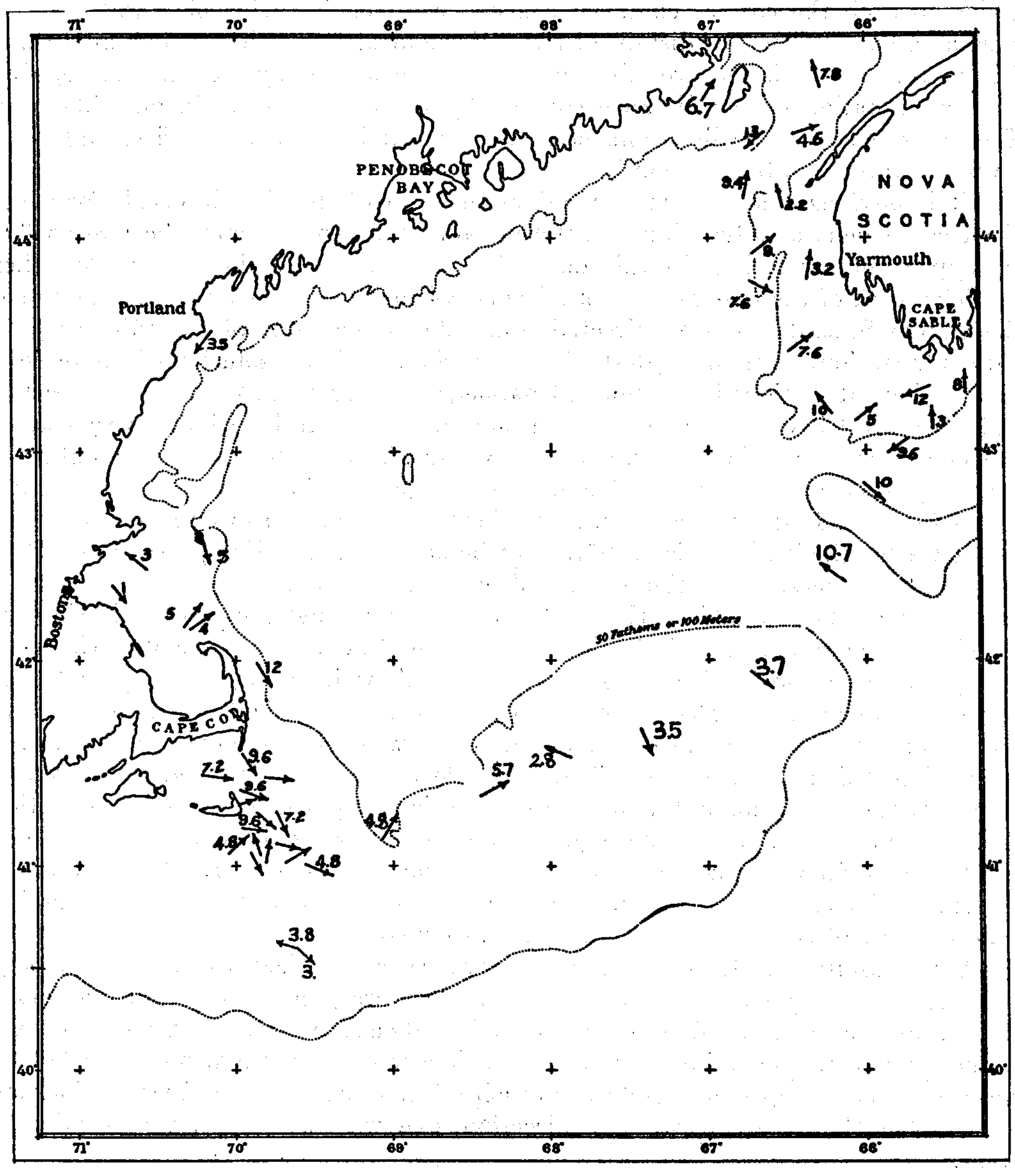

FIG. 173.—Direction and velocity, in miles, of the non-tidal current, per tidal day of 24 hours and 50 minutes, at stations of the United States Coast and Geodetic Survey and of the Tidal Survey of Canada. The feathered arrow is for the one *Albatross* station (20051)

would of themselves be strong evidence of a general tendency inward and northward along the western shores of Nova Scotia and out to the southeastward past Cape Cod and the Nantucket Shoals region for the summer and autumn months when the current measurements were taken.[54] Mavor (1922, p. 109) has already emphasized the inward movement thus indicated around Nova Scotia and so into the eastern side of the Gulf of Maine. The drift to the westward past Cape Sable is shown to be irregular, however, and perhaps intermittent, for a very rapid dominant drift toward the west of about 12 miles per day, at Dawson's station R in the offing of Cape Sable, contrasts with contrary and much weaker resultant currents at two localities nearby (Dawson's stations P and Q). In the same way the water in the offing of Shelburne was setting strongly in toward the shore on June 25 to 29, 1907, showed no dominant drift in any direction at a neighboring station two weeks later,[55] but was drifting toward the southwest at a rate of about 8 miles per day on July 27 to 28, 1914 (Bigelow, 1917, p. 203, station 10231; current measurements at 6 meters depth with Ekman current meter).

The most that can be said is that the current arrows show some movement to the westward past the cape at times during the summer.

The general tendency northward along the western shores of Nova Scotia, toward the Bay of Fundy, is decidedly impressive, because not one of the arrows, as calculated from Dawson's tables (1908), runs counter to this rule, the only exceptions being two (his stations L and M), which point almost directly in toward the land. The arrows also show the water drifting into the Bay of Fundy along its southern (Nova Scotian) side, then turning northward toward New Brunswick and out again to the eastward and southward of Grand Manan. In the channel on the northern side of the latter, however, the water has been found to set inward toward the Bay of Fundy, suggesting a clockwise circulation around Grand Manan, which corroborates the local report that the flood current predominates over the ebb along the eastern part of the coast of Maine (Coast Pilot).

It is unfortunate that no measurements of currents are available for any points between the Bay of Fundy, on the east, and Portland lightship, to the west, for the tides run strong along this sector of the coast line.

At Portland lightship the currents are weak but slightly rotary (United States Coast and Geodetic Survey, 1923, p. 69).

The Coast and Geodetic Survey has supplied the following statement of the dominant (nontidal) set for several 29-day series at this location (lat. 43° 31′ 30,″ long. 70° 05′ 38″).

Duration of series	Rate per day (24 hours) in miles	Direction	Duration of series	Rate per day (24 hours) in miles	Direction
Oct. 3-31, 1913	11.3	S. 67° W.	July 1-29, 1919	2.4	N. 62° E.
Nov. 1-29, 1913	9.6	S. 31° E.	Aug. 1-29, 1919	2.2	S. 74° W.
Nov. 30-Dec. 28, 1913	11.3	S. 11° W.	Sept. 1-29, 1919	.5	N. 47° E.
June 1-29, 1919	4.3	S. 36° W.	Oct. 1-29, 1919	1.7	N. 58° E.

[54] So far as I have been able to learn, the only winter measurements made in the Gulf of Maine have been at Nantucket Shoals Lightship and one *Albatross* station off Gloucester (station 20051, p. 857).

[55] The resultant drifts for these two stations (Dawson, 1905 and 1908, statations S and T) are taken from Mavor's chart (1922, Pl. IV).

It is natural to think of the wind as partly responsible for these variations in the direction and velocity of the drift, and this is borne out by the following table giving the wind movements and directions at Portland, Me., for each month, and the resultants calculated therefrom by traverse tables.[56]

Month	Wind movement, miles								Resultant
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	
October, 1913	2,471	449	597	813	667	574	264	1,247	N. 2° W., 2,030.
November, 1913	933	132	425	442	915	1,736	664	1,701	S. 84° W., 2,274.
December, 1913	1,848	443	235	232	208	1,422	942	2,255	N. 50° W., 3,697.
June, 1919	362	464	836	400	1,904	584	348	875	S. 3° E., 1,290.
July, 1919	382	186	551	411	2,094	826	1,013	624	S. 28° W., 2,279.
August, 1919	382	382	623	505	1,455	863	535	983	S. 33° W., 1,247.
September, 1919	690	575	485	462	2,088	638	504	1,097	S. 27° W., 1,118.
October, 1919	695	407	449	679	1,116	870	758	1,020	S. 73° W., 1,073.

When the directions and velocities of winds and currents are compared for the individual months it becomes clear that the drift is not purely a wind current, though considerably affected by the wind. With winds prevailing from anywhere between north and west, the drift has a southerly component, driven eastward and offshore by strong west winds (as in November, 1913), but setting toward the southwest, when the average wind direction is between north and west. It is when drifting southward (whether with an easterly or a westerly component) during periods when winds prevail between west and north that the surface set attains its greatest daily velocities of 9 to 11 miles per day. By common knowledge this applies also during northeast winds. During the one month (June, 1919) when south winds prevailed, the current ran, none the less, toward the southwest, though held back by the head wind to an average rate of only about 4 miles per day. The dominant drift was also very slow (0.5 to 2.4 miles per day) during the three months when southwesterly winds prevailed, setting against the wind (WSW.) for one month, but with the wind (between north and east) during the other three.

According to this correlation between current and wind, the direction of the nontidal current at this station is between WSW. and SE. and reaches a considerable velocity when westerly or northerly winds prevail; but its inherent stength is so small that southerly winds greatly reduce its velocity, or may even reverse it and produce a slow surface drift toward the northeast.

The wind table for Portland (p. 965) shows that the average direction of the wind there, from early autumn until April, is between northwest and a few degrees south of west.[57] Consequently we may assume that the dominant sets recorded at the lightship for the months of October, November, and December are representative for autumn, winter, and for the first two months of spring. These combined (by the traverse tables) give a resultant movement toward the south and west (S. 15° W.) at an average rate of about 8 miles per day. In spite of the prevalence of southwest winds in summer the resultant of the combined drifts for June, July, August,

[56] From data supplied by the United States Weather Bureau. The directions are those from which the wind blows, as in every-day parlance.

[57] Calculated on a time-percentage basis.

and September (similarly representative of that season) is a very slow set toward the southwest at less than 1 mile per day. If all the sets for all the months be combined, the resultant drift is toward the south by west ½ west (S. 18° W.) and its average daily rate about 3½ miles per day.

The underlying dominant drift at Portland lightship is thus shown to be southerly, so far as the general transference of water is concerned, and it is so shown on the chart. Westerly winds may give it an offshore (easterly) component; and persistent southwesterly winds, such as prevail in summer, may reverse the drift, driving the surface water to the northward and eastward. Such reversals, however, are only temporary, and while operative produce drifts much slower than the dominant southerly movement. It is only while the nontidal current is setting toward the southern half of the compass that it has velocities of 4 miles per day or greater.

No measurements have been made of the currents between Portland lightship and Cape Ann, but observations taken by the United States Coast Survey at a point 10 miles southward from Cape Ann, on September 27 and 28, 1877 (U. S. Coast Pilot, 1911, p. 151), showed a dominant set of about 3 miles per day toward the WNW. (N. 66° W.) for that particular 24 hours. Fourteen miles to the southeastward of this we found a dominant set of about 5.4 miles per day toward the SSE. (S. 26° E.) at a depth of 5 meters (with the Ekman meter) on March 1 and 2, 1920 (station 20051, p. 857). These drifts, approximately at right angles to each other, probably represent the dominant tendency at their respective locations more closely than might have been expected of one-day sets, because drift-bottle experiments also indicate a tendency inshore and into Massachusetts Bay from the inner of these two stations (Coast Guard station), southerly across the mouth of the bay from the outer (p. 890).

At Boston lightship (situated near the head of Massachusetts Bay, about 9 miles off the mouth of Boston Harbor) there is a very slow dominant drift toward the eastward, a 29-day series of observations (from September 24 to October 22, 1913) giving a resultant of about 2.6 miles per 24 hours toward the S. 6° E., while a second 58-day set (October 28 to December 19, 1913) showed a dominant drift of about 1 mile per day toward the N. 24° E.[58] These two combined point to a general dominant movement of the surface stratum toward the SSE. (S. 25° E.) at the rate of slightly less than 1 mile per day, and it is so shown on the chart (fig. 173). A dominant set outward from the head of the bay toward its mouth is thus indicated in its southern side, but one governed so much by the direction of the wind that the surface water may make but a short distance good in this general direction over a considerable period.

The dominant drift at a station in the channel, between the tip of Cape Cod and Stellwagen Bank, where the tidal currents were measured by the Coast Survey on August 24 and 25, 1877 (Coast Pilot, 1911, p. 151; lat. 42° 07′, long. 70° 15′), was toward the N. 53° E. at a rate of about 4 miles per day, with about 5 miles per day (2.5 miles for 12 tidal hours) toward the N. 36° E. on the southern side of Stellwagen Bank, a few miles to the northward, on September 17, 1855 (Coast Pilot, 1911, p. 151; lat. 42° 10′, long. 70° 16′).

[58] Information supplied by U. S. Coast and Geodetic Survey.

The directions and velocities given on the chart (fig. 173) for the stations off Cape Cod and in the region of Nantucket Shoals are copied direct from the Coast Pilot (1912, chart to face p. 9; based on observations taken by the U. S. Coast and Geodetic Survey). A south-southeasterly drift of about 12 miles a day at a station 7 miles off Nauset Light illustrates the general tendency toward a southerly movement of the water along Cape Cod, mentioned in the Coast Pilot. Observations taken at the Pollock Rip lightship and at Round Shoal lightship, at the entrance to Nantucket Sound, from June 20 to September 14, 1911, have also brought out dominant drifts toward the southeast at rates, respectively, of 9 to 10 and 2 to 3 miles per 24 hours. By this evidence, corroborated by bottle drifts (p. 886), the surface water sets southerly across and out of the eastern end of Nantucket Sound, not into the latter. This is corroborated by an east-southeasterly set of about 7 miles per 24 hours, recorded at a station 4 miles within the sound (2 miles south of Handkerchief Shoal lightship).

Sets of varying duration, taken by the Coast and Geodetic Survey at 11 stations in the general region of Nantucket Shoals, show a general dominant set between south and east, roughly paralleling the chief axis of the shoal ground, at rates varying from about 2 miles per day to about 14 miles (average about 3 miles). However, this is complicated by evidence of subsidiary eddying movements, such as might be expected over this uneven bottom, where strong tidal currents are complicated by rips and deeper channels.

Earlier studies pointed to the conclusion that the tidal currents at a point about 16 miles to the eastward of Nantucket light vessel are not only rotary but run at an equal velocity at all hours (Coast Pilot, 1912, p. 10); and it seems to have been taken generally for granted that there is no dominant set at the lightship, which is situated about 10 miles to the southward of the 40-meter contour of the shoals and 42 miles SSE. from Nantucket Island (lat. 40° 37′, long. 69° 37′), but that the currents there are purely tidal. This, however, is contradicted by 19 sets of current measurements, each of 29 days' duration, taken at this lightship by the United States Coast and Geodetic Survey in the months of June, July, August, September, October, November, December, February, March, April, and May of the years 1911, 1912, and and 1914, tabulated below.[59] In 13 cases a dominant set results toward the north and west; a set toward the south and east in four; and one series showed no appreciable set in either direction, as tabulated.

Dominant set at Nantucket lightship for various months

Month and year	Direction of dominant set	Drift per 24 hours	Month and year	Direction of dominant set	Drift per 24 hours
June, 1914	N. 46° W	2.2	September-October, 1913	N. 89° W	5.3
June-July, 1914	N. 55° W	2.2	Do.	N. 80° W	8.2
June-July, 1911	N. 5° E	1.1	October, 1913	N. 86° W	5.3
July, 1914	N. 53° W	2.7	November, 1913	S. 68° E	2.4
July, 1911	N. 25° W	1.9	December, 1913	S. 44° E	4.0
August, 1914	N. 45° W	4.8	February, 1914	S. 51° E	2.9
August, 1911	N. 53° W	3.8	March, 1914	S. 40° E	1.0
August-September, 1911	N. 45° W	2.4	April, 1914	N. 75° W	1.4
September, 1914	N. 74° W	7.4	May, 1914	N. 62° W	4.3

[59] Data supplied by the U. S. Coast and Geodetic Survey.

Analysis of these sets shows a dominant drift toward the north and west (average direction about NW. by W.) during the spring, summer, and early autumn, averaging about 3.4 miles per day; but about as strong a southeasterly set (3 miles daily) during the late autumn, winter, and early spring, averaging about S. 50° E. in direction. If January and February be credited with about the same dominant drift as is recorded for December and March, the average set of water for the year works out at about 1.3 miles per day toward the N. 74° W. The rate has averaged lowest (less than 0.1 knot) from March through June, and drifts as strong as 0.2 knot have been recorded only during the months from August to December, a fact of some interest in connection with the discharge of surface water from the gulf (p. 974). This series of observations gives evidence of a considerable balance of movement of water toward the WNW. past the southern slopes of Nantucket Shoals, and whether the set be in that direction or toward the southeast, it is away from the gulf in either case.

This seasonal reversal in the direction of the dominant current is probably caused by the wind, with the southeasterly drift of winter reflecting the prevalence of strong northwest winds at that season; but the fact that the summer drift toward the west or northwest is not parallel with the prevailing southerly and southwesterly winds, but at right angles to them, reveals the dominant tendency for the water here to move westward.

Current measurements taken at eight stations along the southern rim of the the Gulf of Maine by the United States Coast and Geodetic Survey in 1877 show in each case a considerable nontidal resultant; and the indicated drift at any one of these may have been affected by the wind, for all were of short duration. However, they prove so consistent with the theoretic expectation of a clockwise movement around a shoal (p. 972) that they are probably representative of the prevalent summer state. The resultant drifts, as calculated by Mitchell (1881, p. 189, table 8), are as follows:

Station	Latitude		Longitude		Region	Directions	Velocity per 24 hours[1]
	°	′	°	′			*Miles*
1	41	10	68	55	South Channel	N. 31° E.	4.5
2	41	21	68	23	Northwest slope of Georges Bank	N. 79° E.[2]	5.7
3	41	31	67	52	West side of Georges Shoals	N. 70° W.[2]	2.8
4	41	36	67	24	East side of Georges Shoals	S. 14° E.	3.5
5	41	56	66	28	East end of Georges Bank	S. 42° E.	3.7
6	42	25	66	08	Eastern Channel	S. 76° W?	6.0
6	42	25	66	08	Do.	N. 51° W	10.7
7	42	50	65	56	South side of Northern Channel	S. 51° E.	7.3
8	43	04	65	41	North side of Northern Channel	S. 59° W.	4.7

[1] The U. S. Coast and Geodetic Survey writes that "resultant," in Mitchell's (1881, p. 189) original account, refers to the set for a tidal day of 24 hours and 50 minutes. This is reduced here to the set per 24 hours.

[2] The dominant drift is given as southeasterly at station 2, northeasterly at station 3, by Harris (1907, chart 7), and in the 1912 edition of the Coast Pilot (1912, chart to face p. 9); but a fresh calculation of the nontidal set at these stations by the Coast and Geodetic Survey shows a very good agreement with Mitchell's results.

These drifts indicate a general movement of the water northwestward around the western side of Georges Bank and southeastward over the eastern side, which is corroborated by bottle drifts (figs. 174, 176). They also suggest a subsidiary clockwise movement around the shoal part of the bank, drifting northward around its western flank and southward past the eastern flank. Drifts into the Gulf of Maine basin, at considerable velocities, result from the two stations in the center of the Eastern Channel.

At the time these observations were made the Northern Channel seems to have been dominated (as basins generally are in our latitudes) by an anticlockwise drift, southwesterly (toward the Gulf of Maine) in its northern side and southeasterly (away from the gulf) in its southern side. This latter drift, with the inward current in the Eastern Channel, suggests that Browns Bank was then the center of a clockwise eddy.

Current measurements also were taken in the center of the gulf, near Cashes Ledge (lat. 42° 53′, long. 68° 54′), on September 1 to 4, 1875, through a period of 58 hours, from which Harris (1907, pl. 7) has deduced a southerly set of about 4 miles per day. This agrees with the clockwise circulation to be expected around Cashes Ledge, this station being situated on its southeastern slope. Examination of the original data (supplied by the U. S. Coast and Geodetic Survey), however, makes it more likely that the dominant set varied with the wind there during the period of observation. The first 48 hours of the set (which apparently covered two tidal periods, because extending from "no current" to "no current") show a resultant toward the S. 26° W. of about 4 miles per 24 hours, as Harris represents it; but this period includes 8 hours (in groups of 3, 1, and 4) when no readings were taken, but during at least four of which the current almost certainly had an easterly component, judging from the stage of the tide as indicated by the veering of the current. The successive hourly directions also proved much more nearly rotary for the second tidal period than for the first, and with wide variation in its velocity while running in corresponding directions. It is wisest, therefore, to attempt no deduction of the dominant direction of the set from these data.

SUMMARY

The current measurements so far taken in the gulf when combined indicate the following circulatory movements: In the eastern side of the gulf the tendency is northward along Nova Scotia into the Bay of Fundy in its southern side, northward toward New Brunswick, and out of the bay along the south side of Grand Manan, with a counterflow into the bay via the Grand Manan Channel.

There is a gap in the observations for the coast section between Grand Manan and Cape Elizabeth. Off the latter the general set is southerly, though often deflected or temporarily reversed by the wind.

Two drifts are indicated in the region of Massachusetts Bay—one anticlockwise around its coast line and the other southerly across its mouth and down along Cape Cod. The drift is out to the eastward from Nantucket Sound, generally southerly and easterly past Nantucket Shoals. The records taken at Nantucket Lightship show a veering to the west and northwest around the shoals in summer, though not in winter. Two clockwise movements are suggested farther east—one around Georges Bank as a whole and a smaller one around its shoalest part.

In general, the dominant set has been found most rapid in the region of Cape Cod and Nantucket Shoals, averaging about 8 miles daily. The average velocity (about 7 miles per 24 hours) is nearly as great for the stations along the west coast of Nova Scotia and in the Bay of Fundy; but the resultant set into this side of the gulf is not so rapid, because most of the stations show components either to the west or to the east. Perhaps 5 miles per day approximates the rate at which a bottle might be expected to drift northward along Nova Scotia by this evidence.

EXPERIMENTS WITH DRIFT BOTTLES

Measurements with the current meter, such as have just been discussed, give both the direction and the rate of the dominant set, as well as of the tidal currents, at that particular place and time, assuming always that the observations are taken at frequent enough intervals and extended over a sufficient period of time.

The setting free and recovery of a drift bottle can never yield information so definite, because only the two end points of its journey are known, the route it has traveled from the one to the other always remaining a matter for deduction. Our drift bottles, furthermore, reflect the dominant movement of the uppermost stratum of water only; a fathom or two deep, at most, for the bottles with the longest drags. Neither does the drift of a bottle necessarily reproduce the drift that would have been followed by a particle of water, because the bottle floats on the surface, while the water may sink to lower levels by vertical currents, while new water may well up to the surface from below to take its place.

Because only the end points of the drifts are known and the intervening tracks can only be assumed, their value depends on a number of factors, especially on their consistency, one with another; the length of time they are adrift; the extent of the oceanic area covered; and on general information from other sources as to the local currents. In all these respects the Gulf of Maine has proved an especially favorable region for the study of the dominant circulation by the drift-bottle method. Since all the drifts from all the lines set out have, without exception, proved reducible to one scheme, entirely consistent with the current measurements (p. 866) and with general report as to the dominant set along various parts of the coast, with temperature and salinity, with the distribution of the plankton, and with the internal hydrostatic forces (p. 936), I believe they may be taken as representing the main features usually prevailing in spring, late summer, and early autumn.

The greater the time interval between release and recovery, the greater does the uncertainty become, because the longer the bottle is afloat, the greater distance it may have covered in its journey—i. e., the farther its track is apt to have diverged from the direct point to point line. By this same reasoning, when bottles are released in numbers the time interval becomes an important factor in deducing their probable tracks. If, for example, bottles released near Cape Elizabeth were to drift repeatedly to a point in Nova Scotia in as short a period as bottles released at Mount Desert, it is a fair assumption that the latter have diverged enough from the direct route to make their journey approximately as long as that of the former, assuming, of course, an approximately equal rate of drift for both. I should also point out that in a region where the tidal currents are as strong as they are in the Gulf of Maine, little information as to the *dominant* drift is to be had from a bottle until it has been adrift through several tidal periods. Consequently, when a bottle set adrift within 3 or 4 miles of shore at the beginning of the flood tide is recovered on the beach it does not mean that a dominant inshore set brought it in, but simply that it drifted and stranded with the tide.

These remarks are elementary, but are introduced here because, in conversation, I have found a very general tendency to ascribe a direct drift to any drift bottle.

BOTTLES SET OUT IN THE BAY OF FUNDY

The first systematic attempt to plot the dominant or nontidal circulation of any part of the gulf by the use of drift bottles was undertaken by the Atlantic (St. Andrews) biological station of the Biological Board of Canada in the summer of 1919, when 396 bottles were set adrift on lines crossing the Bay of Fundy, with results so positive that they are extremely welcome for the light they throw on the returns from the several series subsequently released in the open gulf by the Bureau of Fisheries. The complete data of localities of release and recovery are given by Mavor (1922), who has also discussed the probable tracks in such detail that a brief summary will suffice here.

The recoveries[61] may be divided into two groups—first, from within the Bay of Fundy, and second, from the Gulf of Maine.[62]

Bottles picked up within the Bay of Fundy were all set out in August and September, 1919, along lines at right angles to the general axis of the bay. Five bottles, set out at distances of 1 to 10 miles from shore on a line running northwest from Brier Island, at the mouth of the bay, and picked up along its Nova Scotian shore after drifts of 25 to 65 miles, show a definite set inward along the southern side of the bay consistent with the current measurements that have been taken there (Mavor, 1922, p. 116, fig. 13). One of these traveled at a rate of more than 4 nautical miles per day. It seems, however, that this inward drift involved only a narrow belt, probably not more than 6 or 7 miles wide at the time, because only one bottle from the next line to the west (one set adrift about 7 miles from the shore of Digby Neck) took this route, while two others released closer in to the land drifted across the bay to the New Brunswick shore and to Grand Manan.

Most of the recoveries from all the other lines were from points on the New Brunswick shore; a few were from the neighborhood of Grand Manan and a few (to be considered later) were in the Gulf of Maine outside the bay. Mavor's (1922) analysis brings out the interesting fact that the bottles that were picked up farthest east on the New Brunswick shore[63] were all set out in the southern side of the bay within 12 miles of the Nova Scotian shore.

The bottles set out in the southern side of the bay (several lines) thus exhibit one or the other of two rather definite tendencies. Those set adrift near the Nova

[61] Only those reported within 4 months after the bottles were set out are considered here.

[62] Mavor (1922, p. 116) states that "all the drift bottles which have been recorded from outside the Bay of Fundy were picked up in the Gulf of Maine." Two also have been reported from Europe (Mavor, 1921; Moor [Mavor], 1921).

[63] Between Musquash Harbor (long. 66°15′W.) and St. John.

Scotian shore at the mouth of the bay, or inward to Digby Gut, tended to drift eastward, hugging the southern coast. Those set afloat more than 5 to 10 miles out from land in the southern side of the bay rarely stranded on that shore, but usually drifted northward across the bay to the New Brunswick shore. It is evident that they did not go far up the bay, for only one bottle was picked up east of St. John, while most of the recoveries of bottles set out on the Nova Scotian end of the innermost line were west of the longitude at which they were set out.

Bottles set out in the northern side of the Bay of Fundy showed a westerly drift, the majority of recoveries coming from the New Brunswick shore west of Point Lepreau (especially concentrated in the region of Passamaquoddy Bay), with some from the southern and eastern sides of Grand Manan.

The southern edge of the inflowing current in the southern side of the bay hugged the shore—witness the stranding of bottles along Nova Scotia. Its outer (offshore) edge, on the contrary, showed as evident a tendency to veer, anticlockwise, across the bay toward the New Brunswick shore, and so to eddy westward, made evident by the tendency of bottles from the Nova Scotia side to strand farthest east (inward), along New Brunswick, and for bottles set out in the northern side of the bay to follow the coast line of New Brunswick farther to the westward.

Some idea of the routes followed by bottles crossing from the Nova Scotian to the New Brunswick side of the bay can be gained from the relative lengths of the intervals between release and recovery,[64] when these prove as consistent as they did in this instance. Mavor (1922, p. 116) has already commented on the fact that the bottles set out on the Nova Scotian end of a line abreast of Point Lepreau (his line G) averaged longer afloat than those set out on the New Brunswick end, suggesting that they took a longer route, going up on the Nova Scotian side and down on the New Brunswick side. The time intervals between release and recovery for bottles drifting from Nova Scotia to New Brunswick were also longer for those set out nearest the mouth of the bay (25 to 48 days) than for those set adrift farther in the bay (8 to 22 days), with a discrepancy much wider than the varying width of the bay would account for. Bottles set out on the southern end of the innermost line and picked up eight days later on the New Brunswick side must have followed a comparatively direct route in their crossing. A longer time interval for bottles set out nearer the mouth of the bay points to a more extended circling drift; but the fact that on the whole bottles set out farther and farther east along the Nova Scotian side fetched up farther and farther up the bay in the New Brunswick side is evidence that the south-north drift was of considerable breadth.

A cross section of the Bay of Fundy from Nova Scotia to Grand Manan would thus have shown a rather sudden transition, at the time, from a current flowing toward the southwest in the northern side to a northeast drift in along the southern shore. The fates of four bottles that were set out close together on a line abreast of Point Lepreau, but were picked up far apart and on opposite sides of the bay 37 to 70 days later, locates the boundary of these two currents nearer Nova Scotia than New Brunswick (Mavor, 1922, p. 116).

[64] Always remembering that a bottle may lie a long time on some seldom-visited beach.

8951—28——56

These bottle drifts justify Mavor's (1922) general conclusion that in the summer of 1919 the water was drifting in along the southern side of the bay, circling northward across to the New Brunswick shore about abreast of St. John, setting west and southwest along New Brunswick and out of the bay past the southern side of Grand Manan. This, as he points out (1922, p. 116), is entirely consistent with the dominant set resulting from Dawson's current measurements; more consistant, indeed, than one might have expected of observations of these two sorts taken several years apart in such tide-swept waters.

The drift westward along New Brunswick, according to Mavor's analysis, was at a rate of at least 5 nautical miles per day. This, with the rates for the bottles that drifted inward along the Nova Scotian shore (p. 868), suggests a general daily rate of 4 to 5 miles for the periphery of the Bay of Fundy eddy.

Fifteen of the bottles set out in the Bay of Fundy in 1919 were picked up outside the bay in the Gulf of Maine—2 from the June series and 13 from the August series. The two June bottles, however, represent a much larger percentage than do the August recoveries; for only 10 bottles were set out in June, and these were the only ones picked up, whereas 220 were set out in August, most of the recoveries coming from within the Bay of Fundy. None of the September bottles (75 in number) were picked up in the Gulf of Maine.

The two June bottles were put out, respectively, 14 and 18 miles south of Grand Manan on the 18th. One was picked up at Bailey's Mistake (a cove on the north shore of the Grand Manan Channel) about midway of its length; the other was recovered in Penobscot Bay. Both of these bottles undoubtedly passed out of the bay in the outflowing current along the south side of Grand Manan; but the one circled Grand Manan, to be caught up in the indraft demonstrated by current measurements for the Grand Manan Channel; while the other, put out only 4 miles farther south, escaped this eddy and traveled westward along the coast of Maine. There is every reason to suppose that the 13 August bottles also went out of the Bay of Fundy along the south side of Grand Manan, for they show very uniform drifts. One was returned from Jonesport, Me., one from Schoodic Head, near Mount Desert, and all the rest from the Massachusetts Bay region and Cape Cod. Bottles from the innermost as well as from the outermost lines in the Bay of Fundy (Mavor's lines D and G) partook of this drift (curiously enough, however, none from the intermediate line).

Mavor (1922, p. 118) has emphasized the uniform time intervals of 7 of the 11 bottles that were picked up in Massachusetts Bay 73 to 80 days after being put out. This, with the fact that so large a proportion of all the bottles picked up outside the Bay of Fundy within four months after being set adrift were found along so short a stretch of the coast line, is evidence enough of a very definite surface drift from the northeastern to the southwestern side of the gulf during the late summer and early autumn of 1919; and the recovery of two bottles on the eastern coast of Maine makes it probable that this line of drift lay rather close in to the shore as far as the mouth of Penobscot Bay. However, since none were found between Penobscot Bay and Cape Ann they seem to have followed tracks farther out from the land along this sector of the coast line.

The distance from the Bay of Fundy to Cape Cod being about 220 miles, these bottles, as Mavor points out, must have drifted at an average rate of at least 4 miles per day. Actually, the rate was no doubt somewhat more rapid than this, because the track probably followed is approximately 260 miles, at the smallest reckoning.

The regional distribution of the recoveries in the Massachusetts Bay region is also interesting, none being from the shore line between Cape Ann and Plymouth, but seven scattered around the shores of Cape Cod Bay from Plymouth to the tip of the cape.[65] The hook of Cape Cod seems, therefore, to have acted as a sort of catch-basin for flotsam at the time these bottles were adrift, evidence that the set of surface water was then from north to south across the mouth of Massachusetts Bay, as it was in March, 1920 (current measurements at station 20051; p. 863), not around the shore line of the bay, as current measurements show it at times (p. 863).

Two bottles, evidently having crossed the mouth of the bay somewhat farther out, stranded on the outer shore of Cape Cod (near Pamet River Coast Guard Station and near South Wellfleet wireless towers), and one went to Monomoy Island at the southern angle of Cape Cod.

BOTTLES SET OUT IN THE GULF OF MAINE

The drifts of the bottles set out in the Bay of Fundy by the Biological Board of Canada in 1919 were so significant and agreed so well with the dominant set calculated from current measurements that the United States Bureau of Fisheries has since released 1,606 drift bottles in the Gulf of Maine and its tributary waters along the following lines, the returns from which are tabulated below:

DRIFT-BOTTLE RECORD, INCLUDING RECOVERIES UP TO SEPTEMBER 1, 1926

SERIES A: Bottles Nos. 1 to 300; two every half mile on a line running 125°, true, from Cape Elizabeth to the vicinity of Cashes Ledge, June 30 to July 1, 1922.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
23	43	30	06	70	04	42	Small Point Harbor, east of Littlewood Island, Me	July 26	26
26	43	29	48	70	04	06	Between Richmond Island and Cape Elizabeth, Me	July 5	5
27	43	29	30	70	03	30	Near Bald Head, Small Point, Me	July 28	28
28	43	29	30	70	03	30	1 mile east of Cape Elizabeth Lighthouse	July 4	4
30	43	29	12	70	02	54	Northwest side of Monhegan Island	Aug. 16	47
32	43	28	54	70	02	18	Richmond Island Bay, Me	July 13	13
43	43	27	06	69	58	42	Woodwards Cove, Grand Manan Island	Oct. 12	104
52	43	25	57	69	56	18	Metinic Shoal (northwest of it)	Sept. 13	75
65	43	23	48	69	52	06	Loon Point, Jonesport, Me	Sept. 18	80
70	43	23	12	69	50	40	Chebeague Island, Me	July 25	25
72	43	22	54	69	50	18	Prouts Neck Beach. Scarboro, Me	do	25
75	43	22	18	69	49	06	Boothbay Harbor, Me	Aug. 1	32
76	43	22	18	69	49	06	5 miles east of Prouts Neck, Me., opposite Richmond Island	Sept. 10	72
79	43	21	42	69	47	54	Thompsons Point, Cundys Harbor, Me	do	72
83	43	21	06	69	46	42	Birch Point, Winnegance Bay, Me	Aug. 20	51
87	43	20	30	69	45	30	South Beach, Matinicus Island, Me	Oct. 12	103
88	43	20	30	69	45	30	Eastern Wolves Island, Bay of Fundy	do	103
90	43	20	12	69	44	54	Bald Head, Casco Bay, Me	July 25	25
98	43	00	19	69	42	30	¾ mile northeast from outer John's Island, near Swans Island, Me	Sept. 1	63
99	43	18	42	69	41	54	Bay of Fundy, Nova Scotia	Sept. 18	80
105	43	17	48	69	40	02	1 mile west of Hartsville Breakwater, south shore of Bay of Fundy	Oct. 6	98
124	43	15	06	69	34	42	South side of Cedar Island, Isles of Shoals, N. H	Oct. 8	100

[65] White Horse Beach, Plymouth; Sagamore Highlands; Sagamore Beach; Scorton Beach; North Truro; and three between Wood End and Peaked Hill Bar Coast Guard Station.

No.	Set out: Latitude			Set out: Longitude			Where found	Date, 1922	Interval
	°	′	″	°	′	″			Days
127	43	14	30	69	33	30	2 miles off Hillsburn, Hants County, Nova Scotia	Sept. 28	90
128	43	14	30	69	33	30	New Meadows River, Casco Bay, Me	Sept. 15	77
153	43	10	36	69	25	42	1 mile north of Beaver River, county line [N. S. ?]	Oct. 26	118
165	43	08	48	69	22	06	Scotts Bay Beach, Nova Scotia	Oct. 21	113
190	43	05	12	69	14	54	Entrance of Grand Passage, Nova Scotia	Oct. 24	116
206	43	02	48	69	10	06	Digby Neck, Sandy Cove, Nova Scotia, Bay of Fundy side	Sept. 28	90
210	43	02	12	69	08	54	½ mile off west side of Isle au Haut, Me	Sept. 23	85
215	43	01	18	69	07	06	1½ miles east of Port Lorne Lighthouse, Nova Scotia	Nov. 23	146
222	43	00	24	69	05	18	Port Lorne, Nova Scotia	Oct. 21	113
230	42	59	12	69	02	54	Meteghan Cove, Nova Scotia	Nov. 14	135
241	42	57	24	68	59	18	Port Lorne, Bay of Fundy, Nova Scotia	Sept. 26	88
242	42	57	24	68	59	18	14 miles west-southwest from Digby, in Bay of Fundy, 3 miles offshore	Sept. 8	70
248	42	56	30	68	57	30	Broad Cove Breakwater, 2 miles from Point Prim Light, Bay of Fundy	Sept. 13	75
255	42	55	18	68	55	06	9 miles from Point Prim, Bay of Fundy	Sept. 28	90
264	42	54	06	68	52	42	Bay of Fundy shore of Long Island, at Central Grove, Nova Scotia	Sept. 19	81
280	42	51	42	68	47	54	Northwest from Salvages fog alarm, Nova Scotia	Sept. 5	67
284	42	51	06	68	46	42	Southern Point, Matinicus Island, Me	Oct. 11	103
299	42	48	42	68	41	54	Advocate Harbor Beach, Cumberland County, Nova Scotia	Oct. 15	107

SERIES B: Bottles Nos. 301 to 900; two every half mile, running 141° from the offing of Chatham, Cape Cod, 150 miles, July 4, 1922.

No.	Set out: Latitude			Set out: Longitude			Where found	Date, 1922	Interval
	°	′	″	°	′	″			Days
301	41	41	00	69	53	00	1½ miles north of Coast Guard station 41, Nausett Beach, Mass	July 11	5
302	41	41	00	69	53	00	Stonewall Beach, Chilmark, Mass. (east of Old Bull bell buoy)	Aug. 26	51
303	41	40	36	69	52	36	Sakonnet River, R. I	July 30	24
304	41	40	36	69	52	36	Chatham, Mass	July 9	3
308	41	39	45	69	51	48	Cuttyhunk, Mass	Sept. 10	66
309	41	39	24	69	51	24	West side of Nantucket Harbor, mouth of jetty	Dec. 31	180
311	41	39	00	69	51	00	60 miles south-southeast of Cape Cod Light	July 21	15
314	41	38	36	69	50	36	West end, Cuttyhunk Island	Aug. 7	32
317	41	37	48	69	49	48	On Beach near north lighthouse, Block Island	Aug. 11	36
331	41	35	00	69	47	00	¼ mile north of Gay Head, Mass	Aug. 6	30
333	41	34	36	69	46	36	On Beach near southeast light, Block Island	July 7	1
334	41	34	36	69	46	36	Newport Beach, Newport, R. I	Sept. 12	67
337	41	33	38	69	45	48	South side, Marthas Vineyard Island	July 23	16
343	41	32	36	69	44	36	Chilmark, south shore Marthas Vineyard	Aug. 29	53
348	41	31	48	69	43	48	5 miles north of Finis-terre Light, France	[1] Sept. 16	----
357	41	29	48	69	41	48	75 miles southeast from Cape Cod [light ?]	Oct. 3	88
358	41	29	48	69	41	48	Hampton, Annapolis County, Nova Scotia	Oct. 21	106
362	41	29	00	69	41	00	75 miles southeast ½ south from Cape Cod Light	July 12	5
376	41	26	12	69	38	12	Between Horseneck Beach and Barney's Joy Point	Sept. 10	65
389	41	23	24	69	35	24	Head of Miacomet Pond, Nantucket, Mass	Aug. 19	43
396	41	22	12	69	34	12	75 miles south-southeast from Cape Cod [light]	July 15	8
405	41	20	12	69	32	12	48 miles south-southeast from Cape Cod Light	do	8
422	41	17	00	69	29	00	12 miles south of Sakonnet Point light	Sept. 5	60
433	41	14	36	69	26	36	Hampton, 26 miles east of Digby, Nova Scotia	Sept. 27	82
435	41	14	12	69	26	12	Lat. 42° 07′ N., long. 66° 41′ W	Oct. 11	96
445	41	12	12	69	24	12	1½ miles west of U. S. Coast Guard Station 47, Muskeget	Aug. 10	34
447	41	11	48	69	23	48	300 yards east of boat house, Fishers Island, N. Y	Aug. 16	40
462	41	09	00	69	21	00	Near Port George, Nova Scotia	Oct. 20	105
484	41	04	36	69	16	36	South shore of Marthas Vineyard, east of No Mans Land	Sept. 12	67
510	40	59	24	69	11	24	72 miles southeast by east from Cape Cod Light	July 10	3
528	40	55	48	69	07	48	West shore, Mishaum Point, Mass	Aug. 13	37
536	40	54	12	69	06	12	East-southeast ½ mile from mouth of Vineyard Sound, Mass	July 30	23
541	40	53	00	69	05	00	South Beach, Katama Bay, Edgartown, Mass	Aug. 28	52
543	40	52	36	69	04	36	Georges Bank, lat. 41° 15′	Aug. 11	35
547	40	51	48	69	03	48	On beach, Nantucket, Mass	Aug. 20	44
548	40	51	48	69	03	48	4 miles southwest of Vineyard Sound Lightship, Mass	July 29	22
557	40	49	48	69	01	48	Katama Bay, Edgartown, Mass	Aug. 13	37
569	40	47	24	68	58	24	Near Buoy, Gay Head, Mass	July 29	22
580	40	45	24	68	56	24	1 mile east of U. S. Coast Guard Station 47, Mass	July 25	18
582	40	45	00	68	56	00	Southeast shore, Block Island, R. I	Sept. 12	67
584	40	44	36	68	55	36	Horseneck Beach, Mass	July 31	24
585	40	44	12	68	55	12	On Massachusetts and Rhode Island line	July 28	21
587	40	43	48	68	54	48	Off Grace Point, Block Island	Sept. 13	68
588	40	43	48	68	54	48	Penikese Island, Mass	Aug. 2	26

[1] 1923.

No.	Set out: Latitude °	′	″	Longitude °	′	″	Where found	Date, 1922	Interval (Days)
590	40	43	24	68	54	24	Crescent Beach, Block Island, R. I.	Aug. 18	37
591	40	43	00	68	54	00	Middle Ground Shoal, Vineyard Haven, Mass.	Aug. 9	33
593	40	42	36	68	53	36	Bathing Beach, Southampton, Long Island	Sept. 12	67
596	40	42	12	68	53	12	¼ mile north of Sakonnet Lighthouse, Sakonnet River, R. I.	July 30	23
597	40	41	48	68	52	48	On Beach at Horseneck, Westport, Mass.	Aug. 7	31
600	40	41	24	68	52	24	Tarpaulin Cove, Naushon Island, Mass.	Aug. 26	50
602	40	41	00	68	52	00	Near Lighthouse, south beach, Gay Head, Mass.	July 29	22
603	40	40	36	68	51	36	2½ miles northwest of Vineyard Sound Lightship, Mass.	Aug. 1	25
604	40	40	36	68	51	36	Old Harbor Point, Block Island, R. I.	Aug. 10	34
605	40	40	12	68	51	12	West Horseneck Beach, Westport, Mass.	July 29	22
606	40	40	12	68	51	12	West shore Block Island, R. I.	Aug. 19	43
608	40	39	48	68	50	48	Narragansett Pier, R. I.	Aug. 7	31
609	40	39	24	68	50	24	North-northwest of Old Harbor Breakwater, east side, R. I.	Aug. 4	28
611	40	39	00	68	50	00	1 mile north of Wasque Hill, Chappaquiddic Island, Mass.	July 27	20
613	40	38	36	68	49	36	1 mile east of Coast Guard station 72, Long Island, N Y.	Aug. 7	31
614	40	38	36	68	49	36	1½ miles West of Barney's Joy Point, Mass.	July 29	22
615	40	38	12	68	49	12	5 miles below Edgartown, south shore Martha's Vineyard, Mass.	Aug. 20	44
617	40	37	48	68	48	48	Pleasant View Beach, R. I.	July 28	21
618	40	37	48	68	48	48	Westport Point, Mass.	[1]Dec. 29	(2)
620	40	37	24	68	48	24	Horseneck, Beach, Mass.	July 31	23
621	40	37	00	68	48	00	Horseneck Beach, Westport, Mass.	do	22
622	40	37	00	68	48	00	Matunuck Beach, R. I.	Aug. 8	32
624	40	36	36	68	47	36	Near Warren Point, Little Compton, R. I.	July 29	22
627	40	35	48	68	46	48	Cornwall, England	[3]Aug. 14	(4)
628	40	35	48	68	46	48	3½ miles west of Montauk Light Station	Sept. 10	65
629	40	35	24	68	46	24	West Horseneck Beach, Mass.	Aug. 1	25
630	40	35	24	68	46	24	South shore, Chilmark, Mass.	Aug. 2	26
631	40	35	00	68	46	00	4 miles below Edgartown, south shore Marthas Vineyard, Mass.	Aug. 6	30
634	40	34	36	68	45	36	2 miles northwest of Vineyard Sound Lightship, Mass.	Aug. 1	31
635	40	34	12	68	45	12	1 mile southeast of Westport Harbor, Horseneck Beach, Mass.	Aug. 7	31
637	40	33	48	68	44	48	3 miles south-southeast of Cuttyhunk Lighthouse, Cuttyhunk, Mass.	July 28	21
638	40	33	48	68	44	48	Between North Light and New Harbor Channel, West Beach, R. I	Aug. 6	30
639	40	33	24	68	44	24	Halfway between Coast Guard Stations 66 and 67, Montauk, L. I	Sept. 16	71
641	40	33	00	68	44	00	On beach near Falmouth, Mass.	Aug. 20	44
644	40	32	36	68	43	36	West end of Nashawena Island, Mass.	July 29	22
645	40	32	12	68	43	12	½ mile southeast of light on beach, Block Island, R. I.	July 7	1
646	40	32	12	68	43	12	Charlestown Beach, R. I.	Aug. 5	29
647	40	31	48	68	42	48	10 miles west of Montauk Point, south side Long Island, N. Y.	Aug. 7	31
648	40	31	48	68	42	48	Between Point Judith and Charleston, opposite East Island	Aug. 17	31
649	40	31	24	68	42	24	Sakonnet Point, R. I.	Aug. 4	28
650	40	31	24	68	42	24	6 miles southeast from Sakonnet Point Light, R. I.	Aug. 3	27
651	40	31	00	68	42	00	Little Compton, R. I.	July 28	21
652	40	31	00	68	42	00	Easthampton, L. I.	Sept. 12	67
653	40	30	36	68	41	36	Near Life Guard Station 65, Ditch Plains, Montauk, L. I	Sept. 9	64
654	40	30	36	68	41	36	½ mile east of Coast Guard Station 73, opposite Hampton Bays, N. Y	Sept. 11	66
655	40	30	12	68	41	12	East side of Block Island, R. I.	Sept. 9	64
656	40	30	12	68	41	12	Sagaponack, L. I. northeast of Bridgehampton	Sept. 12	67
658	40	29	48	68	40	48	Gay Head, Mass.	Sept. 3	58
661	40	29	00	68	40	00	1½ miles west of Charlestown, R. I. (?)	Sept. 17	72
662	40	29	00	68	40	00	1½ miles from light, south shore, Gay Head, Mass.	Aug. 5	29
664	40	28	36	68	39	36	1 mile south of No Mans Land, Mass.	July 28	21
665	40	28	12	68	39	12	Start Point, bearing north-northwest, 15 miles, England	[5]Sept. 19	(6)
666	40	28	12	68	39	12	West Beach, Horseneck, South Westport, Mass	Aug. 7	31
668	40	27	48	68	38	48	3½ miles from light, south shore, Gay Head, Mass.	Aug. 5	29
669	40	27	24	68	38	24	2 miles north of Coast Guard Station 172, Kitty Hawk, N. C	Sept. 26	81
676	40	26	12	68	37	12	Coast Guard Station 176, near Manteo, N. C	Sept. 30	85
679	40	25	24	68	36	24	1 mile north of Coast Guard Station 165	Oct. 1	86
680	40	25	24	68	36	24	¼ mile north of Coast Guard Station 171	Sept. 22	77
684	40	24	36	68	35	36	1 mile north of Coast Guard Station 170	do	77
686	40	24	12	68	35	12	Near Coast Guard Station 179	Sept. 27	82
688	40	23	48	68	34	48	1 mile north of Coast Guard Station 176	Sept. 30	85
695	40	22	12	68	33	12	Kitty Hawk, N. C	Sept. 27	82
700	40	21	24	68	32	24	1½ miles west of Coast Guard Station 56, Green Hill, R. I	Sept. 12	67
702	40	21	00	68	32	00	8 miles west of Montauk Lighthouse, Long Island, N. Y	Sept. 19	74
703	40	20	36	68	31	36	1½ mile south of Coast Guard Station 170	Sept. 21	76
707	40	19	48	68	30	48	Near life-saving station, east beach, Montauk, L. I	Sept. 12	67
718	40	17	48	68	28	48	2½ miles east of Quonochontaug life-saving Station, R.I.	Sept. 13	68
724	40	16	36	68	27	36	Edgartown Harbor, Edgartown, Mass.	Oct. 15	100
727	40	15	48	68	25	48	1½ mile south of Coast Guard Station 9	[7]Mar. 4	(8)
728	40	15	48	68	25	48	2¼ miles north of Coast Guard Station 170, on beach	Sept. 22	77
731	40	15	00	68	25	00	The Azores	(9)	(10)
732	40	15	00	68	25	00	Off Gooseberry Neck, near Westport Harbor, Mass	Sept.	58

[1] 1923.
[2] One year 4 months and 22 days.
[3] 1926.
[4] Four years 1 month and 7 days.
[5] 1924.
[6] Two years 2 months and 12 days.
[7] 1923.
[8] Seven months 25 days.
[9] July, 1923.
[10] About 1 year.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
739	40	13	24	68	23	24	2 miles south of Coast Guard Station 170, Duck, N. C	Sept. 29	84
745	40	12	12	68	22	12	West end of Baileys Beach, Newport, R. I	Sept. 13	68
749	40	11	24	68	21	24	Grand Canary Island	[1] Apr. 1	([2])
752	40	11	00	68	21	00	Southeast by south ½ south, 35 miles from No Mans Land	Sept. 20	75
753	40	10	36	68	20	36	6 miles southwest of Gay Head, Mass	Sept. 6	61
762	40	09	00	68	19	00	Point O Wood, Fire Island, Long Island, N. Y	Oct. 8	93
770	40	07	24	68	17	24	Lat. 41° 20′ 45″, long. 70° 38′ 30″	Sept. 4	59
775	40	06	12	68	16	12	2 miles east of Coast Guard Station 70	Sept. 20	75
777	40	05	48	68	15	48	½ mile south of Coast Guard Station 169	Oct. 14	99
779	40	05	24	68	15	24	1 mile south of Coast Guard Station 181	Sept. 27	112
787	40	03	48	68	13	48	Roughley, Sligo Bay, Ireland	[3] July 18	([4])
790	40	03	24	68	13	24	South shore of Marthas Vineyard, Mass	Sept. 4	59
802	40	01	00	68	11	00	South Beach, Edgartown, Mass	Aug. 29	53
804	40	00	36	68	10	36	Southwesterly shore of Marthas Vineyard, Mass	Sept. 7	62
806	40	00	12	68	10	12	¾ mile on the shore northeast from the breakwater, Sakonnet Point, R. I	Sept. 6	61
822	39	57	00	68	07	00	1 mile south of Coast Guard Station 173	Sept. 28	83
824	39	56	36	68	06	36	Horseneck Beach, Westport, Mass	Sept. 16	71
835	39	54	12	68	04	12	1 mile below Bodies Island Lighthouse, N. C	Oct. 2	87
837	39	53	48	68	03	48	½ mile north of Coast Guard Station 177	do	87
839	39	53	24	68	03	24	In Bay at Nantucket, Mass	Nov. 22	141
844	39	52	36	68	02	36	10 miles southwest by west of Sankaty light, Nantucket, Mass	Aug. 28	52
845	39	52	12	68	02	12	9 miles north of Bodies Island light Station	Sept. 18	73
890	39	43	24	67	53	24	South side of Marthas Vineyard, Mass	Oct. 1	86
900	39	41	24	67	51	24	South Beach, Marthas Vineyard, Edgartown, Mass	Aug. 28	52

[1] 1924.
[2] One year 8 months and 24 days.
[3] 1923.
[4] One year 11 days.

SERIES D: Bottles Nos. 1501 to 1600; two bottles every half mile on a line running 150° from Bakers Island, off Mount Desert, for 25 miles, August 6, 1923.

No.	Set out						Where found	Date, 1923	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
1503	44	13	19	68	10	25	Duck Island, Me	Aug. 8	2
1504	44	13	19	68	10	25	Near Baccaro lighthouse, Shelburne County, Nova Scotia	Oct. 18	73
1506	44	12	53	68	10	05	Comeau Cove, Digby County, Nova Scotia	Oct. 7	62
1510	44	12	01	68	9	25	Great Duck Island, Me	Aug. 8	2
1511	44	11	35	68	9	05	Winter Harbor, Me	[1] July 19	------
1515	44	10	43	68	8	25	Point of outer Long Island, Me	Aug. 8	2
1521	44	9	25	68	7	25	Kennebunk Beach, Me	Sept. 7	32
1523	44	8	59	68	7	05	8 miles southeast of Isle au Haut, Me	Aug. 7?	(?)
1530	44	7	41	68	6	00	Salmon River, Digby County, Nova Scotia	Dec. 17	133
1531	44	7	15	68	5	45	East side Petite Passage, Digby County, Nova Scotia	Oct. 16	71
1541	44	5	05	68	4	05	West side Egg Rock light, Hancock County, Me	Sept. 11	36
1546	44	4	13	68	3	25	Deep Cove, Isle au Haut, Me	Sept. 14	39
1547	44	3	47	68	3	05	Salmon River Beach, Digby County, Nova Scotia	Oct. 9	64
1550	44	3	21	68	2	45	Scudish Island, Me	Sept. 10	35
1551	44	3	00	68	2	45	Pubnico Harbor, Nova Scotia	[1] Jan. 4	151
1553	44	2	29	68	2	05	1¾ miles WNW. of Matinicus, Me	Sept. 12	37
1554	44	2	29	68	2	05	Clark Island, Me	Sept. 9	34
1557	44	1	37	68	1	25	Pubnico Point, Nova Scotia	[1] Jan. 4	151
1563	44	0	19	68	0	25	Pleasant Cove, Digby County, Nova Scotia	Oct. 8	63
1565	43	59	53	68	0	05	States Point, St. George, Me	Sept. 9	34
1566	43	59	53	68	0	05	Wooden Ball Island, Me	Sept. 11	36
1568	43	59	27	67	59	45	Meteghan River, St. Marys Bay, Digby County, Nova Scotia	Oct. 7	62
1576	43	57	43	67	58	25	3 miles west from Petit Manan light, Me	Sept. 13	38
1581	43	56	25	67	57	25	West side of Grindstone Neck, Winter Harbor, Me	Sept. 8	33
1584	43	55	59	67	57	05	Haycocks Harbor, Washington County, Me	Nov. 7	93
1587	43	55	07	67	56	25	Near Port George, Annapolis County, Nova Scotia	Nov. 2	88
1599	43	52	31	67	54	25	Near bell buoy, Burnt Island, Me	Sept. 10	35
1600	43	52	31	67	54	25	Northeast Matinicus	Sept. 8	33

[1] 1924.

SERIES E: Bottles Nos. 1701 to 1800; two every half mile along a line running 125° from Cape Elizabeth whistling buoy, for 25 miles, August 4, 1923.

No.	Set out: Latitude			Set out: Longitude			Where found	Date, 1923	Interval
	°	′	″	°	′	″			Days
1702	43	32	00	70	12	00	Beachwood, Me	Sept. 7	31
1712	43	30	35	70	09	10	Siasconset, Mass	Dec. 24	139
1720	43	29	27	70	6	54	Clifford's Cove, Long Island, Nova Scotia	Oct. 20	74
1721	43	29	10	70	6	20	4 miles southeast Seguin light, Me	Sept. 8	32
1726	43	28	36	70	5	12	Entrance Grand Harbor, New Brunswick, Nova Scotia	Nov. 26	111
1728	43	28	19	70	4	48	New River Beach, Charlotte County, New Brunswick, Canada	Oct. 22	76
1731	43	27	45	70	3	40	North Beach, Chatham, Mass	Dec. 6	121
1732	43	27	45	70	3	40	New Meadows River, Me	Sept. 14	38
1733	43	27	28	70	3	06	Mascabin Point light, New Brunswick, Canada	Oct. 21	75
1734	43	27	28	70	3	06	Pond Island, Casco Bay, Me	Oct. 1	55
1740	43	26	37	70	1	24	Shore of Round Pond Harbor, Me	Nov. 2	77
1763	43	23	23	69	54	36	Salmon River, St. Marys Bay, Nova Scotia	Nov. 5	90
1764	43	23	23	69	54	36	Centreville, Digby County, Nova Scotia	Oct. 9	63
1768	43	22	49	69	53	28	Bay of Fundy shore, Digby County, Nova Scotia	Oct. 10	64
1769	43	22	32	69	52	54	Comeau Cove, Digby County, Nova Scotia	Oct. 10	64
1773	43	21	58	69	51	46	Big Wood Island, Grand Manan, Nova Scotia	Oct. 2	56
1780	43	21	07	69	50	04	Bay of Fundy, Brier Island, Digby County, Nova Scotia	Nov. 4	79
1792	43	19	25	69	46	40	Metinic Island, Me	Oct. 10	64
1793	43	19	08	69	46	06	Sheepscot River, Me	Sept. 10	34

SERIES F: Bottles Nos. 1601 to 1700; two bottles every half mile along a line running 99° from Thatchers Island, Cape Ann, for 25 miles, August 9, 1923.

No.	Set out: Latitude			Set out: Longitude			Where found	Date, 1923	Interval
	°	′	″	°	′	″			Days
1635	42	36	22	70	19	23	Yarmouth Harbor, Yarmouth County, Nova Scotia	Oct. 18	60
1636	42	36	22	70	19	23	Port Maitland, Yarmouth County, Nova Scotia	Oct. 12	64
1645	42	36	02	70	15	58	Cockeritt Passage, Shelbourne County, Nova Scotia	Oct. 13	65
1648	42	35	58	70	15	17	15 miles north of Yarmouth Cape, Nova Scotia	Dec. 25	138
1672	42	35	10	70	7	05	East side Digby Gut, Nova Scotia	Nov. 2	85
1677	42	34	58	70	5	15	Dogs Bay, Roundstone West, County Galway, Ireland	[1] Jan. 2	-------
1692	42	34	30	70	0	15	East of Preston Littlehampton, Sussex, England	[2] Sept. 25	-------

[1] 1925. [2] 1924.

SERIES G: Bottles Nos. 1801 to 1900; two every half mile on a line running 73° from a point half a mile off the radio towers at South Wellfleet, Cape Cod, for 25 miles, August 16, 1923.

No.	Set out: Latitude			Set out: Longitude			Where found	Date, 1923	Interval
	°	′	″	°	′	″			Days
1815	41	56	03	69	52	40	Nauset Harbor, Mass	Sept. 12	27
1826	41	56	48	69	49	36	Nauset Lighthouse, North Eastham, Cape Cod, Mass	Aug. 18	2
1881	42	00	57	69	31	20	Eastern edge of Georges Bank, latitude 41° 50′, longitude 66° 0′	Oct. 14	59
1885	42	01	15	69	30	06	Bally Teique Bay, Kilnare Quay, County Wexford, Ireland	[1] Sept. 20	-------
1892	42	01	42	69	28	15	Tiverton, Digby County, Nova Scotia	[1] Jan. 12	149

[1] 1924.

SERIES H: Bottles Nos. 1 to 85, placed in Nantucket and Vineyard Sounds in 1924, as follows:

1. On a line from Great Point, Nantucket Island, N. 10° W., running about one-half mile west of Handkerchief Shoal lightship to within about 1½ miles of the coast of Cape Cod. Bottles dropped approximately one-third mile apart. Bottle

No. 1 was dropped nearest Great Point at 11.17 a. m., August 4. Bottle No. 45 was dropped nearest the mainland at 12.45 p. m.

2. On a line from Succonesset Point to Cape Pogue. Bottle No. 46 was dropped nearest Succonesset Point at 10.17 a. m., August 5, while No. 67 was dropped nearest Cape Pogue at 10.59 a. m.

3. On a line from Pasque Island to Menemsha Bight. Bottle No. 68 was dropped nearest Pasque Island at 12.04 p. m., August 6, and bottle No. 85 was dropped nearest shore in Menemsha Bight at 12.38 p. m.

No.	Set adrift		Recovered	
	Date, 1924	Place	Date, 1924	Place
2	Aug. 4	From Great Point north 10° west ⅔ mile.	Oct. 4	Point Pleasant Beach, N. J.
3	...do....	From Great Point north 10° west 1 mile.	Sept. 29	1 mile east of Mecox station, Bridgehampton, Long Island, N. Y.
14	...do....	From Great Point north 10° west 4⅔ miles.	Sept. 22	East Hampton, Long Island Beach.
19	...do....	From Great Point north 10° west 6⅓ miles.	[1] Mar. 4	Eorabus, Bunessan, Mull, Argyle, Scotland.
27	...do....	From Great Point north 10° west 9 miles.	Sept. 30	Lonelyville, Fire Island, N. Y.
28	...do....	From Great Point north 10° west 9⅓ miles.	Oct. 7	About 72d Street, Holiday Beach, N. J.
31	...do....	From Great Point north 10° west 10⅓ miles.	Sept. 29	Beach Haven, N. J.
37	...do....	From Great Point north 10° west 12⅓ miles.	Aug. 22	In Bucks Creek, South Chatham, Mass.
38	...do....	From Great Point north 10° west 12⅔ miles.	Aug. 20	Harwichport, Mass.
39	...do....	From Great Point north 10° west 13 miles.	Aug. 7	1 mile west of Monomoy Coast Guard station (south of Chatham, Mass.).
41	...do....	From Great Point north 10° west 13⅔ miles.	Aug. 11	Forest Beach, South Chatham, Mass.
42	...do....	From Great Point north 10° west 14 miles.	Aug. 9	Hardings Beach light, Chatham Bay, Mass.
43	...do....	From Great Point north 10° west 14⅓ miles.	Aug. 16	½ mile from Hardings Beach light, West Chatham, Mass.
44	...do....	From Great Point north 10° west 14⅔ miles.	Aug. 9	Bucks Creek, South Chatham, Mass.
45	...do....	From Great Point north 10° west 15 miles.	Aug. 10	South Chatham, Mass.
46	Aug. 5	From Succonesset Point south ⅓ mile.	Aug. 26	4 miles southeast of Rose and Crown Buoy, Nantucket Shoals Mass.
47	...do....	From Succonesset Point south ⅔ mile.	Aug. 16	1 mile off Wiano Point, Cape Cod, Mass.
49	...do....	From Succonesset Point south 1⅓ miles.	Aug. 11	West side of Great Island Point, Hyannis Harbor, Mass.
50	...do....	From Succonesset Point south 1⅔ miles.	Aug. 10	Near Hyannis Lighthouse, South Hyannis, Mass.
51	...do....	From Succonesset Point south 2 miles.	Aug. 29	Mouth of Bass River, Cape Cod, Mass.
52	...do....	From Succonesset Point south 2⅓ miles.	Aug. 9	Between Marthas Vineyard and Succonesset Point, Mass.
53	...do....	From Succonesset Point south 2⅔ miles.	Aug. 18	West side of Hyannis Harbor, Mass.
55	...do....	From Succonesset Point south 3⅓ miles.	Aug. 10	West Beach, Hyannisport, Mass.
56	...do....	From Succonesset Point south 3⅔ miles.	Sept. 11	Bass River, Mass.
63	...do....	From Succonesset Point south 6 miles.	Aug. 31	Dennisport Beach, Cape Cod, Mass.
64	...do....	From Succonesset Point south 6⅓ miles.	Aug. 26	Foot of Morey Lane, Siasconset, Mass.
66	...do....	From Succonesset Point south 7 miles.	[2] Dec. 17	At entrance to Chatham Harbor, Mass.
67	...do....	From Succonesset Point south 7⅓ miles.	Nov. 10	1 mile west of the Green Hill Coast Guard station (R. I. ?).
68	Aug. 6	From Pasque Isle south ⅓ mile.	Aug. 18	Northeast shore of Cuttyhunk Island, Mass.
69	...do....	From Pasque Isle south ⅔ mile.	Aug. 14	2 miles north of Woods Hole, Mass.
71	...do....	From Pasque Isle south 1⅓ miles.	Aug. 7	¼ mile northeast of Cedar Tree Neck, Vineyard Sound, Mass.
72	...do....	From Pasque Isle south 1⅔ miles.	Sept. 21	Extreme end of Tuckernuck Island, Mass.
74	...do....	From Pasque Isle south 2⅓ miles.	Sept. 22	Brant Beach, N. J.
76	...do....	From Pasque Isle south 3 miles.	Aug. 14	4 miles northwest of Vineyard Sound Lightship.
79	...do....	From Pasque Isle south 4 miles.	Aug. 27	Menemsha Bight, Vineyard Sound, Mass.
80	...do....	From Pasque Isle south 4⅓ miles.	Aug. 10	East Passage, Narragansett Bay, R. I.
81	...do....	From Pasque Isle south 4⅔ miles.	Sept. 29	1 mile north of Sea Isle City, N. J.
82	...do....	From Pasque Isle south 5 miles.	Sept. 30	Hereford Inlet, Anglesea, N. J.
83	...do....	From Pasque Isle south 5⅓ miles.	Aug. 11	Ribbon Reef, ½ mile west of buoy.

[1] 1926 [2] 1924.

SERIES I: Bottles Nos. 1 to 60, set adrift in Massachusetts and Cape Cod Bays, February 6 and 7, 1925, by the *Fish Hawk*, cruise No. 6. (For station record, see p. 1004.)

No.	Set out							Where found	Date, 1925	Interval
	Hour	Latitude			Longitude					
		°	′	″	°	′	″			Days
15	12.45 p. m.	42	12	00	70	23	30	Near radio station, Nantucket	June 14	128
22	2.50 p. m.	42	03	18	70	14	42	Fire Island Coast Guard station, N. Y.	July 4	87
25	3.40 p. m.	42	00	45	70	11	50	Beach, Provincetown, Mass	Feb. 11	5
26	do	42	00	45	70	11	50	Pilgrim Heights, Mass	Feb. 26	20
27	do	42	00	45	70	11	50	East end of breakwater, Provincetown, Mass	Feb. 12	6
28	4.10 p. m.	41	58	12	70	10	48	Pickett Wharf, Provincetown, Mass	Feb. 14	8
29	do	41	58	12	70	10	48	C. L. Birch's store, Provincetown, Mass	Feb. 11	5
30	do	41	58	12	70	10	48	Can factory wharf, Provincetown, Mass	do	5
32	4.40 p. m.	41	55	30	70	09	30	Beach at Provincetown, Mass	Feb. 12	6
33	do	41	55	30	70	09	30	Beach at North Truro, Mass	Feb. 11	5
34	5.35 p. m.	41	52	18	70	10	30	East Harbor, Provincetown, Mass	do	5
35	do	41	52	18	70	10	30	Eastern cold-storage wharf, Provincetown, Mass	do	5
36	do	41	52	18	70	10	30	Smiths Bathing Beach, Mass	Feb. 12	6
37	6.00 p. m.	41	49	30	70	11	15	Provincetown Harbor, Mass	Feb. 11	5
38	do	41	49	30	70	11	15	On beach, Provincetown Harbor, Mass	Feb. 14	8
39	do	41	49	30	79	11	15	Provincetown Harbor, Mass	Feb. 12	6
40	6.52 p. m.	41	52	27	70	15	24	North Truro Beach, Cape Cod Bay, Mass	Feb. 17	11
42	do	41	52	27	70	15	24	Bay shore, North Truro, Cape Cod, Mass	Feb. 22	16
43	7.15 p. m.	41	56	00	70	18	30	Beach Point, Provincetown Harbor, Mass	Feb. 23	17
44	do	41	56	00	70	18	30	Provincetown Harbor, Mass	Feb. 18	12
74	10.45 a. m.	42	07	18	70	36	36	29 miles from Eastern Point, Stellwagen Bank	Feb. 16	10
78	11.00 a. m.	42	09	30	70	38	15	Surfside, south shore, Nantucket	June 30	144
85	12.50 p. m.	42	16	06	70	42	30	Freeport, Digby County, Nova Scotia	July 2	146
89	1.10 p. m.	42	18	15	70	44	00	28 miles east-southeast from Thatchers Island		

SERIES J: Bottles Nos. 91 to 101, set out in Ipswich Bay and off Cape Ann by the *Fish Hawk*, April 7, 1925.

No.	Set out							Fish Hawk station	Where found	Date, 1925	Interval
	Hour	Latitude			Longitude						
		°	′	″	°	′	″				Days
95	3.20 a m.	42	49	30	70	40	00	23	¼ mile west of Race Point, Cape Cod	Apr. 21	14
96	do	42	49	30	70	40	00	23	¼ mile southeast of Race Point, Cape Cod	Apr. 24	17
97	4.30 a. m.	42	46	00	70	40	00	21	2 miles off Cutler, Me.	July 21	105
99	6.10 a. m.	42	38	00	70	33	00	29	2 miles north of Brant Rock, Mass., Coast Guard station	Apr. 29	22

SERIES K: Bottles Nos. 102 to 141, set out in pairs by the *Fish Hawk* in Massachusetts Bay, May 20 to 22, 1925, cruise No. 13 (p. 1004).

No.	Set out							Fish Hawk station	Where found	Date, 1925	Interval
	Hour	Latitude			Longitude						
		°	′	″	°	′	″				Days
103	6.41 a. m.	42	18	15	70	44	00	17	Dennisport, Mass	June 6	17
106	9.10 a. m.	42	16	54	70	30	30	18A	3 miles northwest of Race Point Light, Cape Cod	May 26	6
108	11.15 a. m.	42	05	00	70	35	00	14	1¼ miles north of Pamet River Coast Guard station, Cape Cod.	May 30	10
109	do	42	05	00	70	35	00	14	Coast Guard station, Provincetown, Mass	May 25	5
112	3.10 p. m.	41	56	00	70	18	30	6A	Race Point, Mass., Coast Guard station	June 1	12
113	do	41	56	00	70	18	30	6A	South Beach, Edgartown, Mass	July 24	65
114	4.45 p. m.	41	49	30	70	11	15	7	6 miles east of Gurnet Light, Plymouth, Mass	May 29	9
115	do	41	49	30	70	11	15	7	South Truro, Mass	May 26	6
117	5.55 p. m.	41	55	30	70	11	15	6	5 miles west of Race Point, Cape Cod	May 31	11
118	5.50 a. m.	42	05	30	70	17	00	4	Nauset Beach, near Coast Guard station, Eastham, Mass.	July 12	52
120	7.00 a. m.	42	09	30	70	19	30	3	75 miles southeast by south from Cape Cod Light	June 12	22
126	12.55 p. m.	42	23	30	70	15	30	32	1¼ miles West of Race Point Coast Guard station, Cape Cod.	May 27	6
127	do	42	23	30	70	15	30	32	2 miles off Peaked Hill bar, Cape Cod	do	6
136	7.10 a. m.	42	30	15	70	43	15	36	Marblehead Neck, Mass	July 15	54
137	do	42	30	15	70	43	15	36	Pea Island, Nahant, Mass	June 1	10
139	8.25 a. m.	42	28	00	70	48	00	37	¼ mile east of Tinkers Island, Marblehead, Mass	May 31	9
140	9.20 a. m.	42	24	15	70	52	15	38	Lynn Beach, Mass	May 27	5
141	do	42	24	15	70	52	15	38	Long Island, Boston Harbor, Mass	May 28	6

SERIES L: Bottles Nos. 1901 to 1941, set out by H. C. Stetson on a line running 75° for 10 miles from Dry Salvages Beacon, off Cape Ann, 1 bottle every one-fourth mile, April 19, 1926. First bottle put out at 7 a. m.; last bottle at 9.11 a. m.

No.	Distance out from starting point	Where found	Date, 1926	Interval
	Miles			*Days*
1904	1	1 mile east of Madakket Coast Guard station, Nantucket Island	June 30	70
1907	1¾	Monomoy Point, Mass	June 7	49
1911	3	South shore of Marthas Vineyard, between Gay Head and Edgartown	July 4	74
1913	3¼	2 miles south of Chatham Light, Mass	May 30	30
1915	3¾	1 mile north of Pamet River Coast Guard station, Cape Cod	June 26	66
1916	4	1 mile north of Old Harbor Coast Guard station, Chatham, Mass	May 27	38
1917	4¼	Beach near Hummock Pond, Nantucket	June 2	44
1918	4½	South shore, Nantucket, near radio station	Sept. 8	142
1919	4¾	1½ miles west of Race Point Coast Guard station, Cape Cod	May 21	32
1922	5½	Lepreau Harbor, Charlotte County, New Brunswick	July 24	94
1923	5¾	Harts Island, Port Clyde, Me	July 15	85
1927	6¾	12 miles below Digby Gut, Nova Scotia, 1 mile offshore	Aug. 16	119
1937	9¼	10 miles west of Brier Island, Digby County, Nova Scotia	July 3	73
1941	10	¼ mile from Weymouth Light, Digby County, Nova Scotia	July 7	77

SERIES M: Bottles Nos. 1942 to 1970, set every one-half mile on a line from light buoy off Manomet Point, Mass., to Wood End, Provincetown, by Henry C. Stetson, April 21, 1926. First bottle put out at 11 a. m.; last bottle at 3.30 p. m.

No.	Distance set out from Manomet	Where found	Date, 1926	Interval
	Miles			*Days*
1945	1½	Wood End Coast Guard station, Provincetown	May 22	31
1946	2	Provincetown Bay, Provincetown, Mass	May 3	12
1949	3½	Wood End station, Provincetown, Mass	Apr. 28	7
1953	5½	Provincetown Bay, Mass	June 12	52
1956	7	3 miles north of Wood End station, Provincetown, Mass	Apr. 28	7
1960	9	⅛ mile south of Race Point Light, Cape Cod	June 9	49
1961	9½	Race Point Light, Provincetown, Mass	Apr. 23	2
1963	10½	Race Point Light station, Provincetown, Mass	May 10	19
1964	11	Near Race Point Light, Provincetown, Mass	May 2	11
1965	11½	2 miles north of Wood End Light, Provincetown, Mass	do	11
1967	12½	1 mile south of Race Point, Provincetown, Mass	May 12	21
1968	13	Wood End Run, Provincetown, Mass	May 15	24

SERIES N: Bottles Nos. 1971 to 1980, set out by Henry C. Stetson every one-half mile on a line running 244° for 5 miles from a point 1 mile west of the mouth of Pamet River, Truro, Mass., April 21, 1926. Outer bottle set out at 3.55 p. m.; innermost bottle at 4 p. m.

No.	Distance set out offshore	Where found	Date, 1926	Interval
	Miles			*Days*
1974	4	½ mile south of Wood End Coast Guard Station, Provincetown, Mass	Apr. 24	3
1975	3½	1 mile off Church Point Light, St. Marys Bay, Digby County, Nova Scotia	July 9	79
1978	2	Off Wood End Light, Provincetown Mass	Apr. 29	8
1980	1	Seeleys Cove, 5 miles west of Beaver Harbor Light, Charlotte County, New Brunswick	July 22	92

SERIES O: Bottles Nos. 1952 and 1981 to 2000, set out on July 18, 1926, by T. E. Graves, on a line running 107° from Cape Neddick, Me., for 9 miles, 1 bottle every one-half mile. First bottle (No. 1952) put out at 8.17 a. m.; last bottle (No. 2000) at 10.44 a. m.

No.	Distance set out from Cape Neddick	Where found	Date, 1926	Interval
	Miles			*Days*
1982	1½	Kenwood Bridge, Salem, Mass	Aug. 4	17
1985	3	10 miles southeast by south from Thatchers Island, Mass	Aug. 3	16
1987	4	do	do	16

GENERAL DISCUSSION OF THE RECOVERIES

With the Bay of Fundy experiments as a guide, it was natural to expect a considerable number of the bottles released in the Gulf of Maine on the several lines off Mount Desert, Cape Elizabeth, and Cape Ann, in 1922 and 1923, to be picked up in the Massachusetts Bay region. This, however, did not prove to be the case. Not a single bottle from any of these series has been found anywhere between Cape Ann and the southern elbow of Cape Cod, and only five of them south of Kennebunkport. It is therefore evident that the dominant surface drift was not the same in the summers of 1922 and 1923 as it was in 1919, but drifts of the 1919 type were recorded for series L and O, as described below.

The most striking aspect of the experiments carried out in all these summers is that more than 30 per cent of all the recoveries of bottles put out north of the southern angle of Cape Cod have been from the Bay of Fundy and Nova Scotia, which (if these were the only data available on the circulation of water in the gulf) would obviously suggest a drift from south and west to north and east. However, as we have just seen, the bottle drifts of 1919 and of 1926, on the contrary, point to an anticlockwise current skirting the shores of the gulf from northeast to southwest, and salinities (p. 910), temperatures (p. 918), and the distribution of the plankton (p. 923) all point in the same direction. It therefore becomes necessary to reduce these apparently contradictory lines of evidence to a rational order, which may best be done by analyzing the results for the years 1922 to 1926 regionally, not chronologically, to test whether they prove consistent, one with the other. The dominant sets of the surface water are shown rather clearly for the southwestern part of the gulf by the lines off Cape Ann, in Massachusetts Bay, off Cape Cod, and in Vineyard and Nantucket Sounds. These, therefore, may be considered first, leaving until later the study of the more puzzling drifts of the bottles set out in the northern side of the gulf.

SOUTHWESTERN SERIES

These bottles were set out off Cape Ann, in Massachusetts Bay, off Cape Cod, and to the southward of the latter.

The Cape Cod line of July, 1922 (line B), proved, in some ways, the most instructive of all, for out of these 600 bottles, 131, or 22 per cent, were picked up within

4 months. The line may be divided into three sections, according to the localities of recovery: First, an inner section, from Cape Cod across the mouth of Nantucket Sound and skirting the easterly edge of Nantucket Shoals; second, a middle section, from the shoals out nearly to the edge of the continent; and third, the outer end of the line to the seaward of the continental edge.

Ten bottles out of the 250 set out along the inner section were picked up to the eastward, three of them on the Nova Scotian shore of the Bay of Fundy, one on the northeastern part of Georges Bank, and five (after short drifts) in the south channel and along the northwestern side of Georges Bank (fig. 174).[66] This last group of recoveries is especially instructive as evidence that the surface water to the south and southeast of Cape Cod was setting in a southeasterly direction at the time. Bottle No. 362, picked up 40 miles to the southeast of the place of its release, after 5 days' drift, and Nos. 396 and 405, found 30 miles away after 8 days, can hardly have diverged from a direct line except to follow the spiral tracks induced by the veering tidal currents of this region, unless the dominant set was more rapid at the time than other experiences in the gulf would suggest.[67] A southeasterly set is also indicated in this general region by the current measurements carried out by the United States Coast and Geodetic Survey (p. 864).

The uniformity of these southeasterly drifts makes it likely that the bottles that went from the inner end of line B to the eastern end of Georges Bank and to Nova Scotia also drifted in a southeasterly direction at first, veering to the eastward—i. e., anticlockwise.

It seems that this inner section of line B followed the boundary of demarkation between this southeasterly set and another drift directed more to the southward from the mouth of Nantucket Sound, veering westward past Nantucket Shoals, because 20 bottles from this section were picked up along the southern coast of New England. The fact that current measurements show a general southeasterly set over Nantucket Shoals and a summer set to the west and northwest at the lightship a few miles farther south, makes it more likely that these bottles rounded the shoals than that they crossed the latter.

It is a question of considerable interest whether 11 bottles, spaced across the eastern entrance to Nantucket Sound, which were picked up along the south shores of Nantucket, Marthas Vineyard, and of New England between Buzzards Bay and and Block Island, drifted directly westward through Nantucket and Vineyard Sounds or whether they also traveled southward around Nantucket Island and Shoals. Of course, a positive answer can not be given; but it seems hardly conceivable that some of them would not have been picked up afloat in the sounds or stranded along shore there if they had gone through, because these beaches are thronged with vacationists. Actually, however, not one of the bottles from line B was found along the northern coast of the sounds, and only one of them on the northern shore of Nantucket, 159 days after it was set afloat. One, however, after 30 days afloat, was found 1 mile inside Gay Head at the western end of Marthas Vineyard, where many species of tropical fishes have been recorded in summer. Thus, it seems almost certain that

[66] One bottle from this section went to France.

[67] Bottle No. 510 was reported on the northwest slope of Georges Bank, 50 miles from where it was set out, within 3 days. This ostensible drift is so rapid, however, that some error in the reported locality seems probable.

this group of bottles went out around Nantucket.[68] Bottle No. 536 journeyed to the south shore of Marthas Vineyard (85 miles) at a rate of at least 4 miles per day.

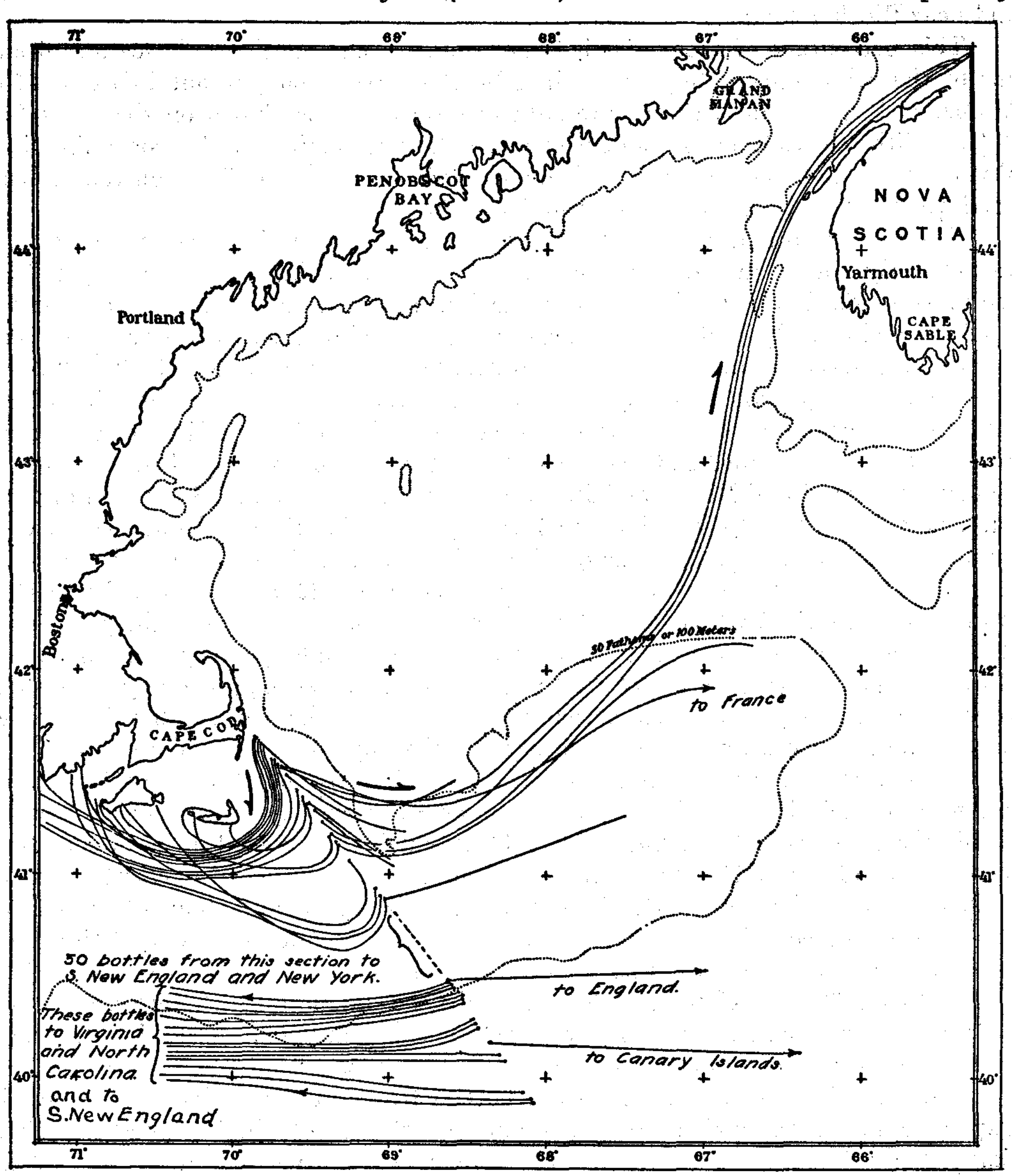

FIG. 174.—Assumed drifts of representative bottles recovered from line B, set out off Cape Cod, July 6 to 8, 1922. ●, place of release.

The mid-section of line B (lat. 40° 50′ to lat. 41° 30′) was clearly involved in this same set, veering clockwise around Nantucket Shoals, because 50 of these bottles out of a total of 103 were picked up along the shores of southern New England, from

[68] The assumed routes for this group of bottles are laid down on the chart without reference to Nantucket Shoals. Actually, however, the complex tidal currents among these banks and through the channels between them must give a very circuitous route to any flotsam in that region.

Nantucket westward, and along the eastern half of Long Island, New York, the great majority on the south shore of Marthas Vineyard, at the mouth of Buzzards Bay, and near Block Island.

This percentage of recoveries is larger than for any considerable section of any one of the other lines along which drift bottles have been put out in the Gulf of Maine, so large, in fact, that representatives only can be shown on the chart (fig. 174). With the recoveries condensed in so short a section of the coast line, it is obvious that these bottles came within the grip of a very definite current setting northward and inshore, probably around the shoals.

The alteration along line B, from westerly drifts at the inshore end to easterly and westerly both from the next section of 40 miles, and then to westerly again from the mid-section, is clear evidence that the line followed the boundary between the Gulf of Maine eddy and the clockwise drift around the shoals to the west just stated, locating the southern boundary of the former at about latitude 40° 50′.

This westerly drift certainly involved the water right out to the edge of the continent, because 22 bottles from the outer section of line B (including the outermost of all, set adrift 40 miles out from the 200-meter contour) were picked up between Nantucket Island and Fire Island Beach on Long Island, N. Y. Seventeen of these outer bottles (10 from just inside and 7 from just outside the continental edge) were found on the North Carolina beach, a few miles north of Cape Hatteras,[69] after time intervals averaging 85 days (73 to 112 days). The mean distance traveled by this last group of bottles (if they followed a straight line) is about 410 miles—slightly longer by their probable route—giving a minimum rate of nearly 5 miles per day. It is probable, also, that the time intervals between the dates of setting out and recovery correspond very closely to the periods when actually afloat, because the sector of beach on which they stranded is continuously and closely patrolled by the Coast Guard stations.

Some further light is thrown on the tracks that the bottles of this last group followed on their journey, by recoveries set adrift a few days later along a line (C) running southeasterly from New York, 111 of which were picked up between Delaware Bay and Cape Hatteras. Most of those that reached the North Carolina coast from the outer part of this line were spaced from a point about 45 miles from the New Jersey coast out to a point some 40 miles beyond the edge of the continent, as marked by the 100-fathom contour. It is therefore fair to assume that the bottles from the Cape Cod line that drifted farthest south likewise passed Delaware Bay within a few miles (one way or the other) of the continental edge, where they would have intersected the New York line.

The fact that so many of the other bottles from the same outer section of the Cape Cod line drifted inshore, to strand along southern New England, makes it likely that this whole group of bottles set northwestward, in over the outer part of the continental edge at first, and then separated, some veering to the westward and southwestward along the outer part of the shelf, others turning northward toward the coast. There must also have been a rather direct drift of surface water in that direction from the offing of Nantucket Shoals, and so in toward the land, at the time, for if the bottles that traveled that route had gone far west before turning

[69] Scattered from False Cape to a point 9 miles north of Hatteras Light.

north the New York line would have been involved in this same drift and so have stranded along the coast of Long Island to the east of Fire Island lighthouse, where only three of them actually were found.

The combined evidence of these Cape Cod and New York lines thus points to a dominant movement of the surface water along the edge of the continent, westward and southward from the offing of Nantucket to Cape Hatteras, but complicated by a clockwise eddy movement in toward the land west of Nantucket Shoals, just where flotsam from the so-called "Gulf Stream" (gulf weed and various tropical animals) most often drifts in to the coast. No such tendency for the surface water to set inshore from the outer part of the continental shelf is reflected in the drifts to the west of this, however, not a single bottle from the Cape Cod line having been found between New York and Chesapeake Bay, though bottles from the New York line were picked up all along this 250-mile sector.

No further discussion of the bottles set out off New York is called for here, as they do not immediately touch the Gulf of Maine, except to emphasize that neither they nor the Cape Cod line afford any evidence whatever of surface water entering the gulf around Nantucket from the southwest. It has long been known that the southern angle of Cape Cod marks a rather abrupt faunal division between the waters of Nantucket and Vineyard Sounds, on the one hand, and the more boreal Gulf of Maine, on the other. It is obvious that a division of this sort, with no change of latitude, is associated with the nontidal circulation of the water.

It was to check the evidence of the drifts from line B and measurements with current meters (p. 864) pointing to a set of water outward from the eastern end of Nantucket Sound, and so toward the southeast, that lines H (p. 875) were set out along three sections of the sounds during August, 1924.

Thirty-seven of these 85 bottles have been recovered within the sounds, along the outer shores of Nantucket, and still farther west, but not one of them within the limits of the Gulf of Maine.

The drifts from the western end of Marthas Vineyard (Pasque Island to Menemsha Bight) may be passed over briefly. Eleven of these were picked up—1 on Cuttyhunk Island, 2 in Vineyard Sound, 1 on Tuckernuck Island, 1 within Buzzards Bay, 2 at the mouth of the latter, 1 in Narragansett Bay, and 3 on the Rhode Island shore (fig. 175). It is not easy to reconstruct the probable paths of all of these.

The series was set adrift on the first of the ebb, which sets westward here through Vineyard Sound and northward from the latter through the "holes" between the Elizabeth Islands into Buzzards Bay. It is probable that the bottles found in Buzzards Bay and on Cuttyhunk went north through Quick's Hole, because they were put out close to Pasque Island at about high water and would soon have been carried in that direction by the ebb. If this line had been put out on the flood instead of at the beginning of the ebb it would probably have been carried far enough up the sound before the tide changed to come within the easterly set that appears to dominate Nantucket Sound. Actually, however, most of these bottles must have drifted westward for the first 5 or 6 hours, carrying them about to the mouth of Vineyard Sound, where a division evidently took place. Two bottles from the northern end seem to have been carried back into the sound by the next flood, one of them to be picked up two days later on the Marthas Vineyard shore, 6 miles to the east of where it was put out, the other on Tuckernuck Island, between Nantucket and Marthas Vineyard, after 46 days.

The others, from the southern end of this line, seem to have been carried far enough out of the sound on the first ebb to escape the next flood back again. The two that were picked up at the mouth of Buzzards Bay must have drifted on a comparatively direct route, for one was picked up after five and the other after six days. Evidently they came within the sweep of the Buzzards Bay tides. The bottles that went to New York and New Jersey must have escaped this. The one that was picked up at the entrance to Narragansett Bay only five days after it was put out evidently followed a route directly westward, making it a fair assumption that the three others set afloat close by, which went to New Jersey, also traveled via the same route, paralleling the coast.

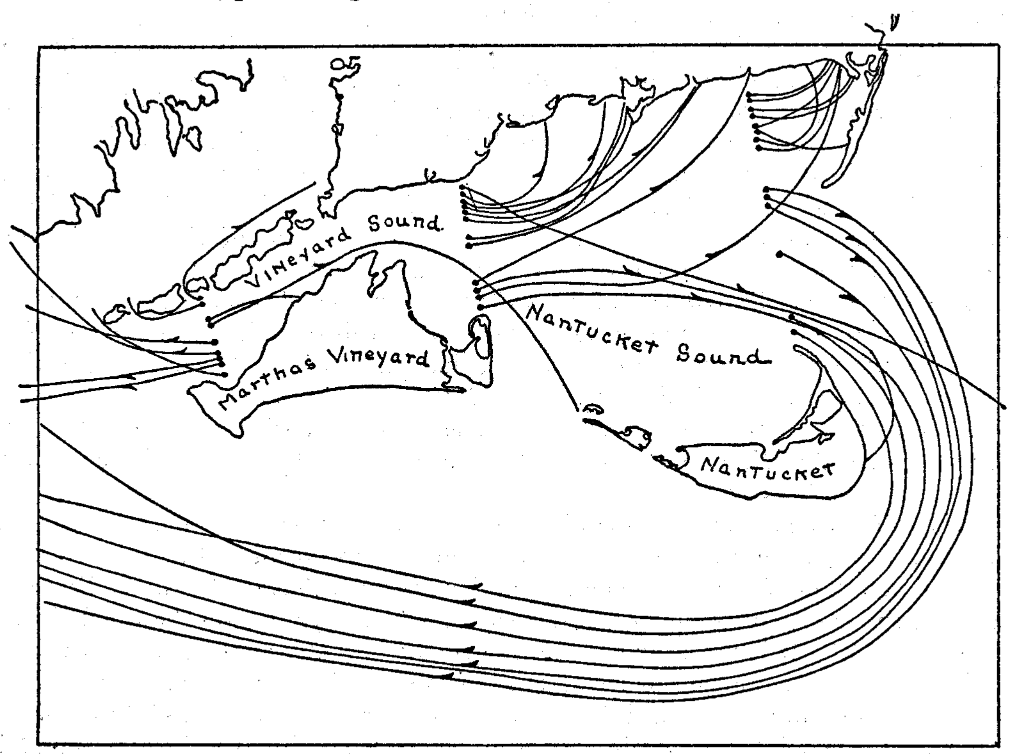

FIG. 175.—Assumed drifts of representative bottles recovered from lines H, set out in August, 1924. ●, place of release

It would be an instructive experiment to put bottles out on this same line early on the flood tide, so that they would journey eastward, up the sound at first, not out of it, so to determine what net movement results from tides whose velocity (1.7 to 2.5 knots at strength) is so great that "a certain part of the water, at least, travels a distance of one-half or more of the length of Vineyard Sound during a single phase of the tide." (Sumner, Osburn, and Cole, 1913, p. 36.) The earlier current tables published by the United States Coast and Geodetic Survey (Coast Pilot, 1912, Appendix I) indicate a net westerly drift of the water along the axis of Vineyard Sound at a rate of about 2 miles per 24 hours, the easterly movement averaging about 3½ miles during the flood, the westerly ebb about 4½ miles. More recent information, however, does not substantiate this, ebb and flood being given as approximately equal along the axis of the Sounds in the current tables for 1924 (United States Coast and Geodetic Survey, 1923); and the fact that considerable quantities of gulf weed so often drift into Vineyard Sound and through into Nantucket Sound in the summer season points rather to a net movement inward into the former from the westward.

The returns from the line next to the east (Succonnesset Point to Cape Pogue; fig. 175) are consistent with a dominant set from west to east along the southern side of Nantucket Sound, because all but one of the recoveries were to the eastward of where the bottles were set out—9 of them from points along its northern shores as far as Chatham; 1 close to Rose and Crown Buoy outside the sound, about 11 miles east of Nantucket Island; 1 from the southeast shore of Nantucket; and 1 from the coast of Rhode Island. Bottles from all parts of the line stranded along the north shore, and the drifts that went out of the sound were from both ends of the line (the bottle picked up near Rose and Crown Shoal was thrown out closest to Succonnesset). This suggests that all traveled eastward at first, as would naturally happen, as they were put out one to two hours after low water; but this first flood, running at an average rate of about 1 knot, can only have carried these bottles 4 or 5 miles east.

It is possible, of course, that the bottles that went from this line to the eastern side of Nantucket and to Rose and Crown Shoal passed out of the sound via the Tuckernuck Channel; but the more direct route eastward is the more probable when these drifts are studied in connection with the line put out across the eastern end of the sound.

Fourteen bottles from this line were recovered, 6 of which (set out abreast the channel between Nantucket and Monomoy) made long journeys to Long Island, New York, and New Jersey, while 8 bottles set out behind Monomoy Island were picked up along the coast near by, between Harwichport and Monomoy. This division, and the fact that the only bottles from this line that were recovered within the sound were those just mentioned, makes it fairly certain that the bottles that made the long journeys did not go westward through the sound, but drifted eastward out of the latter at first and then veered clockwise to the southward and so around Nantucket by the same general route followed by bottles set out off the mouth of the sound in 1922 (line B, p. 880), and so continued westward, paralleling the coast, to the points where they were finally picked up.

This division between the drifts followed by the bottles from the southern and northern parts of the line clearly reflect a tidal difference. All were put out two to three hours before high water; but while the first group was carried eastward by the flood and out of the sound, the second group was caught up in the current flooding northward into Chatham Roads. The fact that so many then stranded there, instead of coming out again with the ebb, and that so many bottles from the line next to the west were found along the northern shore of the sound, shows that the bight inclosed between Monomoy Point (with its submarine extension in Handkerchief Shoal) and the south shore of Cape Cod is the site of a subsidiary anticlockwise eddy, as might be expected from the trend of the coast and from the contour of the bottom.

The combined evidence afforded by the drifts from the two lines last discussed points unmistakably to an easterly set as dominating the southern side of Nantucket Sound, with a net movement of the surface water out through the channel between Great Point and Monomoy. The time intervals for the bottles picked up at Rose and Crown Shoal and on the east shore of Nantucket (21 days in each case) show a daily rate of at least 1½ to 2 miles in this direction at the time.

With none of the bottles from Nantucket Sound reported within the Gulf of Maine, but abundant evidence of drifts veering to the south and west around Nantucket Island and Shoals, it is established with reasonable certainty that the outflow from Nantucket Sound usually shares in the clockwise eddy movement away from the gulf, which involved the water to the southeast of Cape Cod in 1922 (p. 880) and which is indicated by the measurements made of the currents along the eastern side of Nantucket Shoals (p. 864).

The fact that three bottles set out in Nantucket Sound in 1924 were picked up in New Jersey, whereas none of the bottles set out abreast the mouth of the sound in 1923 were reported so far west, suggests that those that passed eastward out of the sound in 1924 then drifted far enough southward to become involved in the drift followed by the bottles put out on the middle section of the Cape Cod line in the year before. An interesting annual difference thus appears in this respect.

If this general type of circulation prevails as constantly from year to year and throughout the summer season, as the bottle drifts suggest, it goes far to explain the fact that tropical fishes, planktonic animals, and floating plants (notably gulf weed), which are so commonly swept from the "Gulf Stream" into Vineyard Sound, only exceptionally enter the gulf around Cape Cod. Passing out of Nantucket Sound to the eastward by the same route followed by the drift bottles, their course would then veer to the southward and so away from the gulf, not into the latter.

An earlier paragraph, the reader will recall, points out that several bottles from the inner (northern) end of line B, set out of Cape Cod in July, 1922, were carried eastward into the Gulf of Maine, though the majority were swept away from the gulf, locating the division between these two circulating movements (p. 882).

Series G was set out normal to the coast, about midway of Cape Cod, in August, 1923 (p. 875), in the hope of throwing more light on the southern side of the eddying circulation that dominates the surface waters of the Gulf of Maine. Only 5 out of the 100 have been recovered, this being the lowest percentage of recoveries for any of the lines. Two of them, put out, respectively, 4 and 6 miles from the land, were picked up at Nauset near by, one within 2 days after it was set adrift. One bottle, set afloat about 20 miles out at sea, was found 2 months later (October 14) floating on the eastern edge of Georges Bank (fig. 176); one launched 5 miles farther out was reported 5 months later from Tiverton, Digby County, on the Nova Scotian shore of the Bay of Fundy, near its mouth; and a fifth, also from the outer end of the line, picked up in Ireland in September a year later, completes the brief list (p. 875).

Evidently the outer bottles on this line (but not the inner) took part in a drift of the same sort as carried several bottles, set out southeast of Cape Cod in 1922, across to the eastern part of Georges Bank, to the Bay of Fundy, and to France (fig. 174), so that a set in this direction is to be expected in the southern side of the gulf in summer.

The measurements taken of the currents in the region of Georges Bank (p. 865; fig. 173) suggest that this group of bottles held to the northward of the shoal part of Georges Bank (Georges and the Cultivator Shoals) in their journey, and that a separation of the tracks evidently occurred to the eastward of the latter, some of the bottles then veering southward across the eastern side of Georges Bank, where one was recovered from each year's series (1922 and 1923) 96 and 59 days, respectively, after release.

The two bottles (one from each year's series) that went from close to Cape Cod to Europe (one to France, the other to Ireland, after a year's journey) probably followed much this same route, continuing on out to sea until they came within the influence of the general North Atlantic drift. Bottle No. 543, which was set out in the South Channel on July 7, 1922, and picked up just south of Georges Shoal 35 days later, was probably caught up in the tidal circulation over that shoal ground.

These Georges Bank drifts are good evidence that the bottles that went to the Bay of Fundy from the two Cape Cod lines (B and G; figs. 174 and 176) likewise skirted the northern side of the banks, continuing eastward until they became involved in the current setting northward into the eastern side of the gulf, which has been developed by Mavor (1922) from Dawson's measurements of currents (p. 861; fig. 173). The Bay of Fundy would then be their most likely destination; and the fact that they stranded on its Nova Scotian shore, just as did several of the bottles that Mavor set out at the mouth of the bay in 1919 (p. 868; Mavor, 1922), makes it likely that they, too, drifted in close along its southern side.

The three bottles that drifted from the offing of Cape Cod (line B) to the Bay of Fundy in 1922 were picked up after intervals, respectively, of 82, 102, and 105 days—an average of 97 days. Their probable route (figs. 174 and 176) being about 300 miles, a daily journey of slightly more than 3 miles is indicated. An interval of 59 days for bottle No. 1881, set out off Cape Cod on August 7, 1923, and picked up on the eastern edge of Georges Bank, points to about this same rate as probable; but bottle No. 435, from the Cape Cod series of the year previous, was not picked up on the eastern part of Georges Bank until 96 days after it was set out, though its journey along the general route it may be assumed to have followed was no longer. Another bottle from the same section of this same Cape Cod line was found on the western slope of Georges Bank, only about 50 miles distant from where it was set adrift, after it had been afloat for 88 days. It would be interesting to know whether it had circled to and fro over the banks during that long period. The only bottle from the Cape Cod line of 1923 (line G) that was reported from the Bay of Fundy was either longer afloat or lay longer on the shore before it was noticed, the interval between its release and recovery being 149 days, or less than 2 miles per day.

RECOVERIES FROM THE CAPE ANN AND MASSACHUSETTS BAY LINES

Only 7 of the 100 bottles set out off Cape Ann in August, 1923 (line F; p. 875), ha e ever been heard from. Five of these were found scattered along the Nova Scotian coast of the gulf and of the Bay of Fundy from Cockerwit Passage, in Pubnico Bay (near Cape Sable), to Digby Gut, and two went to Europe (fig. 176). Time intervals of 65 days (between release and recovery) to Pubnico, 60 days to Yarmouth, 64 days to Port Maitland, and 85 days to Digby Gut suggest a somewhat more direct route to Nova Scotia than was followed by the Cape Cod series of the year previous, because it is not likely that they traveled more than 3 or 4 miles per day

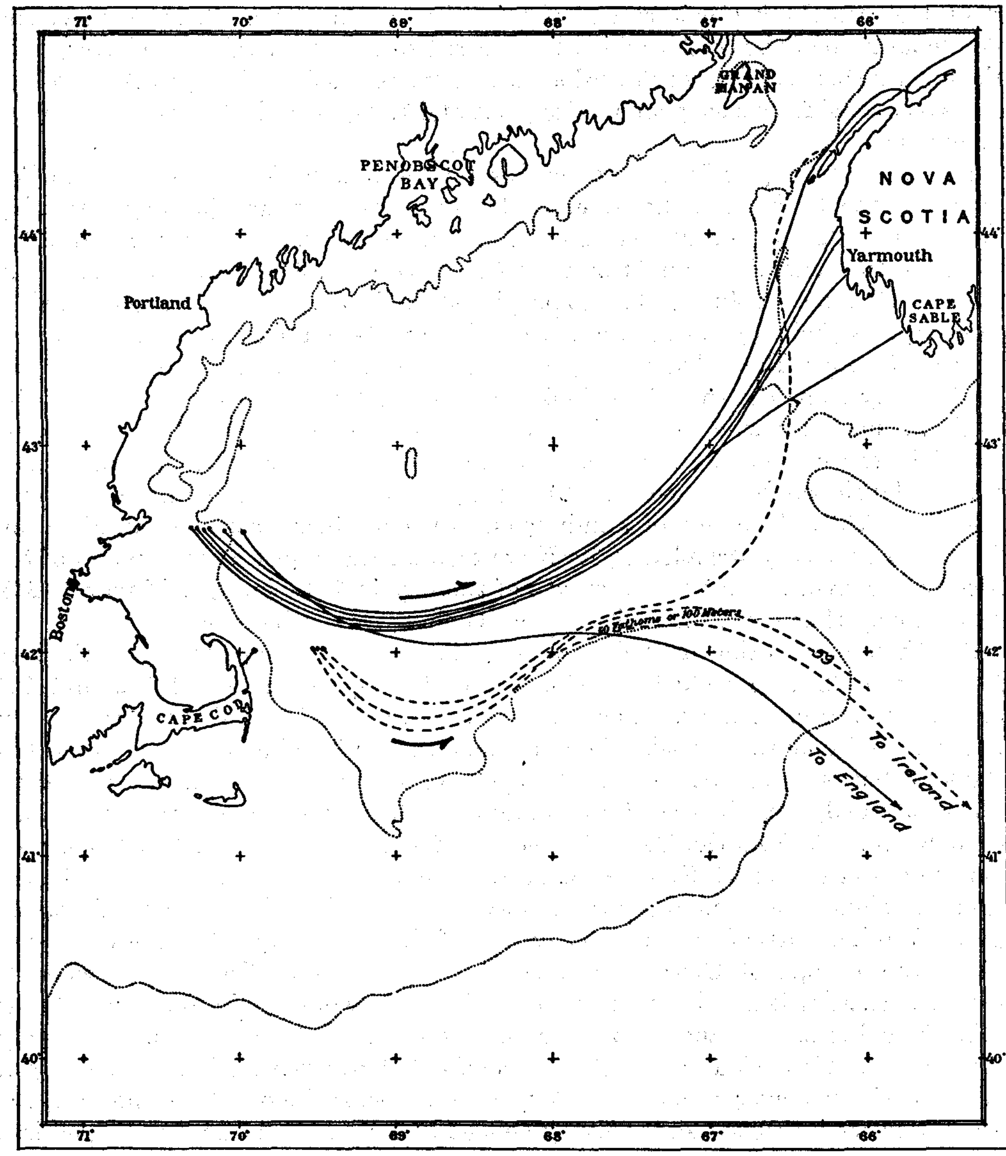

FIG. 176.—Assumed drifts of bottles recovered from lines F (solid curves) and G (dotted curves), set out off Cape Ann and Cape Cod, August 9 and 16, 1923. ●, place of release

until they approached Nova Scotia, where their daily rate may have increased to 5 to 6 miles (p. 867; fig. 173). The probable tracks laid down on the chart (fig. 176) are based on an assumed rate of about 3 miles per day, corresponding to the bottles that drifted from the Cape Cod line (line B) to the Bay of Fundy in 1922 (p. 887).

If these drifts from the offing of Cape Ann to Nova Scotia stood alone, it would be impossible to tell whether their tracks diverged to the left of the direct line along the coast or to the right across the southern side of the basin. Comparison, however, with the bottles that went to the same general destination and eastward along Georges Bank from the Cape Cod lines (figs. 174 and 176) makes the second alternative much the more likely; and when we add the fact that not a single bottle from any of these three lines has ever been found along the coast between Cape Cod and the Bay of Fundy, contrasting with the number of recoveries scattered around the southern and eastern peripheries of the gulf from Georges Bank to the Bay of Fundy, the anticlockwise movement from the offing of Massachusetts Bay around the southern side of the basin and along its offshore rim, as indicated on the charts, seems fully demonstrated for the summers of 1922 and 1923.

The small number of recoveries from the Cape Ann line shows that only those that kept farthest north on this eastward journey came within the influence of the veering drift toward Nova Scotia. This is still more certainly true of the bottles set out off Cape Cod in 1923 (line G). To all intents and purposes these were entirely south of this set, for only odd ones among them were caught up by it. Such of the bottles as dispersed farther to the south from both these lines no doubt drifted to the Georges Bank region, and so, probably, out into the open Atlantic, either circling around the eastern end of the bank or crossing it, probably by the same tracks as were followed by the bottles that went to Europe. The fact that all the recoveries from outside the Gulf of Maine, for the Cape Cod and Cape Ann lines of 1923, were from the other side of the Atlantic, contrasting with the large number of bottles that went west from the line south of Cape Cod in 1922, is sufficient evidence that the eddy movement that carried the latter involved only the western part of Georges Bank at the time. In short, bottles from these lines, which drifted out of the Gulf of Maine in 1923, did so in a southeasterly direction across the eastern end of Georges Bank, traveling to the northward and eastward of its shoal ground.

Of course, it is possible that bottles found along western Nova Scotia after long intervals—say 100 or more days—may have followed this same route at first but then have been caught by an indraft through the Eastern Channel (p. 866). However, we have no positive evidence of this, and the chance that any bottle would be involved in the set toward Nova Scotia after it had once drifted south of latitude 42° is evidently very slight.

It is interesting to find that the bottles that drifted from west to east across the southern side of the gulf from the Cape Cod and Cape Ann lines tended to go far up the Bay of Fundy in 1922, but stranded near its mouth and along the Nova Scotian coast to the southward in 1923. Apparently the northerly set, which dominates the eastern side of the gulf, hugged that coast more closely in the one year than in the other, perhaps reflecting the prevalent winds at the time; but a difference of this sort is trivial, contrasted with the uniformity of these drifts and of those to the eastern part of Georges Bank, just discussed.

In 1919, the reader will recall, bottles from the Bay of Fundy stranded in Cape Cod Bay, marking a set into the latter; but in 1923 the Cape Ann line, by contrast, showed a drift past the mouth of Massachusetts Bay, not into the latter, proving a periodic variation, with the dominant movement following around the coast line of the bay in some summers and passing it as a sort of back water at other times. It was in the hope of throwing further light on this secular alternation, especially in its bearing on the involuntary migrations of fish eggs and larvæ, that series I and K were set out in the bay in February and May, 1925, and series L, M, and N in April, 1926 (p. 877).

Twenty-three (26 per cent) of the February series of 90 bottles have been recovered. Recoveries from bottles set out off the Plymouth shore were distributed as follows: One (No. 74) from Stellwagen Bank, 28 miles off Gloucester; one from an equal distance out in the basin of the gulf (fig. 177); two from Nantucket; one from the Nova Scotian shore of the Bay of Fundy;[70] and one, put out close to the tip of Cape Cod (No. 22), went to Fire Island, New York.

These drifts, combined, show a definite surface set out of the southern side of the bay, dividing off Cape Cod, where some bottles took the southern route down past Nantucket, and so westward (which so many bottles from the Cape Cod line (line B) followed in July, 1922), while one, at least, was caught up in the southern side of the Gulf of Maine eddy, reproducing the drifts of bottles from the Cape Ann line of 1923 (p. 887).

The bottles set out in the eastern side of Cape Cod Bay followed a surprisingly definite set eastward and toward Provincetown, no less than 16 out of 21 stranding in that harbor or near by (all of them to the east and most of them well to the north of where they were set adrift) after intervals of 5 to 17 days (usually 5 or 6). Drifts of this sort suggest an anticlockwise movement of the surface water around Cape Cod Bay, with a subsidiary eddy of the same sort in Provincetown Harbor, which finally caught them up as they set northward along the inner shore of the cape.

Ten bottles set out in Ipswich Bay on April 7 (series J) give definite evidence of a southerly set around Cape Ann and into Massachusetts Bay, one of them having been found at Brant Rock, a few miles north of Plymouth, and two near Race Point, at the tip of Cape Cod, after intervals of 14 to 22 days. A fourth, picked up at Cutler, Me., at the western entrance to the Grand Manan Channel after 106 days, apparently had followed the southern side of the Gulf of Maine eddy, veering southeast, east, and northeast, and so paralleling the drift of bottles set out off Cape Ann in 1923 (line F; p. 887) and at about the same daily rate. A rather definite anticlockwise drift around the Massachusetts Bay region is thus indicated for winter and early spring by the combined drifts of the February and April series, its southern edge involving Cape Cod Bay but with the water farther north setting more to the eastward and so out past Cape Cod.

This same type of circulation is still more clearly reflected by the drifts of 40 bottles put out in Massachusetts Bay on the 20th to the 22d of that May (series K), drifts so easily interpreted as to demand rather detailed study. Eighteen of these were recovered—the largest percentage (45) for any series yet set out in the Gulf of Maine.

Following around the bay from north to south we find one or two bottles set out off Manchester[71] drifting to Marblehead and Nahant, while one bottle set

[70] Freeport, Digby County.

[71] About 3 miles west of Gloucester.

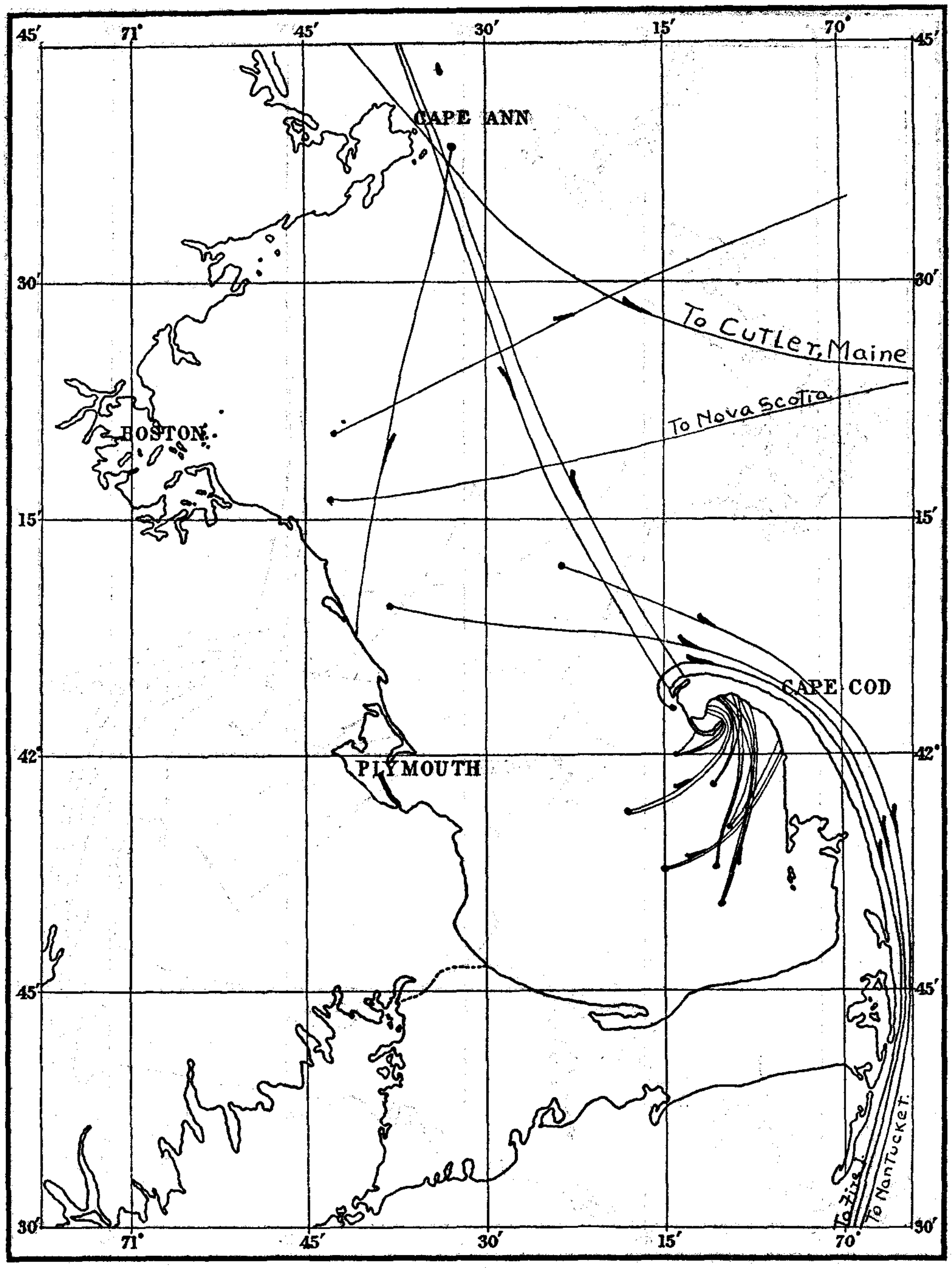

FIG. 177.—Assumed drifts of bottles recovered from Series I, set out in Massachusetts Bay, February 6 and 7, and in Ipswich Bay, April 7, 1925 (Series J). ●, place of release

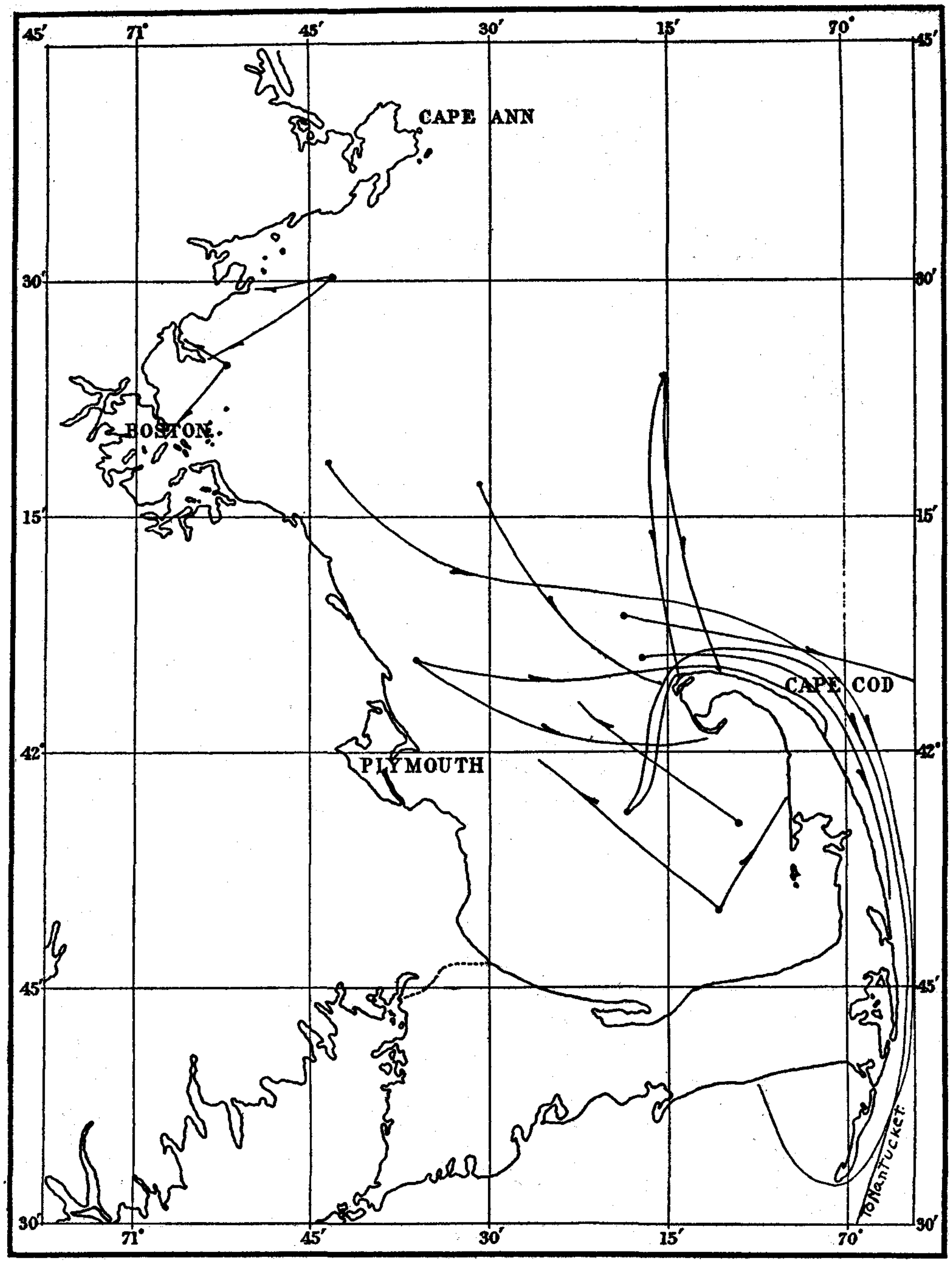

FIG. 178.—Assumed drifts of representative bottles recovered from series K, set out in Massachusetts Bay, May 20 to 22, 1925. ●, place of release

out near Nahant drifted west into Boston Harbor,[72] reflecting a definite set inward along the northern shore of the bay. On the other hand, bottles that were set out in the central part of the bay and at its mouth showed a tendency to drift southeastward, either to leave the bay or to be caught up at the tip of Cape Cod. Thus, one launched near Boston lightship reached Dennisport, on the south shore of Cape Cod (fig. 178); one set afloat on the southern side of Stellwagen Bank was picked up 75 miles east of Cape Cod Light 22 days later; while a third drifted from the offing of Race Point, at the tip of the cape, to Nauset Beach, some 16 or 17 miles down its outer shore. One of a pair set out in the western side of the bay a few miles north of Plymouth also rounded Cape Cod, but the other, also drifting eastward, stranded at Wood End, near Provincetown, while one from the center of the bay and two from its mouth, midway between the capes, were picked up on the beach at the tip of Cape Cod or floating near by.

The anticlockwise set, so clearly indicated by the drifts so far discussed from this series, was also shared by bottles set out in the eastern side of Cape Cod Bay; for all recoveries from this group were to the northward of where the bottles were set out. Two of them went out around the cape, one stranding at its tip but the other continuing southward past Cape Cod to Nantucket. One bottle set out off Wellfleet and another off Billingsgate Island would probably have followed a similar route if they had not been intercepted; for they went northwestward and were picked up midway between Plymouth and Provincetown after 9 and 11 days afloat. The companion bottle from the Billingsgate station (*Fish Hawk* station 7), however, was evidently caught in a different tidal current, for it went northeast to the Truro shore (fig. 178).

These Massachusetts Bay studies were continued by series L to N, set out in April, 1926, by Henry C. Stetson (p. 878). Twelve of the 41 bottles put out off Cape Ann (series L, fig. 179) have been recovered. One of these was from Race Point, at the tip of Cape Cod, in 32 days; four were from the outer shore of Cape Cod, south to Monomoy, in 30 to 66 days; two were from the south shore of Nantucket Island, near the western end, after 44 and 70 days. This general tendency southward across the mouth of Massachusetts Bay and so down past Cape Cod recalls the drifts of bottles from Ipswich Bay and out of Massachusetts Bay the spring before. The parallel between the two years is made complete by three returns from Nova Scotia at the mouth of the Bay of Fundy from the series of 1926 and one from the New Brunswick shore of the bay.

One of these Cape Ann bottles went to Point Clyde, at the western entrance to Penobscot Bay. Without the southern drifts just listed, for comparison, the tracks followed by these bottles to the Bay of Fundy would be conjectural. The former, however, make it as clear as evidence of this sort ever can that the general route was southward at first, with a division off Cape Cod, whence some continued southward but others were carried in an eddying course eastward and northward around the basin of the gulf. The Port Clyde recovery alone is puzzling, but the time interval (85 days) is sufficient to allow of a circuitous journey in its case also.

[72] Another stranded close by.

The line (M) set out at the mouth of Cape Cod Bay from Manomet Point, Plymouth, to Provincetown, on April 21, 1926, showed an unmistakable movement of the water eastward, for 12 of the 28 were picked up near the tip of Cape Cod

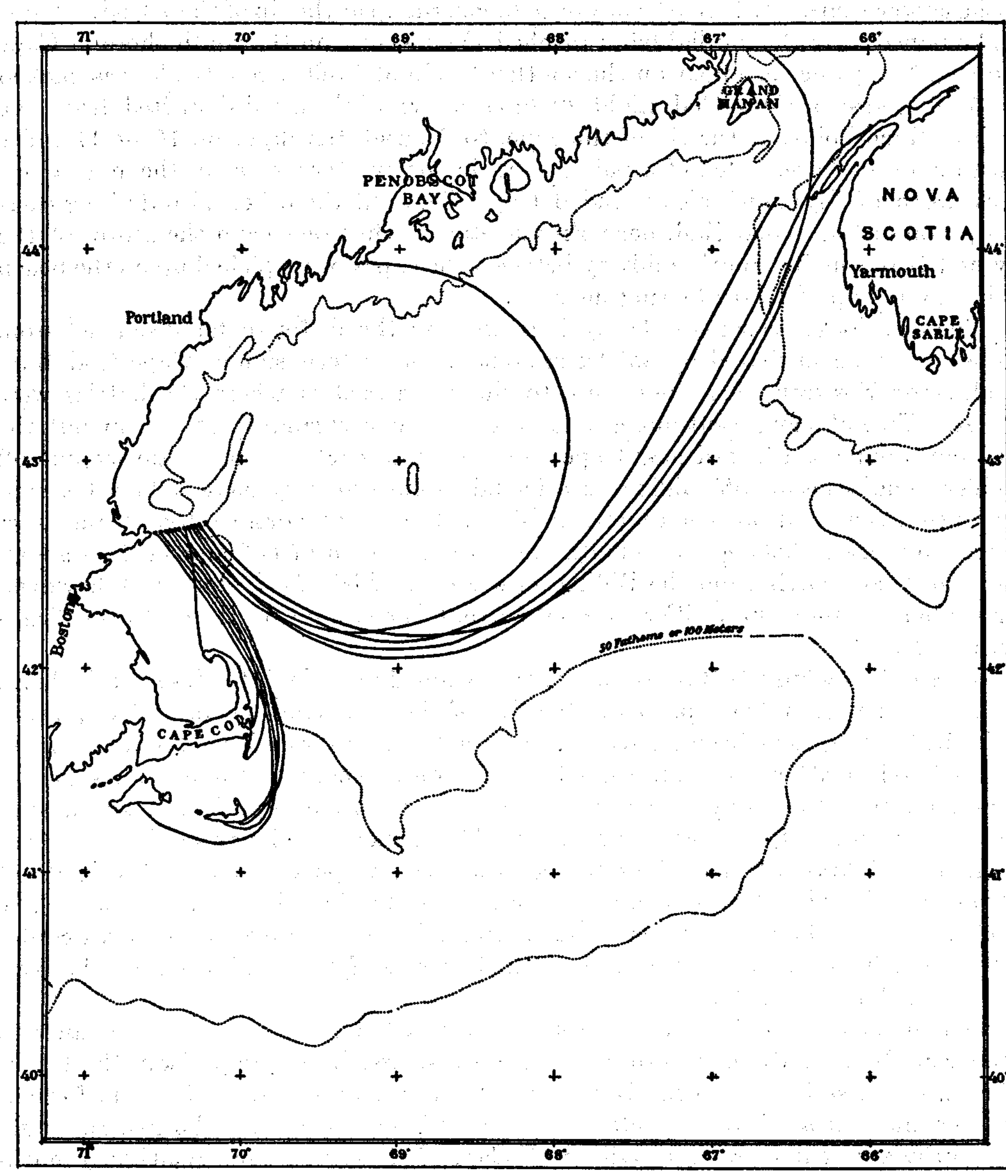

FIG. 179.—Assumed drifts of representative bottles recovered from Series L, set out off Cape Ann by H. C. Stetson, April 19, 1926. ●, place of release

between Provincetown and Race Point, one passing out of the bay and thence southward to Nantucket. Two of the bottles set out off Truro (series N) also drifted to the tip of the cape at Wood End, the entrance to Provincetown Harbor.

In weighing the significance of drifts of this sort, when bottles are set out so close to land, due consideration must be given to the stage of the tide. In this instance all the bottles that showed a drift toward the north were set out on the flood tide, so that they must have traveled up the bay at first. Consequently, the fact that they stranded where they did indicates a predominance of ebb over flood, or in other words, a drift out of Cape Cod Bay along the eastern side.

Before leaving the bottle drifts in Massachusetts Bay, I should emphasize the fact that not one of them is clockwise, but that all can be safely interpreted anticlockwise within the bay or from north to south across its mouth and so down past Cape Cod.

At first sight the evidence (by bottle drifts) of a dominant set out of Cape Cod Bay around Cape Cod, and so southward along the outer shore of the latter, might seem contradicted by the physiography of the cape; for, as Davis (1896) has shown, the so-called "Province lands," which form its tip, were built up by the transference of sand along shore from the south. In fact, the existence of the sand spit known as Wood End, which incloses Provincetown Harbor on the southwest, is sufficient evidence of beach-drifting inward toward the bay, not outward from the latter, as the bottle drifts demand. However, this apparent contradiction vanishes on closer analysis. Beach-drifting[73] is effected chiefly by the longshore component of wave action.

A glance at the chart will make it clear that winds from the only direction (between north and southeast) that can drive a sea against the tip of the cape heavy enough to move much sand necessarily produce a wave current westward around its extremity. This would be the case even if the current a few hundred yards out (tidal or not tidal) were making in the opposite direction, perhaps carrying our drift bottles with it. Neither the tidal nor the nontidal currents scour the shore line here violently enough to be of more than minor importance.[74]

Thus, beach drifting may be constantly in one direction, but the dominant set of the water as constantly the opposite only a short distance out at sea; and it seems sufficiently established that this is the case at the tip of Cape Cod.

Farther south along the cape beach-drifting acts in the same direction as the nontidal drifts, both making to the southward.

The drifts from series O (set out near the coast, about midway between Cape Ann and Cape Elizabeth, on July 18, 1926, by T. E. Graves) proved consistent with these Massachusetts Bay drifts (as, also, with the drifts from the Bay of Fundy in 1919) for the three recoveries so far reported were all from the southward—two from Cape Ann and the other from the north shore of Massachusetts Bay at Salem.

DRIFTS OF BOTTLES SET OUT OFF CAPE ELIZABETH AND OFF MOUNT DESERT

The drifts so far discussed have proved so consistent, both regionally and from year to year, that the type of circulation which they represent may safely be taken as characteristic of the southern and southwestern parts of the gulf. The drifts of bottles put out off Cape Elizabeth and Mount Desert have proven equally consistent among themselves, though interpretation has not been so easy.

---

[73] Johnson (1919 and 1925) has proposed this convenient term for the longshore transference of sand or other débris.

[74] For an illuminating discussion of the relative importance of wave and other currents in causing beach-drifting, see Johnson (1919; 1925, p. 505).

We may first consider the outer half of the Cape Elizabeth line of 1922 (line A, p. 871, fig. 180) as the easiest to understand. Sixteen of these 150 bottles were recovered, as follows: Outer coast of Nova Scotia (Scotts Bay), 1; vicinity of Cape Sable, 1; mouth of Penobscot Bay, 2; western shore of Nova Scotia and southern shore of the Bay of Fundy, 12. Thus, the net drift for the great majority of these bottles was toward the east and northeast. The fact that so many of them stranded along the same sector of the Nova Scotian coast where bottles from the Cape Ann and Cape Cod lines have been picked up (figs. 174 and 176) makes it likely that

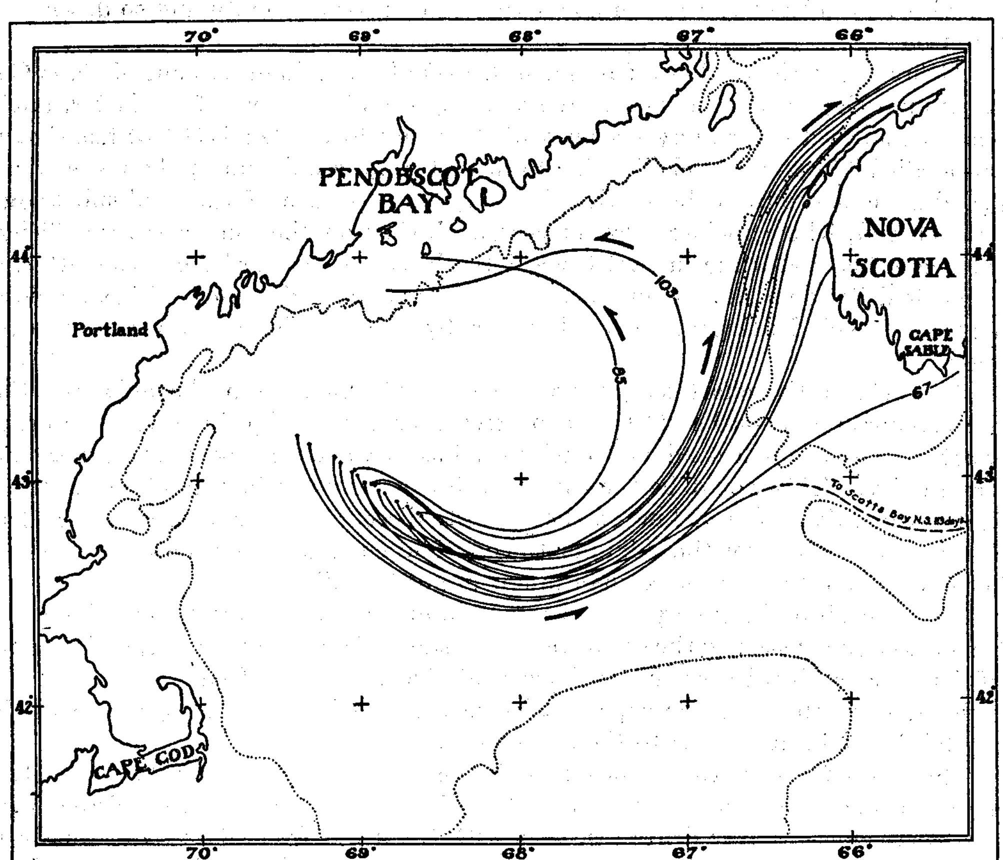

FIG. 180.—Assumed drifts of bottles recovered from the outer half of series A, set out off Cape Elizabeth, July 1, 1922. ●, place of release

they, too, veered from southeast to east in their journey across the gulf, to continue northeastward along the Nova Scotian coast in the drift shown there by current measurements (p. 861). The rapid drift of one bottle from the outer part of this line (No. 280) to the Salvages Ledges (about 25 miles east of Cape Sable), where it was picked up 67 days after release, points similarly to a rather direct track toward the east at first; for it can not have followed a very circuitous route unless it drifted faster than is at all likely. It is on these bases that the probable drifts are laid down on Figure 180.

Why the bottle last mentioned (No. 280) escaped the drift setting northward toward the Bay of Fundy is not clear. However, that it did escape, to continue eastward, proves that the surface current that sometimes flows westward past cape Sable was not active at the time. On the other hand, the fact that only two bottles of all this group were found on the outer Nova Scotian coast east of the cape, while so many turned toward the Bay of Fundy, is conclusive evidence that there was no general flow past the latter, but that its offing was comparatively a dead water at the time so far as any nontidal current is concerned.

It is not possible to reconstruct the track of the "Salvages" bottle in its rounding of the cape; it may have held farther offshore than its line, as laid down on the chart, would suggest, and then have veered inshore again. Bottle No. 165, which drifted from a point a few miles inshore of Cashes Ledge to Scotts Bay, 50-odd miles beyond Cape Sable, may have been caught up in the Nova Scotian eddy, judging from the considerable interval between release and recovery (113 days).

More interesting, in connection with the general circulation of the Gulf of Maine, are the two bottles (Nos. 210 and 284) that went from the outer section of line A to the mouth of Penobscot Bay. The direct route for these would be to the north, of course, but it is most unlikely that they followed such a course at right angles to the general easterly drift followed by the other bottles that went to Nova Scotia from this same section of the line. The fact that they were afloat about as long (85 and 103 days) as several of the bottles that reached the Bay of Fundy [75] also makes it likely that all the bottles of this group drifted southeastward and eastward at first. On this basis the most reasonable explanation for the eventual separation is that while most of the bottles approached the Bay of Fundy close enough to the Nova Scotian shore to be swept inward, reproducing the drifts of Mavor's bottles in 1919 (p. 868), others, circling on a shorter radius, hence following a more northerly route, crossed the mouth of the Bay of Fundy instead of entering it, were picked up in the current that flows out of the bay past Grand Manan, and so were carried westward again. This is made the more likely by the fact that several drift bottles put out in the Bay of Fundy in 1919 traveled by this same route to points along the Maine coast, one of them to the same destination (Penobscot Bay; p. 870). It is probable, therefore, that the two bottles that went from the vicinity of Cashes Ledge to Penobscot Bay in 1922 made a partial, anticlockwise circuit, which brought them well over toward the eastern side of the gulf en route, so that they approached their eventual destination from the east or southeast, not directly from the south.

The route of the Matinicus bottle is carried the farther eastward of the two on the chart (fig. 180), because of its longer interval; but there is no means of knowing whether this apparent difference is actually significant.

On the whole, the most instructive feature of this group is the uniformity of the drifts and the very definite and comparatively rapid movement of the water which these show along a narrow track from the center of the gulf to the Nova Scotian side of the mouth of the Bay of Fundy.

[75] No. 190 to Grand Passage, 116 days; No. 206 to Digby Neck, 90 days; No. 241 to Port Lorne, 88 days; No. 242 to the offing of Digby, 70 days; Nos. 248 and 255 to the vicinity of Point Prim, 75 and 90 days; No. 264 to Long Island, at the mouth of the Bay of Fundy, 81 days; No. 299 to Advocate Harbor, Nova Scotian shore of the Bay of Fundy, 107 days.

The inshore half of the Cape Elizabeth line of 1922 (line A, fig. 181) is more puzzling. These recoveries fall into four groups, so distinct and so far separated that the bottles must have scattered widely within a short time after they were put out. Four bottles from the outer half of the section went to the Bay of Fundy; three others were picked up along the coast of Maine between Jonesport and the western entrance to Penobscot Bay, the same sector to which several bottles drifted from the Bay of Fundy in 1919; one went southward to the Isles of Shoals, off Portsmouth; and six were found in Casco Bay or along the coast a few miles to the eastward of it. The recoveries from the inner end of the line were all from near-by localities, either in the Casco Bay region or along the southern shore of Cape Elizabeth.

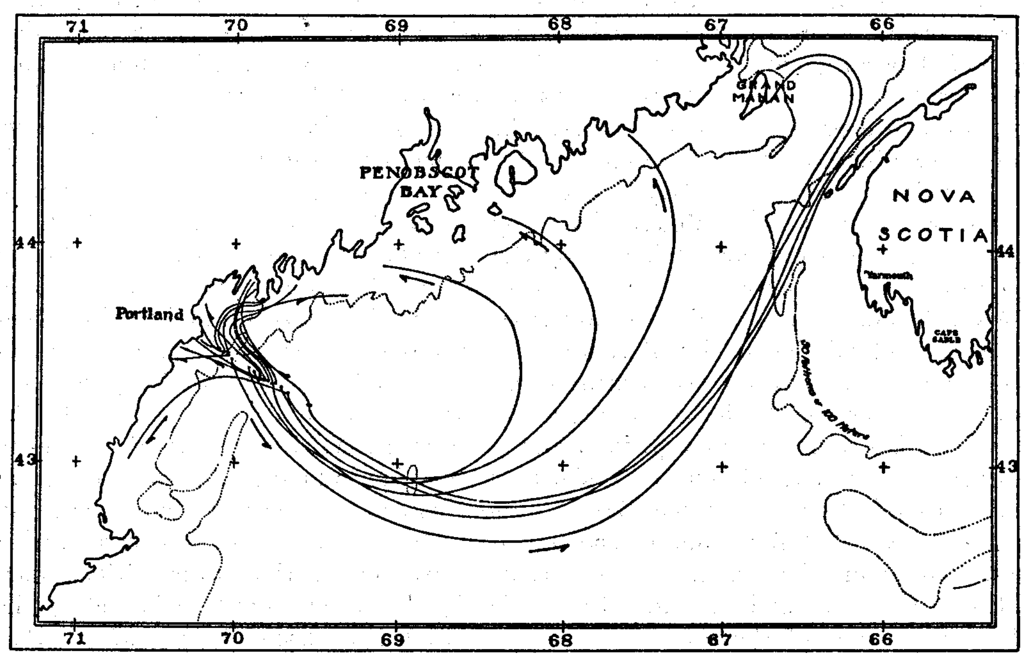

FIG. 181.—Assumed drifts of bottles recovered from the inshore half of Series A, set out off Cape Elizabeth, June 30, 1922
●, place of release

If the two halves of line A be compared (figs. 180 and 181), it is at once evident that the percentage of bottles that went to Nova Scotia was much greater (14 bottles) for the outer than for the inner half, and that all the bottles that traveled this route were set out more than 10 miles from the land. If the drifts from the inner end of line A had been the only evidence available, the natural conclusion would have been that their general set was eastward along the coast of Maine. The evidence of the other series discussed so far forbids this, however. In the first place, the Bay of Fundy series of 1919 drifted in the opposite direction (p. 870), as several bottles set off Mount Desert in 1923 did, also (p. 902). Furthermore, all the bottles from the Cape Cod, Cape Ann, and Cape Elizabeth lines that were recovered in the Bay of Fundy region were reported from so short a sector of the coast that they must have followed a very uniform track, which for the Cape Ann and Cape Cod lines veered unmistakably through southeast, east, and northeast (p. 889). The time intervals are consistent with this, also, the great majority ranging between 70 and 105 days, irrespective of which line the bottle in question was launched from. For any of the bottles from the Cape Elizabeth line to have reached the southern shore of the Bay of Fundy by the alternative route via the coast of Maine and through the Grand Manan Channel would have involved a drift from north to south across the Bay of Fundy directly contrary to the dominant set established there by Mavor's (1922) experiments with drift bottles, as well as by measurements of currents (p. 861). Such an explanation would also be contrary to the time intervals, for the two bottles that went from the offing of Cape Elizabeth to Grand Manan and to The Wolves (Nos. 43 and 88) and were not reported until 103 and 104 days after release, while two others, set afloat near by (Nos. 99 and 105), were reported from the Nova Scotian side of the Bay of Fundy in 80 to 98 days.

By this reasoning the bottles that went to Penobscot Bay from the inner end of line A, and to the coast of Maine farther to the eastward, may safely be credited with essentially the same route as those that reached this same sector of the coast from the outer end of this line, circling anticlockwise at first toward the Bay of Fundy, to return westward again. The time intervals between release and recovery (80 days for No. 65, picked up at Jonesport; 63 days for No. 98, reported near Swans Island; and 103 days for No. 87, found at Matinicus) favor this interpretation.

The general uniformity, both of localities of recovery and of time intervals, for the outer two-thirds of line A, indicates a well-developed, dominant set of the anticlockwise sort just outlined. This, however, seems hardly to have affected the surface water within 15 miles of the land at the time, judging from the regional dispersion of the returns from the inner end of line A and from the fact that the time intervals between release and recovery vary widely for these, quite independent of the distances which this group of bottles made good. Thus we find intervals ranging from 25 to 77 days for 7 bottles that were picked up in the Casco Bay region, 15 to 30 miles from the points of launching, and 5 to 72 days for 5 bottles recovered along the southern side of Cape Elizabeth after journeys of 8 to 23 miles. One was found at Monhegan Island (35 miles) in 47 days, but another, reported from Daniscove (25 miles), was not found until 75 days had passed.

Of course, little stress can be laid on the time interval for any one bottle, because there is no knowing how long it may have lain on the shore, overlooked; but our general experience suggests that if bottles are not reported comparatively soon after stranding they are either broken or buried in windrows of seaweed and never after heard from at all. Consequently, when time intervals vary widely for bottles drifting only a short distance to a coast as frequented as the Casco Bay region is, contrasting with uniformity of intervals for bottles journeying right across the gulf, it is obvious that the former did not follow as definite a set as the latter. On the whole, the regional distribution of the localities of recovery for the inner end of this Cape Elizabeth line trends eastward across Casco Bay, pointing to an irregular eddying drift in that direction as involving the mouth of the latter. Cape Elizabeth, however, seems to have bounded this eddy on the south at the time, witness the several strandings to the south of the cape (fig. 181); the fact that one bottle, set out about midway of line A was recovered at the Isles of Shoals after 100 days points to some movement of surface water southward along the coast sector between Cape Elizabeth and Cape Ann.

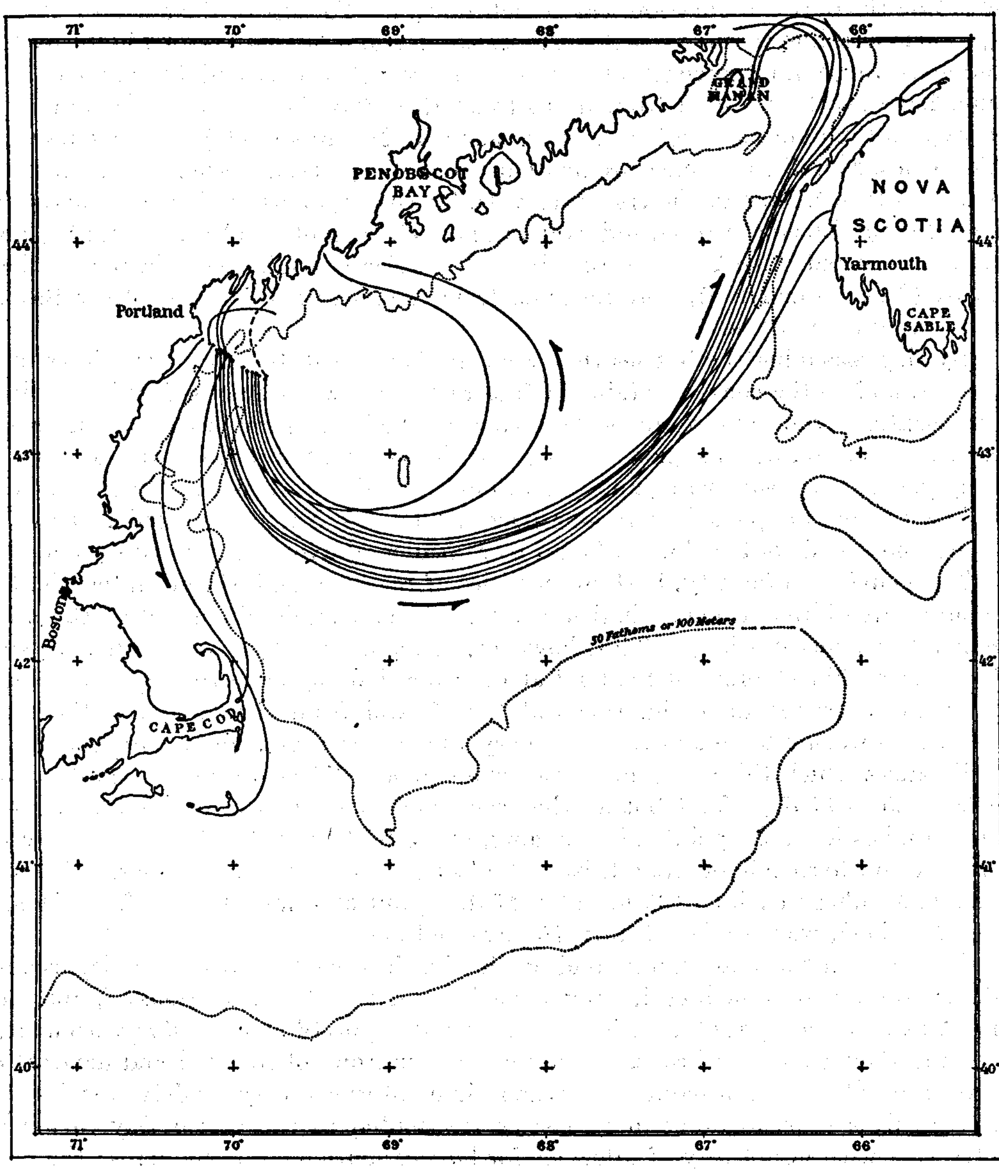

FIG. 182.—Assumed drifts of representative bottles recovered from Series E, set out off Cape Elizabeth, August 7, 1923. ●, place of release

The drift of a second line of bottles set adrift off Cape Elizabeth a year later (in August, 1923; series E, p. 874) showed much the same grouping as that just described for the corresponding line of 1922 (series A). Two recovered from the outer part of the line were from the west coast of Nova Scotia (fig. 182); three were from the entrance