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AT HARVARD COLLEGE.

Vol. LIX. No. 4.

EXPLORATION OF THE COAST WATER BETWEEN NOVA SCOTIA AND CHESAPEAKE BAY, JULY AND AUGUST, 1913, BY THE U. S. FISHERIES SCHOONER GRAMPUS. OCEANOGRAPHY AND PLANKTON.

By Henry B. Bigelow.

With Two Plates.

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Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, by the U. S. Fish Commission Steamer "Albatross," from October, 1904, to March, 1905, Lieutenant Commander L. M. Garrett, U. S. N., Commanding, published or in preparation:—

A. AGASSIZ. V.[5] General Report on the Expedition.
A. AGASSIZ. I.[1] Three Letters to Geo. M. Bowers. U. S. Fish Com.
A. AGASSIZ and H. L. CLARK. The Echini.
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[1] Bull. M. C. Z., Vol. XLVI., No. 4, April, 1905, 22 pp.
[2] Bull. M. C. Z., Vol. XLVI., No. 6, July, 1905, 4 pp., 1 pl.
[3] Bull. M. C. Z., Vol. XLVI., No. 9, September, 1905, 5 pp., 1 pl.
[4] Bull. M. C. Z., Vol. XLVI., No. 13, January, 1906, 22 pp., 3 pls.
[5] Mem. M. C. Z., Vol. XXXIII., January, 1906, 90 pp., 96 pls.
[6] Bull. M. C. Z., Vol. L., No. 3, August, 1906, 14 pp., 10 pls.
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[8] Mem. M. C. Z., Vol. XXXV., No. 1, February, 1907, 20 pp., 15 pls.
[9] Bull. M. C. Z., Vol. L., No. 6, February, 1907, 48 pp., 18 pls.
[10] Mem. M. C. Z., Vol. XXXV, No. 2, August, 1907, 56 pp., 9 pls.
[11] Bull. M. C. Z., Vol. LI., No. 6, November, 1907, 22 pp., 1 pl.
[12] Bull. M. C. Z., Vol. LII., No. 1, June, 1908, 14 pp., 1 pl.
[13] Bull. M. C. Z., Vol. LII., No. 2, July, 1908, 8 pp., 5 pls.
[14] Bull. M. C. Z., Vol. XLIII., No. 6, October, 1908, 285 pp., 22 pls.
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[16] Mem. M. C. Z., Vol. XXXVII., February, 1909, 243 pp., 48 pls.
[17] Mem. M. C. Z., Vol. XXXVIII., No. 1, June, 1909, 172 pp., 5 pls., 3 maps.
[18] Bull. M. C. Z., Vol. LII., No. 9, June, 1909, 26 pp., 8 pls.
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[20] Bull. M. C. Z., Vol. LII., No. 13, September, 1909, 48 pp., 4 pls.
[21] Mem. M. C. Z., Vol. XLI., August, September, 1910, 323 pp., 56 pls.
[22] Bull. M. C. Z., Vol. LIV., No. 7, August, 1911, 38 pp.
[23] Mem M. C. Z., Vol. XXXVIII., No. 2, December, 1911, 232 pp., 32 pls
[24] Bull. M. C. Z., Vol. LIV., No. 10, February, 1912, 16 pp., 2 pls.
[25] Mem. M. C. Z., Vol. XXXV., No. 3, April, 1912, 98 pp., 8 pls.
[26] Bull. M. C. Z., Vol. LIV, No. 12, April, 1912. 38 pp., 2 pls.
[27] Mem. M. C. Z., Vol. XXXV., No. 4, July, 1912, 124 pp., 12 pls.
[28] Bull. M. C. Z., Vol. LVIII., No. 8, August, 1914, 14 pp.
[29] Mem. M. C. Z., Vol. XLII., June, 1915, 397 pp., 109 pls.

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No. 4.— *Exploration of the Coast Water between Nova Scotia and Chesapeake Bay, July and August, 1913, by the U. S. Fisheries Schooner Grampus. Oceanography and Plankton.*

By Henry B. Bigelow

CONTENTS.

ITINERARY.

Oceanographic and plankton studies were carried on by the Grampus during the summer of 1913 from Nova Scotia to Chesapeake Bay. The success of the cruise was largely due to the skill with which Mr. W. W. Welsh, of the Bureau of Fisheries, handled the oceanographic apparatus. It is a pleasure to acknowledge the assistance of Dr. C. O. Esterly for identifying the copepods; Dr. H. J. Hansen the schizopods; Dr. C. McLean Fraser the hydroids; Mr. W. F. Clapp the heteropods, pteropods, and Salpae, and to Capt. John McFarland of the schooner Victor for taking tows and water-samples.

We sailed southward from Gloucester on July 7; occupied the first station off Cape Cod, and then ran across the northwest part of Georges Bank to Nantucket light-ship, to commence the first line to the Gulf Stream. Some thirty miles southward from the light-ship, floating patches of Gulf weed, and the brilliant blue color of the water showed that we were approaching the Stream; but the sea and wind were rising so rapidly meanwhile, that we made the station at the outer edge of the shelf. And even as it was, the nets were badly torn, though water-bottles and thermometers were handled successfully. The wind continued to rise during the afternoon and evening, and by the time we had sailed northward again as far as the 40 fathom curve, there was a very heavy sea running. Nevertheless by using a hemp rope, instead of the wire, for the large plankton net, the work (Station 10062) was carried out without mishap.

From Station 10062 we turned off shore again, occupying the second Gulf Stream station 80 miles south of Montauk Point, at the 500 fathom curve.

The next run was to New York; and it was at one of the Stations on this line (10065) that the extensive beds of sea scallops (*Pecten magellanicus*) which promise great commercial value, were discovered; and I may forestall the narrative by stating that scallops were found in considerable numbers, between the 25 and 50 fathom curves, as far south as the latitude of Cape Charles (Stations 10070, 10072, 10073, 10074, 10077).

Remaining in New York long enough to restock the larder and replenish the supply of gasoline, on the 17th we ran down the coast as far as Barnegat (Station 10069), thence eastward across the shelf to the Gulf Stream (Station 10071). From this point we worked southerly, in a zigzag course, past the mouth of Delaware Bay, to Cape Charles, then off shore once more, for the last complete section of the shelf and so to Norfolk, arriving there on July 24th. The courses and stations are shown on the chart (Plate **1**).

Current measurements were made at three stations between Cape Cod and Norfolk; off Long Island, off Cape May (Station 10072), and off Chincoteague (Station 10074); observations being taken hourly for six hours at each station, both at the surface and on the bottom; the data is given below (p. 225). At Stations 10065 and 10074, the work was done from the dory, but at Station 10072 the Grampus herself was anchored for the purpose.

Refitting in Norfolk until July 29th, the voyage was resumed northward, following the coast, and locating stations to fill the gaps left on the way south. On August 3 the GRAMPUS reached Woods Hole, on the 4th, sailed through Vineyard Sound; and arrived in Gloucester on the 5th after a most successful voyage.

On August 9th we put to sea again for the Gulf of Maine, sailing eastward from Cape Ann to the sink at the mouth of Massachusetts Bay (Station 10087), thence to the centre of the Gulf (Station 10090), crossing the western basin where the deepest Gulf Station (10088, 150 fathoms) was located. Jeffrey's Bank was the next objective (Station 10091), where a strong northwest wind was encountered, though work under shortened sail was possible. We then ran toward Cape Sable, making the same stations as the year before, two in the basin, one on the coast slope, and one on German Bank. And, as in 1912, the sudden cooling of the surface as we approached the Bank was a striking phenomenon. In 1912 the GRAMPUS was wrapped in a blanket of fog day after day in this part of the Gulf, feeling her way about by soundings. But in 1913 the most delightfully clear, calm, weather imaginable, with light northwest breezes, was enjoyed; and so transparent was the air that the whole coast, from Cape Sable to Yarmouth, was plainly visible, though we were nowhere within 20 miles of the land.

We took surface temperature and water-samples close to Lurcher Shoal light-ship on the 12th, and then stood across the mouth of the Bay of Fundy to the Maine coast (Station 10098), making a Station (10097) in the north end of the basin *en route*; and thence followed the outer islands southward to Mt. Desert Rock (Station 10100). The weather now grew foggy, and the Grampus crossed the mouth of Penobscot Bay in the fog, passing close to Matinicus Island (Station 10101). Three stations were made between Monhegan and Cape Ann, two in the trough west of Jeffrey's Ledge, and on August 15th the Grampus returned to Gloucester.

During the cruise oceanographical observations were taken at 50 stations; and, thanks to an ample supply of water-bottles, samples were taken at three to five levels at every station. One hundred and sixty-five tows were made with the various plankton nets; the quantitative net was used at fifteen stations in the Gulf of Maine; the otter trawl employed at ten stations. The distance sailed was about 2100 miles.

The Grampus lay in Gloucester until the 20th, to refit; and on the 20th, sailed southward once more, in charge of Mr. Welsh, for a detailed survey of the scallop beds, a report of which has already been published by the U. S. Bureau of Fisheries (1914).

EQUIPMENT AND METHODS.

The general equipment of the Grampus has been described (1914a, p. 35). In 1913 a second Ekman current-meter, several more Negretti and Zambra reversing deep-sea thermometers, and two more stopcock water-bottles, were added; the latter so arranged that any number could be used simultaneously, in series, on the wire rope, and tripped by a messenger. The outfit was further enlarged by the addition of a Helgoland "shear board" tow-net (Steuer, 1910, p. 131), which proved to be most effective, a 1-meter tow-net of the Michael Sars pattern (Murray and Hjort, 1912), and a Lucas sounding machine. On the other hand the Sigsbee water-bottle, which was unreliable, was discarded and an otter trawl was substituted for the beam-trawl.

The salinities listed below were all obtained by titration by the ordinary method, and are probably correct to $\pm .02$ of salinity. The subsurface temperatures are reliable to $\pm .3°F$; the surface temperatures to $\pm .5°F$ (1914a, p. 40). All temperatures are Fahrenheit.

OCEANOGRAPHY.

1. Temperature, Cape Cod to Chesapeake Bay.

Surface temperature. Surface temperature was taken hourly, day and night, during the cruise (Fig. 1, 2).

Off Cape Cod (Station 10057) the surface temperature, early in July, was 62° to 63°; and similar readings prevailed on the southerly run until the southwest part of George's Bank (Station 10059) was reached where a sudden chilling to 55° and 56° was noted;

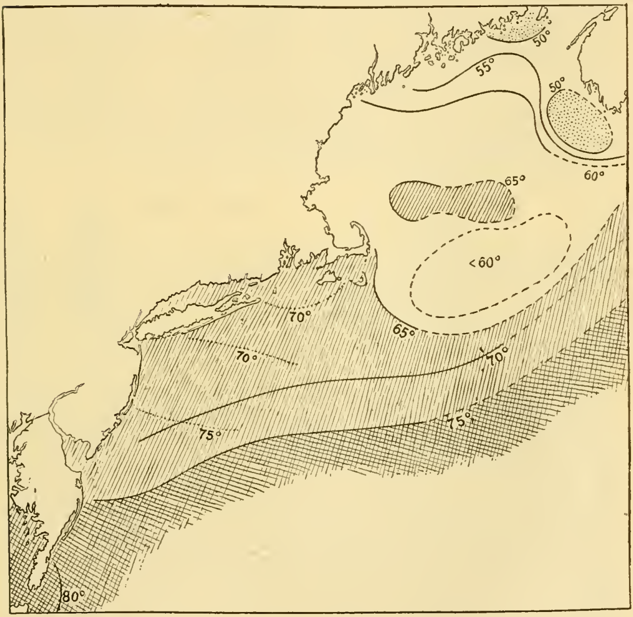

Fig. 1.— Surface temperature for the waters south of Cape Cod in July, and for the Gulf of Maine in August, constructed from the hourly readings. Temperatures below 50°, dotted: 65° to 75°, single hatched; over 75°, cross hatched; dotted curves, July 30–Aug. 1, 75°, 70°.

Low temperature (55° to 56°), characterized the surface waters very generally as Nantucket Shoals were crossed, though with occasional readings of 60° or 61°, irregularities associated with the violent tidal currents of that region. But when the deeper water to the south was reached the temperature rose to 65° and higher. The coldest surface water west or southwest of Nantucket was just off New York (62°–63°) the warmest off the mouth of Chesapeake Bay (79°–80°). And in a general way we found a rise of temperature over the continental shelf from north to south (Fig. 1). Thus it was 64°–67° between Nantucket Shoals and the edge of the continental shelf, rising to 69° and 70° abreast of Long Island, 70 miles off shore. Near New York, however, it was much colder, as pointed out above; though it rose again to 66° and 67° off Barnegat. Off shore on the line from Barnegat to the Gulf Stream, the surface temperature rose to 74° at Station 10071. Off Delaware Bay it was 75°; 76° close in shore off Cape Charles, and 78° off the mouth of the Chesapeake. In general, on the several lines across the continental shelf, the surface water was slightly warmest at the off shore station, *i. e.*, nearest the Gulf Stream, as shown in the following table:—

Line A.	Station	10063	67°	Line C.	Station	10069	69°
		10062	67°			10070	74°
		10061	68°			10071	76°
Line B.		10067	63°	Line D.		10078	78°
		10066	69°			10077	77°
		10065	69°			10076	76°
		10064	70°				

but this was reversed off Chesapeake Bay (Line D), where the off shore station was 76°, the in shore one 78°. Short though the stay in the Chesapeake was, it was long enough for a decided warming of the surface water to take place. On July 29, the surface temperature of the Bay had risen 2° to 80°, and as we sailed northward, a considerably greater discrepancy between our two sets of readings was noted. Thus when the northerly line approached our previous course, south of Cape Henlopen, the temperature had risen from 75° to 78°: off Barnegat from 66° to 75°; and off Fire Island light-ship, where the lines cross, the surface had warmed 4°, (69° to 73°) during the two weeks interval. Since the salinity showed that no shoreward movement of the surface waters of the Gulf Stream had taken place, this rise of surface temperature was no doubt the result of solar warming.

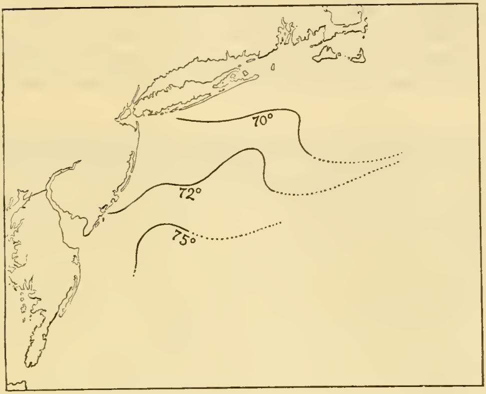

Fig. 2.— Surface temperature south of Cape Cod, Aug. 20–Sept. 1.

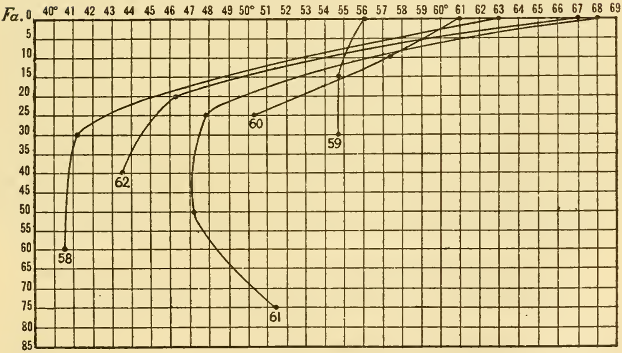

Fig. 3.— Temperature sections in the southern part of the Gulf of Maine (Station 10058); on George's Bank (Station 10059), and on the continental shelf south of Nantucket (Station 10060, 10061, 10062).

And it is probable that the surface was at or near its warmest by the end of July.

The surface temperature off Long Island on August 1st (Station 10083) was 68°; 69° off Block Island; and 72° thence to the entrance of Vineyard Sound, though at the westerly end of the Sound it fell to

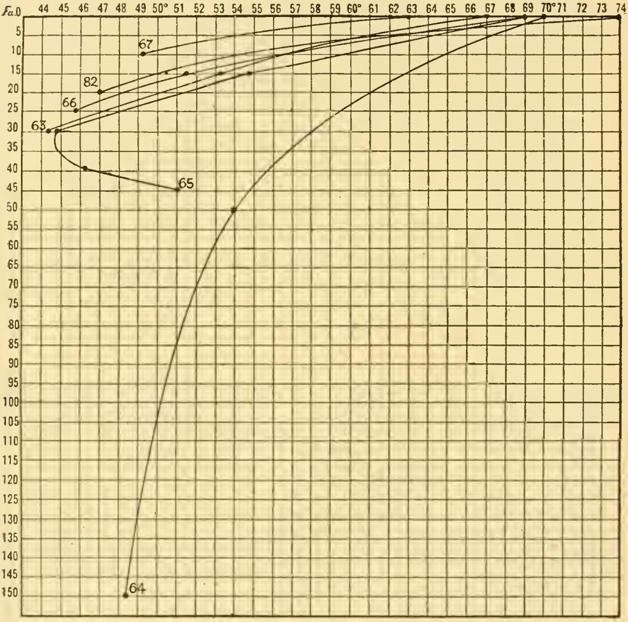

FIG. 4.— Temperature sections on the continental shelf off New York and Long Island (Stations 10063, 10065, 10066, 10067, 10082) and at the edge of the Gulf Stream, Lat. 39° 55′ (Station 10064).

68°, no doubt influenced by the violent tide. Two days later the surface water was 72° from Woods Hole to the east end of the Sound. But it was much colder (61°) off Monomoy; and only 50° on Pollock Rip, this last being evidence, of course, of thorough vertical mixing by the tidal currents. When this dangerous channel was left, the surface temperature rose to 63°, the normal figure for the southern half of the Gulf of Maine at this time of year. Late in August, when the GRAMPUS came southward again (p. 154) the temperature was practically unchanged off Block Island and over the shelf south of

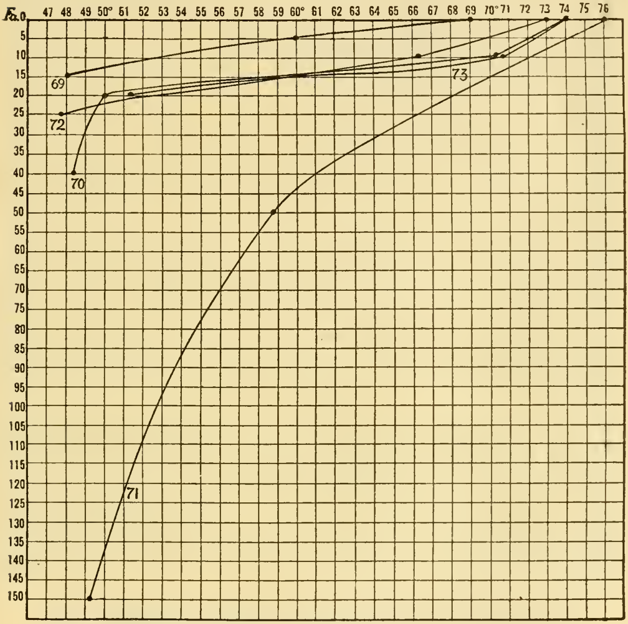

FIG. 5.— Temperature sections on the continental shelf south of New York (Stations 10069, 10070, 10072, 10073) and at the edge of the Gulf Stream in Lat. 38° 56′ (Station 10071).

Marthas Vineyard; but near shore south of New York, the water had cooled to 71°–72°; immediately off Cape May to 74° (Fig. 2). On the other hand, the surface south of Nantucket Shoals was several degrees warmer than it was in July, the temperature having risen from

61° to about 67.5° at Nantucket light-ship; and the curves for 70° and 72° reveal a tongue of warm water extending from the outer edge of the shelf south of Long Island northeastward toward Nantucket. Probably it was Gulf Stream water driven northward over

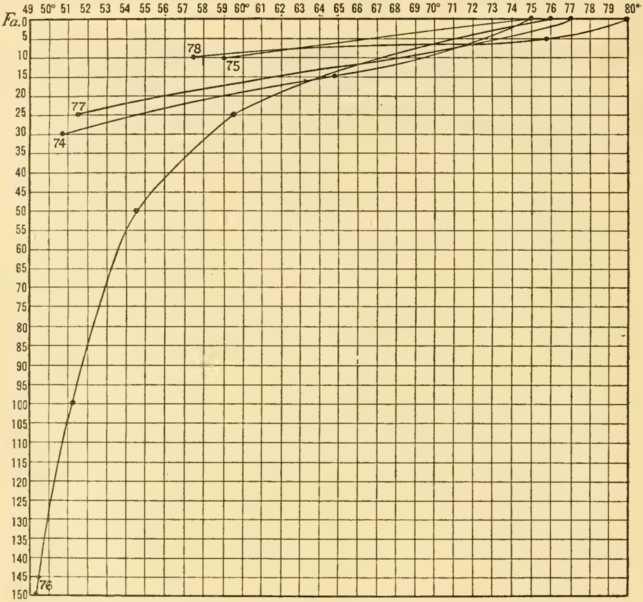

Fig. 6.— Temperature sections on the continental shelf south of Delaware Bay (Stations 10074, 10075, 10077), at the mouth of Chesapeake Bay (Station 10078) and at the edge of the Gulf Stream opposite Chesapeake Bay (Station 10076).

the shelf by the southerly gale of August 23; but no salinities were taken. For a list of the surface temperatures taken by Mr. Welsh, see p. 350.

Temperature sections (Table, p. 344). In general there was a rapid fall in temperature from the surface downward, all over the continental shelf, from Cape Cod to Chesapeake Bay; and the sections show that depth for depth the temperature was lowest in the northwest corner of the broad bight formed by the coast line, off New York; warmest, as might be expected, along the edge of the continental slope, next the Gulf Stream. Over Nantucket Shoals as a whole, there was probably very little difference between bottom and surface water, the surface, in July, often being as cold as 55°; and this rather cold water apparently showed its effect as far westerly as Station 10062 (Fig. 3), which was 1–3° colder at all depths down to 25 fathoms than the next station to the westward (Station 10063). Over the outer part of the continental shelf south of Long Island, the temperature was comparatively uniform, station for station, down to 30 fathoms (Fig. 4) cooling rapidly from the surface downward. But the curves for Stations 10061 and 10065 reveal a warm layer of water on the bottom. The water was very much colder close to the shore near New York than it was further off shore (p. 156), and the same was true along the New Jersey coast, for though by the time we came north, the surface had warmed to about 75°, a rise of about 7°, the bottom water in ten fathoms was still only about 52.6°. Off Barnegat the temperatures increase regularly at all depths from the coast eastward (Fig. 5). The ten fathom temperatures for these stations are successively 52°, 58.5°, 70°, 71°; while the fact that at twenty fathoms there was a difference of 17° between Stations 70 and 71 (50° and 67°) only fifteen miles apart, and that the latter, lying

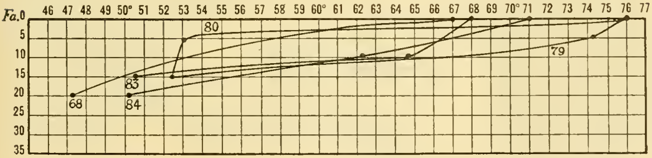

Fig. 7.— Temperature sections close to the land, south of New York (Stations 10068, 10079, 10080) and off Long Island (Stations 10083, 10084).

over the 500 fathom curve, is much warmer than any of the stations on the continental shelf, shows how sudden the temperature transition between coast and ocean water was. Our only station abreast of the mouth of Delaware Bay (Station 10073, Fig. 5) was considerably warmer above twenty fathoms than the station next north of it (10072); and several degrees warmer, at all depths, except for the surface layer of five fathoms or so, than the water south of it (Station

10079). And as the high surface temperature of the latter was almost certainly due to the seasonal warming which had taken place during the interval between our two visits, it is safe to say that at Station 10073 a mass of water warmer than the water either north or south of it was crossed. South of Delaware Bay the water was also found coldest next the coast (the warm surface at Station 10078 was the result of the unusually hot weather of the preceding three or four days). And the curves show, further, that the two stations abreast of Chesapeake Bay (10078 and 10077) were from 1.5° to 3.5° colder, depth for depth, at the lower levels than the two stations immediately north of them, a fact of interest in connection with the salinity of the region.

Fig. 8.— Chart of bottom temperature on the continental shelf for July; and in the Gulf of Maine for August. Temperature below 41°, cross hatched; 41°–45°, single hatched. The dotted line, ... , is the 100 fathom curve.

Station 10071 was considerably the warmest at all depths above 150 fathoms of the three stations outside the continental shelf (Figs. 4, 5, 6) and presented a fairly typical Atlantic curve; the temperature falling rapidly at first from 76° at the surface to 58.8° at fifty fathoms; then more and more slowly until at the lowest level, 250 fathoms, a reading of 43.6 was obtained. Station 10064 was some 6° colder at the surface, the difference gradually decreasing downward; but even at

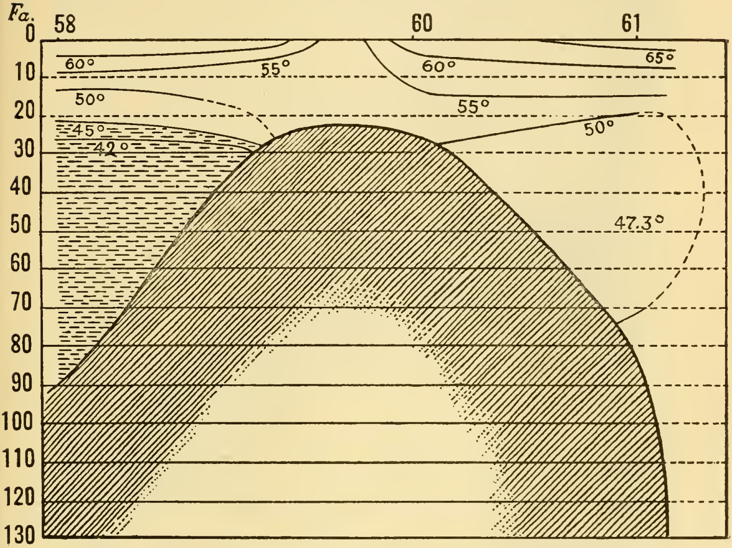

FIG. 9.— Temperature profile from the southern end of the basin of the Gulf of Maine (Station 10058) across Nantucket Shoals to the continental slope south of Nantucket (Station 10061).

250 fathoms it was 2° colder (41.6°). Station 10076 was the most southerly of the three, and might, therefore, have been expected to be the warmest, as it lay at about the same relative position on the slope. But as a matter of fact the temperature (49.3°) at 150 fathoms (the deepest reading) was about the same as that of Station 10071: and above this level, Station 10076 was considerably the colder of the two.

Bottom temperature. The chart of bottom temperature (Fig. 8) illustrates the localization of cold bottom water on the mid-zone of the continental shelf south of Long Island and Marthas Vineyard in July, the southern boundary of which must have been somewhere between the latitude of New York and the line off Barnegat. Shoreward as well as seaward, the bottom water was warmer than 45°. That this should have been the case nearer land was to be expected, because of the steady shoaling of the water. But the fact that the bottom water was warmer (50°–51°) between 50 and 125 fathoms

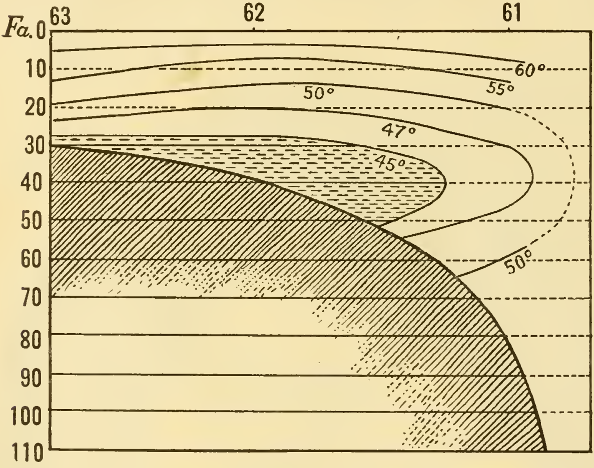

Fig. 10.— Temperature profile across the outer part of the continental slope southwest of Nantucket (Stations 10063, 10062, 10061).

than at 35–50 fathoms, would have been a surprise had not a similar phenomenon been encountered by Libbey (1891) south of Marthas Vineyard in 1889 (p. 241). As pointed out (p. 165) this cold bottom water was not continuous with the cold water in the Gulf of Maine, being interrupted on Nantucket shoals, where the bottom temperature is raised, and the surface correspondingly chilled, by vertical tidal mixing. But no doubt, in winter, the cold water is continuous across the shoals. On the continental slope the temperature was 45° at about 200 fathoms.

The bottom temperature was higher south than north of Delaware Bay, and instead of being coldest over the mid-zone of the continental shelf, decreased from the shore seaward, with increasing depth.

Temperature profiles. The lines were planned to afford three complete profiles across the continental shelf, one abreast of Montauk, one off Barnegat, and one opposite the mouth of Chesapeake Bay respectively, besides several incomplete ones in intermediate positions, and a complete profile from the deep basin of the Gulf of Maine to the Gulf Stream via Georges and Nantucket Shoals. The latter (Fig. 9) shows that there was a marked temperature contrast between the waters on either side of the Shoals which form the southern boundary of the basin of the Gulf. On the north, the deep basin, below twenty-five fathoms, was filled with water of 42° or colder, with a rapid rise in the upper twenty fathoms to the surface temperature of 62°–63°. On the southern side, the coldest water was about 47°, at sixty fathoms, while the surface temperature was some 6° warmer at the off shore end of the profile (Station 10061) than in the Gulf (68°). Over the Shoals in the centre of the profile there are local regions of complete vertical mixing by the tidal currents, as for instance on the southwest side of George's Bank (Station 10059) where the temperature was practically uniform from surface to bottom (54.7°). On outer edge of the continental shelf the coldest water (47.3°) was not on the bottom, but at fifty fathoms, with warmer water (51.5°) below it. And as Gulf Stream water was to be expected only a few miles further off shore, it is fair to assume that this water colder than 50° indented the warmer ocean water like a tongue, as represented by the curve for 50°. The fact that there was no water on this line colder than 47° shows that the cold bottom water (45°) west of Nantucket Shoals (Fig. 10) was not continuous with the still colder water of the Gulf of Maine.

The next profile (Fig. 11), running from the neighborhood of New York to the 500 fathom curve in Lat. 39° 55′, shows the cold water on the shelf at 20–40 fathoms, indenting into the warmer water over the slope. The temperature was much higher, depth for depth, outside the edge of the shelf, than over the latter, as is shown by the sharp seaward dip of all the curves. And at the shore end of the profile the same was the case, the curves rising as the land is approached, with equal temperatures about five fathoms nearer the surface at Station 10067 than at Station 10066. In the central part of the profile (Station 10065 to 10066) there was little horizontal change in temperature from east to west.

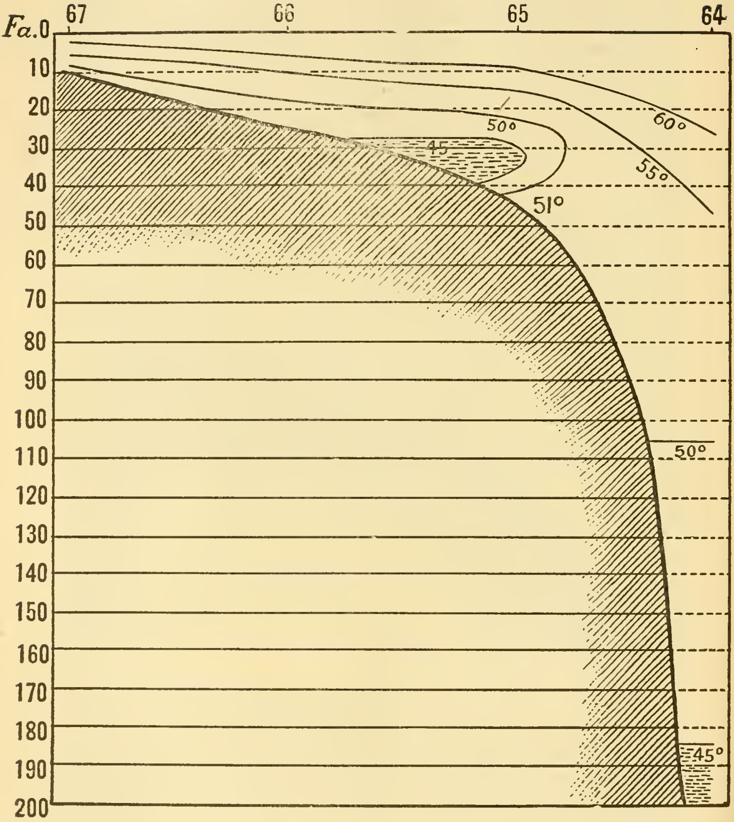

Fig. 11.— Temperature profile across the continental shelf from New York to the edge of the Gulf Stream in Lat. 39° 55′ (Stations 10067, 10066, 10065, 10064).

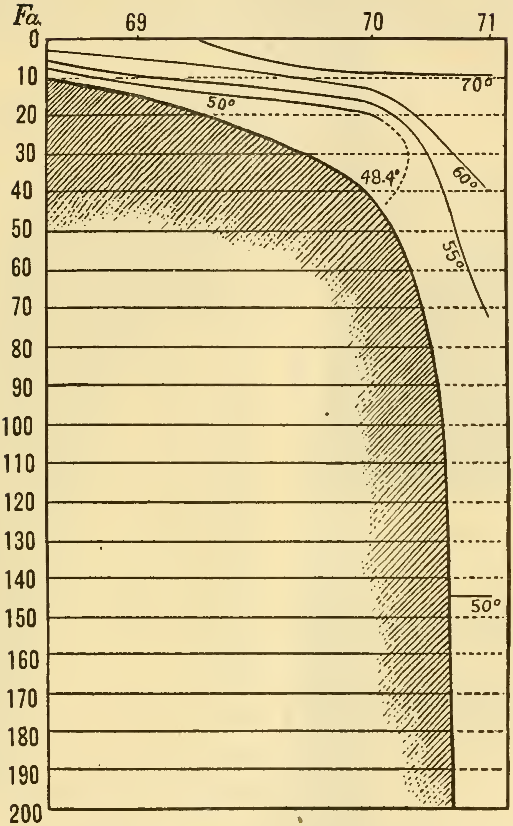

FIG. 12.— Temperature profile across the continental shelf abreast of Barnegat (Station 10069), to the Gulf Stream in Lat. 38° 56′. The immediate shore end of the profile is reconstructed from the temperature section a few miles further north (Station 10068).

In the fourth profile, off Barnegat (Fig. 12), the water on the shelf was warmer, its minimum being 48° on the bottom at 40–50 fathoms. But on the slope it was only below 150 fathoms that the water was as

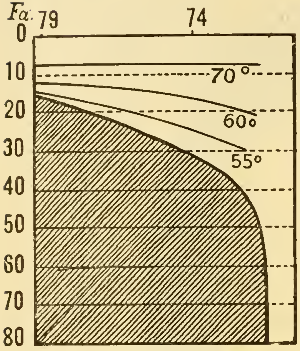

Fig. 13.

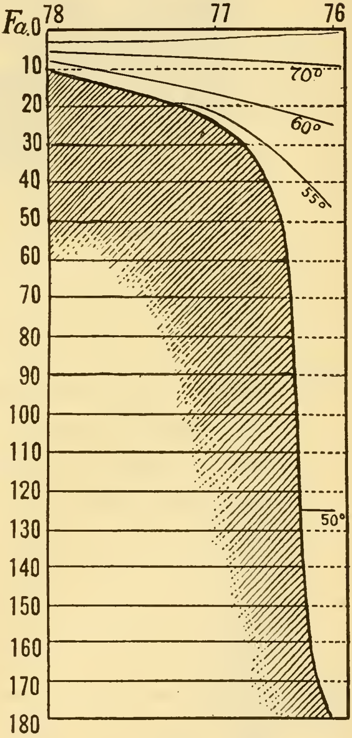

Fig. 14.

FIG. 13.— Temperature profile across the continental shelf 45 miles south of Delaware Bay (Stations 10079 and 10074).

FIG. 14.— Temperature profile across the continental shelf to the edge of the Gulf Stream abreast of Chesapeake Bay (Stations 10078, 10077, 10076).

cold as this. And probably there was a belt of bottom water of 50°–55° at about 100 fathoms, to judge from the other profiles. But there is no bottom reading at this level. In the upper part of the profile

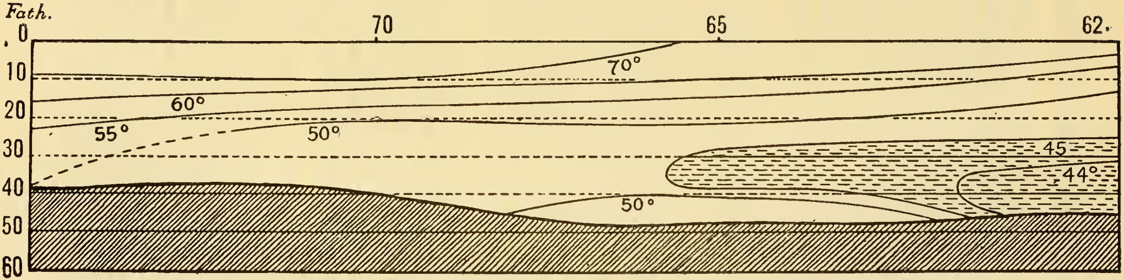

Fig. 15.— Temperature profile along the 40–50 fathom contour from abreast of Delaware Bay to a point south of Nantucket (Stations 10070, 10065, 10062).

the temperature rises, depth for depth, from the land seaward, as in the preceding one. Two partial profiles, one just north, the other just south of Delaware Bay, connect the Chesapeake Bay profile with the one just described. The stations composing the first of these (Stations 10080 and 10072) were, unfortunately, occupied at an interval of two weeks; but other observations have shown that it is only the intermediate surface layer which had warmed up appreciably in the interval. At the outer of the two stations the bottom temperature was 47.8° at twenty-five fathoms; and corresponding to the steepness of the shelf, this cool water was found nearer shore, though at about the same depth, than further north.

Just south of Delaware Bay (Fig. 13) there was no water colder than 50° on the shelf; the lowest temperature being 50.8° at thirty fathoms (Station 10074). But the curves show the progressive warming, depth for depth, from land to sea, which characterize the preceding profiles; the reading (52.5°) being the same at fifteen fathoms at the shore end as at twenty-seven fathoms at the offshore end of the profile.

Off Chesapeake Bay (Fig. 14) the slope was bathed with water of 50°–52° from twenty-five fathoms down to 130 fathoms. There the surface water cooled from the shore seaward instead of warming as it does further north (p. 165). But though the temperature above five fathoms was highest at the shoreward end of the profile, the ten fathom (bottom) temperature was lower (57.6°) there than further off shore.

The general rise in temperature on the shelf from north to south is illustrated by a profile parallel with the coast at about the forty fathom curve (Fig. 15). Below twenty-five fathoms the curves are distorted by the intrusion of warm water (51°) on the bottom near Station 10065, resulting in the extension of cold water southward over warm. The lowest temperature is at the northerly end at forty-five fathoms.

Temperature in the Gulf of Maine.

Surface temperature. The distribution of surface temperature in the Gulf of Maine was the same in general as in 1912, the northeastern part being coldest, the southwestern warmest. The surface water (Fig. 1) abreast of Massachusetts Bay, along shore from Cape Cod to Cape Elizabeth, and eastward nearly to German Bank was 60° or warmer, usually 60°–62°; and although the surface was considerably warmer (64°–66°) northeast of Cape Cod and in the neighborhood of Cashes Bank, this was the result of solar warming, not of Gulf Stream water, as proved by the low salinity (p. 200). The northern, western, and eastern limits of this warm region can be defined with some accuracy from the hourly temperatures; but how far it extended to the south is doubtful. It is not likely, however, that it was directly continuous with the warm surface water south of Georges Bank, for the surface temperature on the latter is lowered by the violent tidal currents (p. 155).

At the eastern side of the Gulf a sudden transition from the high temperature of the basin to cold surface water on German Bank was noted, the temperature dropping from 60° to 48°, the coldest surface reading of the cruise. Off the Nova Scotia coast the surface temperature was 52°–53°, rising to 54°–56° abreast of the mouth of the Bay of Fundy. Off Mt. Desert Rock Station 10100 showed that the zone

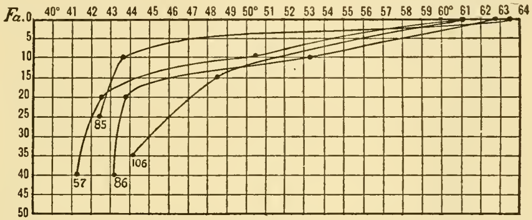

FIG. 16.— Temperature sections off Cape Cod in July (Station 10057) and in August (Stations 10085, 10086) and in Massachusetts Bay in August (Station 10106).

of 54°–56° water was of considerable breadth. Near the northeast coast of Maine the surface temperature was 50°–52°; rising to 54°–56° off Mt. Desert Island.

Temperature sections. The temperature curves off Cape Cod (Station 10057, Fig. 16; Station 10058, Fig. 3) and off Cape Ann (Station 10087, Fig. 17); near Platt's Bank (Station 10089, Fig. 18) and near Cashes Ledge (Station 10090, Fig. 18) show a very rapid cooling from the surface down to about thirty fathoms, followed by a layer, reaching down to the bottom, in which the temperature was almost uniform. In 1912, the temperature of the uniform bottom water was 40.3° at all the stations off Cape Ann and Massachusetts Bay; in 1913 it was 43.9° near Cashes Ledge, 41.3° near Platt's Bank; 40.3° in the southern part of the trough between Jeffrey's Ledge and the mainland. In the northern part of the trough (Station 10104), it was 39.8° at eighty fathoms.

In the summer of 1912, the water of the Gulf was invariably coldest at the bottom; but in 1913 the western basin and two stations in the eastern basin (Stations 10092, 10093, Fig. 17) were coldest in

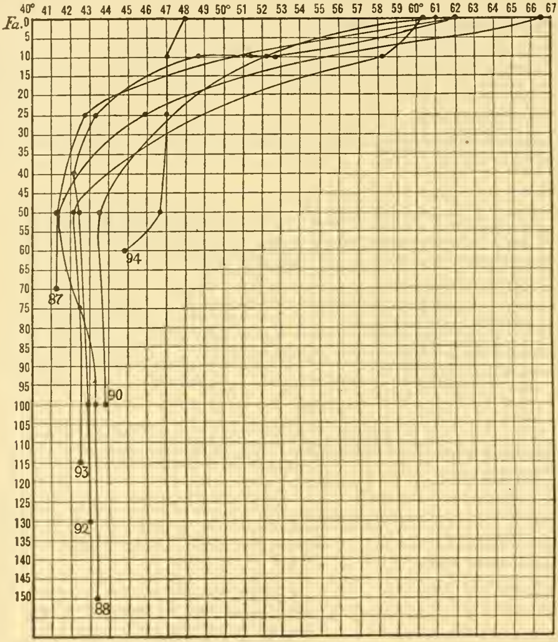

FIG. 17.— Temperature sections in the Gulf of Maine from Massachusetts Bay to German Bank (Stations 10087, 10088, 10090, 10092, 10093, 10094).

the intermediate depths; the minimum in the former being 41.3° at fifty fathoms, *i. e.*, precisely the same as the uniform bottom water nearer shore, rising to 43.3° at 100 fathoms, below which level it was uniform down to the bottom (150 fathoms). On the western side of the eastern basin (Station 10092) the upper layers were colder, but the minimum was warmer (42.2° at forty fathoms), with about 43° at 100 fathoms, below which it was practically uniform to the bottom (130 fathoms). At the eastern side of the eastern basin (Station 10093) the minimum (41.1° at fifty fathoms) was about the same as in the western basin, though the upper layers, and the bottom water (41.6° at 115 fathoms) were both colder than the latter.

All these temperature curves are characterized by a sudden change

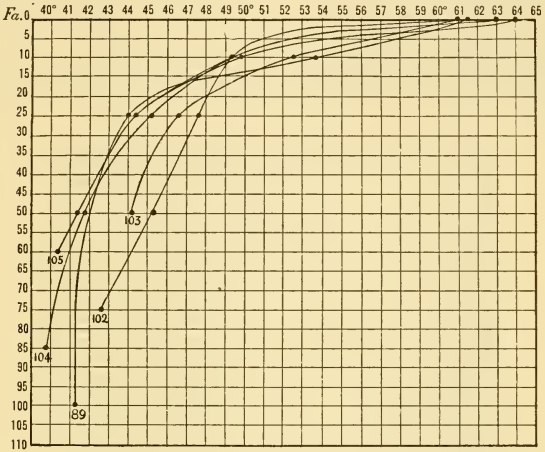

FIG. 18.— Temperature sections in the Gulf of Maine near Platt's Bank (Station 10089) and north of Cape Ann (Stations 10102, 10103, 10104, 10105).

in direction at about the 30–40 fathom level, corresponding to the point at which the fall of temperature ceases to be rapid. And in 1912 this was true of the trough west of Jeffrey's Ledge. But in 1913 the temperature sections at the two Stations in the latter (Stations 10104 and 10105, Fig. 18) show a steadily decreasing rate of cooling from the surface downward. And this is true in general of the Stations off the coast of Maine (Stations 10098, 10099, 10101, 10102, Fig. 19, and 10103) and of the northern end of the eastern basin (Stations 10097, 10100, Fig. 20). The water next the coast was, progressively, colder on the surface, warmer on the bottom, from Cape Ann toward the Bay of Fundy, for example the surface and fifty fathom temperatures were 64° and 41.05° at Station 10105; 61° and 44° at Station 10103; 54° and 47.5° at Station 10101. And though this change was interrupted off Mt. Desert (Station 10099), the difference between surface (50.5°) and bottom (48.3°) off the Grand Manan Channel (Station 10098) was only 2°.

At Stations 10097 and 10100 the temperature agreed at the surface (55°) and at 100 fathoms (43.2°); but from about ten fathoms down to about fifty fathoms, Station 10100 was the colder of the two, with a difference of 3° at twenty fathoms, a fact probably due to an upwelling of cold water from below.

On the Nova Scotia slope, off Lurcher Shoal (Station 10096), the temperature curve (Fig. 19) agrees very closely with that for Station

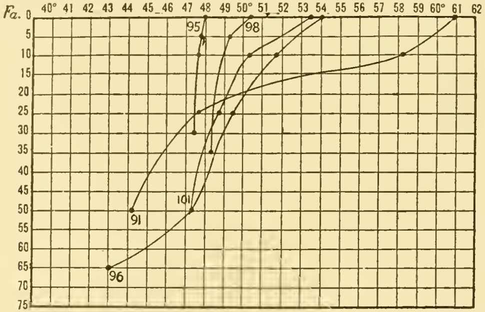

Fig. 19.— Temperature sections in the Gulf of Maine, on Jeffrey's Bank (Station 10091); off Matinicus Island (Station 10101); off the coast of Maine near the Grand Manan Channel (Station 10098); near Lurcher Shoal (Station 10096); and on German Bank (Station 10095).

10097 from the surface down to fifty fathoms, cooling from 54° to about 47°, and although the seventy fathom reading (43°) was colder than the water at the corresponding level in the northern part of the basin, it was almost precisely the same as the bottom water there (Stations 10097 and 10100). The temperature was practically uniform from the surface downward, on German Bank; and even over the seventy fathom curve on its western slope (Station 10094, Fig. 17) the difference between surface and bottom was only about 3° (48°–44.9°).

At the one Station in Massachusetts Bay (Station 10106, Fig. 16) the upper part of the temperature curve agreed almost exactly with the water off Cape Ann, (Station 10087) and near Platt's Bank (Station 10089), cooling from 61° at the surface to 48.5° at fifteen fathoms. But at thirty-five fathoms (bottom) it was 2° warmer (44.1°) than either of these.

All the temperatures described so far for the Gulf were taken in August, during a week's period: and hence directly comparable

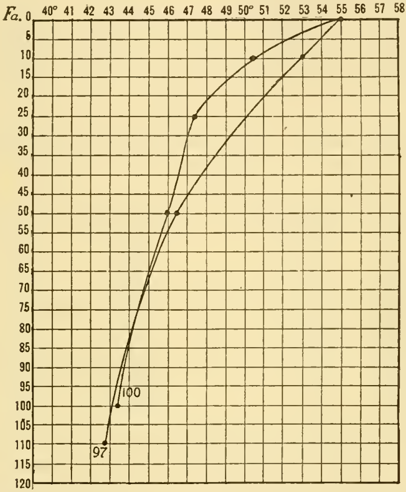

Fig. 20.— Temperature sections in the northeastern part of the basin of the Gulf of Maine (Stations 10097, 10100).

with one another. But three Stations, one off Cape Cod (Station 10057, Fig. 16) at the same location as Station 10086, one over the southern part of the basin (Station 10058, Fig. 3), the third on George's Bank (Station 10059, Fig. 3), were made a month earlier. The surface temperature of the first (61°) is exactly the same as it was at the same locality in August (Station 10086); but below the surface the July section is colder at all depths, the greatest difference being on the bottom (forty fathoms), where the water was 41.2° as against 43.2° a month later. Station 10058 was about 2.5° warmer than the Cape Cod stations down to twenty fathoms; but at thirty fathoms it was about .5° colder (41.1°); with a minimum of 40.6° at sixty fathoms, below which it warmed slightly; and its curve is almost exactly parallel with that of the nearest August Station (10085), though about 3° warmer at all depths.

The water on the southwestern part of George's Bank (Station 10059) was nearly uniform from the surface downward, in temperature as well as in salinity (p. 188).

Mean temperature. If all the temperature curves in the Gulf were parallel, a direct comparison between them would show which regions were potentially warmest, which coldest. But they are so distorted by greater or less active vertical circulation, that it is only by calculating the mean temperatures for each station that light can be obtained on this subject. The mean temperatures for the zone between the surface and the fifty fathom level are given in the following table:—

Station	Mean tem.	Station	Mean tem.
10087	46.3°	10096	50.2°
10088	49.4°	10097	50.3°
10089	47°	10100	48.4°
10090	47.5°	10101	49°
10091	50°	10102	48.5°
10092	46.5°	10103	48.4°
10093	50°	10104	47.2°
10094	47.1°	10105	47°

The mean between the surface and forty fathoms, was 46° at Station 10057; 48.5° at Station 10086; 48.8° at Station 10106; the thirty fathom mean was 47.6° at Station 10095; 55° at Station 10059. Thus the upper fifty fathoms was coldest, as a whole, on the western side of the Gulf. Passing northeastward along the coast, the mean temperature rose from 46.3° near Cape Ann to 48.4° off Cape Elizabeth, 49° off Penobscot Bay, 48.4° off Mt. Desert Rock and 50.3° over the northern end of the basin. In the centre of the Gulf it was generally 49°–50°, except for one cold Station (10092). Off the mouth of the Bay of Fundy the mean (50.3° at Station 10096) was as high as anywhere in the Gulf. But the upper fifty fathoms over the slope of German Bank (Station 10094), and the whole column of water on the Bank itself

Station 10095), was distinctly colder (47.1°–47.5°) than the corresponding layer of water either west, north or northwest of it (Stations 10093, 10096, 10097, 10100). Consequently vertical mixing of the upper fifty fathoms of water immediately surrounding the Bank could not reproduce the temperature observed on the latter; there must have been either an influx of cold water from elsewhere, or some upwelling.

The mean temperature of the layer of water between 50 and 100 fathoms was:—

Station	Mean tem.	Station	Mean tem.
10088	42.4°	10093	42.4°
10089	41.3°	10097	44.5°
10090	43.7°	10100	44.5°
10092	42.6°		

At Station 10087, 50–70 fathoms, the mean was 41.2°; at Station 10104, 50–85 fathoms, 40.5°.

Thus the bottom water of the deeper parts of the Gulf, like the upper layers was warmest in the northern part of the eastern basin (Stations 10097, 10100); coldest, next the western shore (Stations 10087, 10104).

In the preceding sentences the differences in mean temperature have been emphasized; but in reality the striking result of the calculation is the uniformity of the Gulf, the extreme divergence of the mean of the upper fifty fathoms being only about 4°, that of the mean between fifty and 100 fathoms about the same, over an area of about fourteen thousand square miles.

The mean temperature of the upper 15 fathoms, *i. e.*, of the zone most subject to solar warming, shows a much greater range (about 11.2°), as illustrated in the following table:—

Station	Mean tem.	Station	Mean tem.
10087	54.5°	10096	52.3°
10088	58.5°	10097	53.5°
10089	55.1°	10098	49.3°
10090	55.5°	10100	52°
10091	55.1°	10101	51.5°
10092	53.7°	10103	55.2°
10093	58°	10104	53.2°
10094	47.3°	10106	55°
10095	47.7°		

The distribution of the fifteen fathom mean, highest in the central part of the Gulf (Stations 10088 and 10093), falling to about 54°–55° over the western half of the Gulf generally, and lowest in its northeast corner and on German Bank, corresponds with the distribution of surface temperature, and with the proportional strength of the tidal currents, just as might be expected, solar warming being most effective where vertical circulation is least active.

Temperature profiles. The general distribution of temperature across the Gulf, from east to west, is illustrated by a profile from Massachusetts Bay to German Bank (Fig. 21, Stations 10106, 10087, 10088, 10090, 10092, 10093, 10094, 10095), its most interesting feature being its illustration of the fact (p. 172) that in the central part of the Gulf the water was coldest at about fifty fathoms, not on the bottom. Water of 41°–43° filled the sink at the mouth of Massachusetts Bay, rising there to within twenty-five fathoms of the surface; and projected eastward, like a shelf, over the western basin, without any rise in temperature at fifty fathoms as far east as Station 10088; warming to 43.5° in the middle of the Gulf (Station 10090). In the eastern half of the profile, the coldest water extended from shore, westward into the centre of the Gulf. But on this side there was no water colder than 42°, the lowest reading being 42.°, and the cold mass of water was not horizontal but oblique, rising from a depth of 80–100 fathoms on the shore slope, to 40–60 fathoms at its western end, with the coldest water (42°) limited to a very thin layer 40–50 fathoms. The cold layer was interrupted in the middle of the Gulf (Station 10090) by water 1°–2° warmer at the fifty fathom level. The temperature of the water underlying the cold zone ranged from 43° to 43.9°, coldest at the eastern side of the Gulf, depth for depth, warmest in the centre (Station 10090), *i. e.*, just the reverse of the temperature at fifty fathoms.

Above thirty fathoms the water was warmest at Station 10088, coldest on German Bank and off the mouth of Massachusetts Bay (Station 10087), where the temperature was below 43° at a depth of only twenty-five fathoms. The profile shows the spreading of the curves over German Bank (Station 10095) which characterized that region in 1912 (1914a, p. 56); caused by vertical mixing by the tides. And there is a similar phenomenon in Massachusetts Bay (Station 10106); limited in this case to depths below ten fathoms.

A profile running northeast from the mouth of Massachusetts Bay to Station 10089 (Fig. 22) shows that water colder than 42° extended unbroken across the northern end of the western basin, to the south-

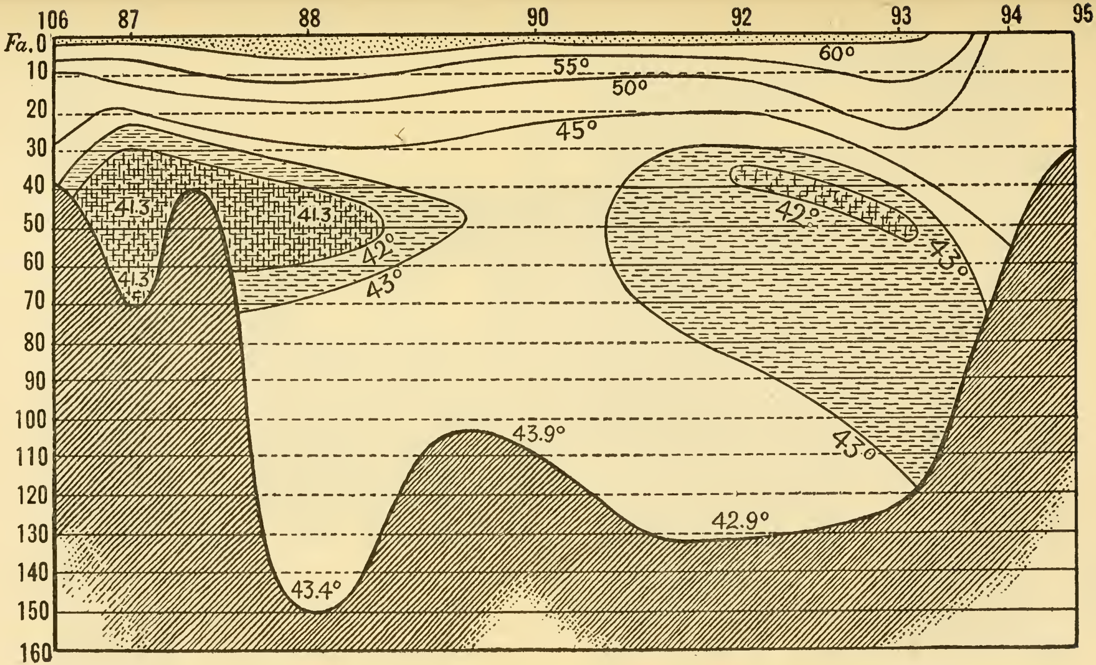

FIG. 21.— Temperature profile across the Gulf of Maine from Massachusetts Bay to German Bank (Stations 10106, 10087, 10088, 10090, 10092, 10093, 10094, 10095).

western slope of Jeffrey's Bank. But it gradually receded from the surface, passing toward the northeast, the curve of 42° dipping from thirty fathoms at Station 10087 to forty fathoms at Station 10089, and to the bottom, in about sixty fathoms, on the slope of the Bank. And there was no water as cold as 42° on the northeast side of the bank. Whether the 42° water was underlaid by warmer water in the

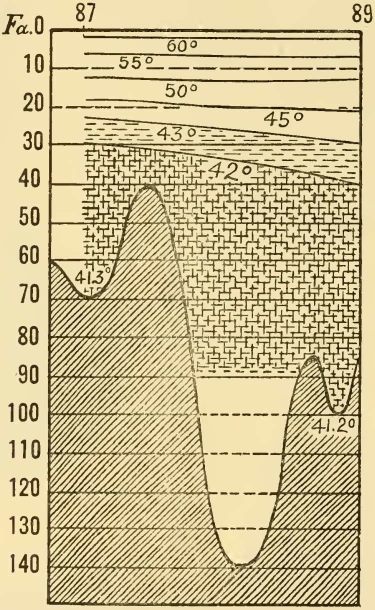

Fig. 22.— Temperature profile running northeastward from off Cape Ann (Station 10087) toward Platt's Bank to Station 10089.

northern end of the western basin, as it was further south (Station 10088), is uncertain; but this was probably the case.

Profiles running off shore from the western side of the Gulf further delimit the 42° water. The first of these, from the trough between Jeffrey's Ledge and the mainland (Station 10104) to the centre of the

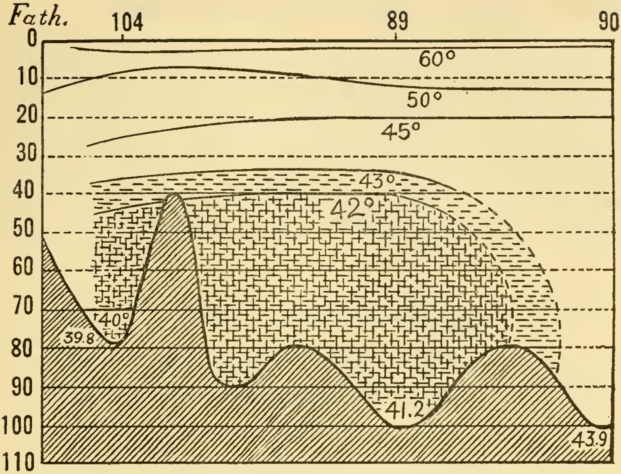

FIG. 23.— Temperature profile from the trough between Jeffrey's Ledge and the coast (Station 10104) toward the centre of the Gulf (Station 10090) via Station 10089.

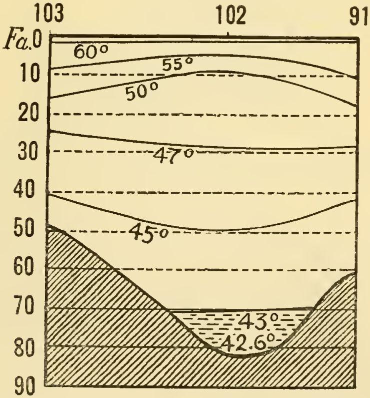

FIG. 24.— Temperature profile from the neighborhood of Cape Elizabeth (Station 10103) to Jeffrey's Bank (Station 10091) via Station 10102.

Gulf (Station 10090, Fig. 23), shows that below forty fathoms the trough was filled with water colder than 42°: and this was also true as far off shore as the ridge which is crowned by Cashes Ledge. But, as already pointed out, 42° water did not extend to Station 10090. And the fact that at the latter the lowest temperature (43.5°) was at fifty fathoms, not on the bottom, suggests a slight shelf-like projection of the 42° water. It is safe to say that Jeffrey's Ledge rises above the coldest water locally, for in places it is covered by less than thirty fathoms. And tidal currents may be expected to cause temperature

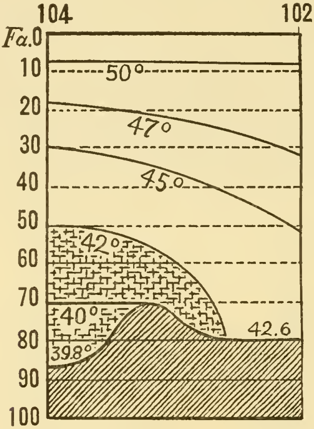

Fig. 25.— Temperature profile lengthwise of the trough between Jeffrey's Ledge and the mainland (Stations 10104, 10102).

disturbances over it. Between the thirty fathom level and the surface the temperature was nearly uniform, depth for depth, from one end of the profile to the other.

A profile (Fig. 24) parallel to the last, but some twenty-five miles further north, from Cape Elizabeth (Station 10103) to Jeffrey's Bank (Station 10091) is warmer at all depths, except the immediate surface, than the preceding one, with water colder than 43° limited to depths greater than seventy fathoms, and a minimum of 42.6° at eighty fathoms. Between five and fifteen fathoms the difference between the two profiles is slight; but below that level it grows progressively greater and greater, as shown by the following table: —

Depths *A*	Temperature	Depths *B*
5 fathoms	55°	5 fathoms
10	50°	12–15
18	47°	about 30
22	45°	40–50
35	43°	70

(*A* is the profile across the Ledge, and *B* the profile off Cape Elizabeth).

The temperature was almost precisely the same, depth for depth, off Cape Elizabeth (Station 10103) as on Jeffrey's Bank (Station 10091).

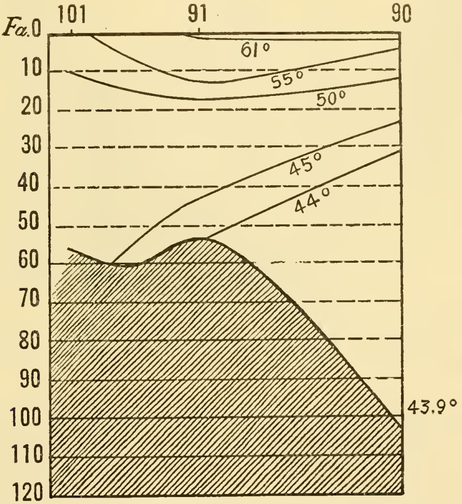

Fig. 26.— Temperature profile from the neighborhood of Matinicus Island (Station 10101) across Jeffrey's Bank (Station 10091) toward the centre of the Gulf (Station 10090).

But in the middle of the profile (Station 10102) there is a pronounced spreading of the curves between ten and fifty fathoms, which, however, is limited to the mid-depths; it is probably an evidence of local disturbances. A profile (Fig. 25) running parallel to the coast (Stations 10104–10102) connecting the preceding two, shows that the 42° water can hardly have extended beyond the northern end of Jeffrey's Ledge,

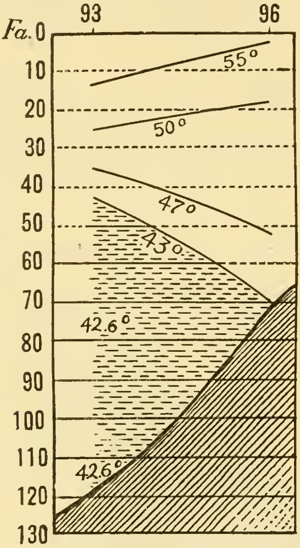

Fig. 27.— Temperature profile from the eastern basin of the Gulf (Station 10093) toward the mouth of the Bay of Fundy (Station 10096).

while water colder than 40° (p. 178) was confined to the deeper parts of the trough. A profile (Fig. 26) running off shore from the neighborhood of Matinicus Island to the centre of the Gulf shows that the bottom water was distinctly warmer on Jeffrey's Bank (Station 10091) than in the centre of the Gulf (Station 10090). And a profile from Station 10102, off Monhegan, to Station 10089, would show an even greater temperature-difference between the two ends.

Evidently then, the immediate coast water from Cape Elizabeth to and across the mouth of Penobscot Bay was distinctly warmer than the coast water further south, or than the water off shore, water colder than 42° being limited, on the northeast by the slope of Jeffrey's Bank. We have no means of knowing how far south water colder than 42° may have extended in August. But the fact that in early

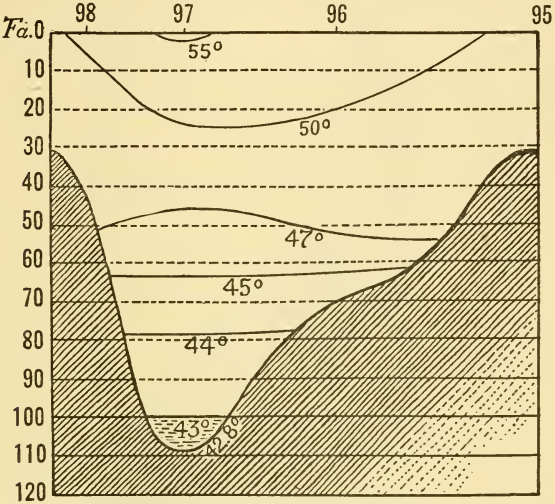

Fig. 28.— Temperature profile across the mouth of the Bay of Fundy, from the coast of Maine (Station 10098) to German Bank (Station 10095) crossing the northern end of the basin (Station 10097).

July it filled the basin off Cape Cod, from thirty fathoms to bottom, suggests that it reached the northwestern side of Georges Bank, though probably underlaid by warmer water in the southern part of the basin, just as at Station 10088.

A profile from the basin toward the Bay of Fundy (Fig. 27) shows that vertical tidal mixing was effective from German Bank to Lurcher Shoal, diminishing toward the north, to reappear again off the coast of Maine (Fig. 28).

Salinity, Cape Cod to Chesapeake Bay.

1. *Surface salinity.* The surface salinity (Plate **2**) from Cape Cod to the southern edge of Nantucket Shoals was 32.2‰–32.6‰. And the record of 32.3‰ at the eastern end of Vineyard Sound agrees so well with Sumner, Osburn, and Cole's (1913) records for the surface waters of that region in August, 1906 (32.2‰ to 32.3‰) that we can

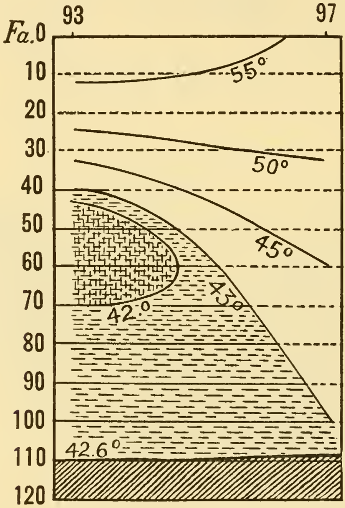

Fig. 29.— Temperature profile lengthwise of the northeastern part of the basin from south to north (Stations 10093, 10097). For 42° read 42.5°.

assume that value as normal for summer. The few stations in this region suggest that the curve of 32.3‰ swings westward toward the mouth of Vineyard Sound, which agrees with their statement (1913, p. 36) that there is a dominant westerly movement of the water through the Sound of about two knots per day.

From Nantucket light-ship out to the edge of the continental shelf there was a steady, and fairly uniform rise in salinity to about 33.4‰

over the seventy-five fathom curve; and there is every reason to assume that by a run of a very few miles further to the south Gulf Stream water of 35‰ would have been found. Close to the shore of Long Island the salinity was only about 31.2‰, with an expansion of water fresher than 32.2‰ off its eastern end. And there was a second tongue of comparatively low salinity abreast of Barnegat. On the other hand Gulf Stream water (35‰) was encountered on the surface at the outer edge of the continental slope off New Jersey, with a rise of salinity from 32.4‰ to 35.25‰ in a distance of only twenty miles (Station 10070 to Station 10071).

Close to the New Jersey coast the salinity rose, north to south, from 31.2‰ near New York to 32.2‰ off Cape May. And the importance of Delaware Bay, like that of the Connecticut and Hudson Rivers, as a source of land water, was shown by the pronounced off shore swing of the curve of 32.2‰ abreast of its mouth. At the time of our visit its influence was evident for at least fifty miles from Cape May (Station 10072). The curves show a tongue of comparatively salt water approaching the shore north of Delaware Bay; and a much more pronounced one just south of it, where the curve of 33.5‰ lies only thirty miles from land, good evidence that the Delaware water had but little effect either south or north of the Bay in July. The approach of water of high salinity toward the coast south of New York is further illustrated by the fact that off Cape Henlopen the curve of 33‰ was within thirty-five miles of land instead of at a distance of eighty miles, as was the case abreast of Long Island. And while this phenomenon is in part a concomitant of the steadily decreasing breadth of the continental shelf, the water was salter over the twenty-five fathom curve off Cape Henlopen than over the 100 fathom curve off Long Island.

The freshening effect of Chesapeake Bay on the surface is unmistakable; the water fifteen miles off its mouth being the freshest (29.25‰) water encountered during the cruise. And the surface salinity was only 32.2‰ over the 100 fathom curve, though 33.5‰ water occupied this relative position on the shelf only thirty miles further north. But the water from the Bay had little effect further seaward, for in the next fifteen miles the salinity rose to 33.5‰, *i. e.*, to practically the same saltness as at the same relative position off Barnegat.

The work south of Cape Cod occupied only about three weeks time; hence it is hardly to be expected that any considerable change in salinity would have taken place. And as a matter of fact the stations on the way north show no clear evidence of any. But water samples collected by Mr. Welsh on August 22, near the sixty fathom curve off Block Island (Station 10112) proved to be very much salter (surface salinity 34‰) than the water in this region during the first of July; salter, in fact, than any water on the shelf at that time, showing that an indraught of ocean water took place in August.

During the spring of 1913, Captain McFarland, of the schooner VICTOR, collected water samples at nine localities between Nantucket and Delaware Bay, seven at the surface, four from 15–25 fathoms, which show that early in June the surface salinity was 32.9‰ thirty miles south of Marthas Vineyard, 32.6‰ over the southwest slope of Nantucket shoals twenty miles west of Nantucket light-ship; and that it was practically unchanged at the latter locality on June 21 (p. 351). Thus the water was salter in June than in July; but while the difference was considerable off Marthas Vineyard (32.9‰ as against 32.2‰) it was very slight over Nantucket Shoals (June 6, 32.65‰; June 21, 32.68‰, July 9, 32.5‰).

Off Cape May, a few miles south of the location of our Station 10072, Capt. McFarland encountered water of 34.18‰ on the surface, and near the bottom at twenty-five fathoms, on May 3 and May 9, which is much salter than it was there in July (about 32.4‰ on the surface). But as the curves show (Plate **2**), 34‰ water would have been reached only fifteen miles further off shore at that season. Apparently, then, the coast water, from Cape Cod to Chesapeake Bay, is freshest in July; and hence, since the outrush of river water is at its maximum in May, seaward expansion must be a slow process. After July, ocean water once more has the upper hand.

Salinity sections. The water is usually freshest on the surface, saltest on the bottom, over the continental shelf south and west of Cape Cod, as, indeed, is the general rule in coastal waters in summer. But at three Stations, 10073, 10074, and 10077, all south of Delaware Bay between the 20 and 30 fathom curves, the intermediate layers, were saltest (Fig. 31, 34). The remaining, more normal, sections fall into several distinct classes. There is, to begin with, one Station (10059) with only a very slight rise in salinity from the surface downward (surface 33.06‰; 30 fathoms, 33.1‰), a type familiar in the northeast part of the Gulf of Maine in regions of strong tidal currents; its location on George's Bank, where the currents are proverbially violent, and where temperature like salinity was practically uniform at all depths, shows that it is a similar example of vertical circulation. Judging from the tidal currents, it is probable that more or less similar conditions obtain locally on Nantucket Shoals; but on their

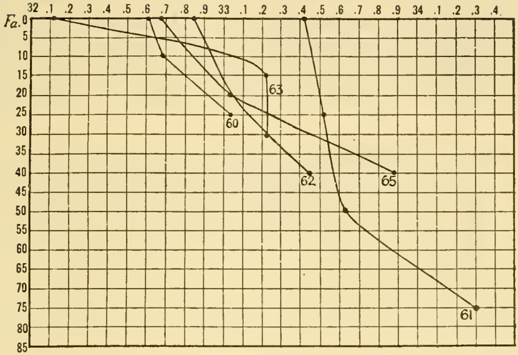

FIG. 30.— Salinity sections on the continental shelf south of Nantucket and Long Island (Stations 10060, 10061, 10062, 10063, 10065).

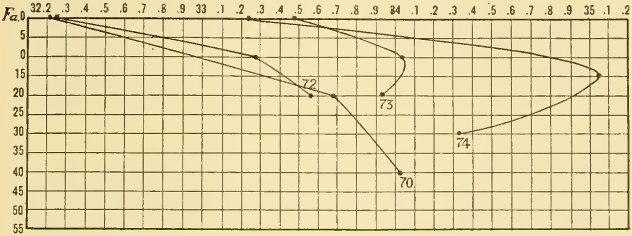

FIG. 31.— Salinity sections on the continental shelf south of New York (Stations 10070, 10072, 10073, 10074).

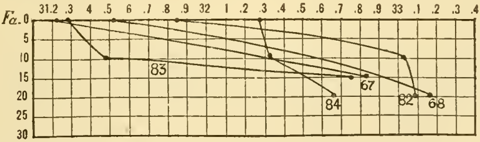

FIG. 32.— Salinity sections close to land off New York (Stations 10067, 10068, 10082) and Long Island (Stations 10083, 10084).

southern slope the vertical range of salinity was greater (Station 10060, Fig. 30). A considerable vertical range in salinity, with more or less regular increase from the surface downward, characterized Stations 10062, 10065, (Fig. 30), 10066, 10070, 10072, (Fig. 31), 10075 (Fig. 33), and probably 10067, and 10068 (Fig. 32). And though

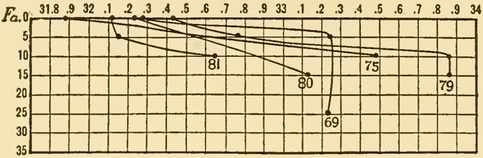

FIG. 33.— Salinity sections close to land, New York to Chesapeake Bay (Stations 10069, 10075, 10079, 10080, 10081).

there was a good deal of variation from station to station in the precise rapidity of increase, as a whole the difference between surface and bottom increased from northeast to southwest. At Stations 10063 (Fig. 30), 10066, 10069 (Fig. 33) and 10082 (Fig. 32), there was a rapid rise immediately below the surface, followed by a bottom zone of uniform salinity, 10–20 fathoms thick. The curves for Stations 10081, 10083, 10084, 10060, 10061, are the reverse, the surface layer being nearly uniform with a rapid rise below. As a whole the water was freshest near shore, saltest over the outer part of the continental

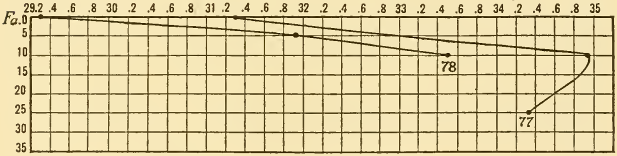

FIG. 34.— Salinity sections on the continental shelf abreast of Chesapeake Bay (Stations 10077, 10078).

shelf, with a progressive rise in salinity from northeast to southwest at stations occupying the same relative positions on the shelf.

The salinity sections at the three Stations outside the 100 fathom curve (10064, 10071, 10076, Fig. 35) are all of one type, fresh at the surface, saltest in the intermediate layers, and growing slowly fresher once more below 100 fathoms or so. Station 10064 is the freshest of the three, with 10071 the saltest, 10076 is intermediate between these two. And they approach one another so closely below 150 fathoms as to suggest that they would have been all alike below that depth, had the stations been located a few miles further off shore.

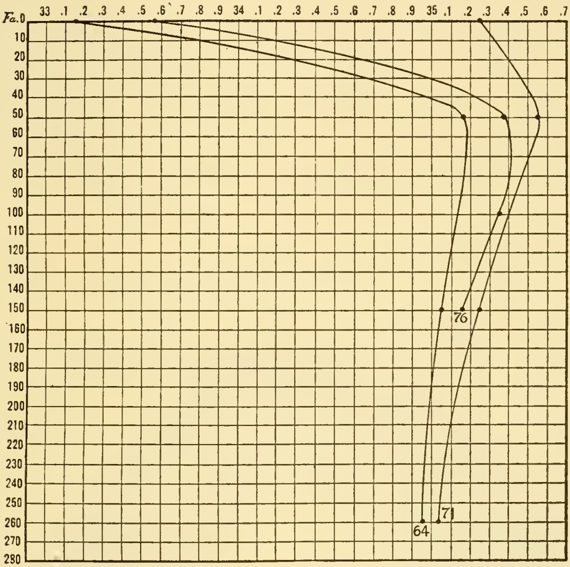

FIG. 35.— Salinity sections at the edge of the Gulf Stream at Lat. 39° 55′ (Station 10064); Lat. 38° 56′ (Station 10071) and abreast of Chesapeake Bay (Station 10076).

Of the three, Station 10071 most nearly approaches a typical oceanic section; but even here the effect of coast water is evidenced by the fact that the surface salinity is lower than that of the intermediate layers, while Stations 10064 and 10076 both give a similar result though to a greater degree.

Salinity on the bottom. The salinity on the bottom of the shelf

(Fig. 36) is of comparatively little importance in oceanography, because so largely dependent on depth; but it can not be neglected because of the part it plays in the biology of the bottom fauna. South and west of Cape Cod the bottom salinity (leaving out of consideration the zone between the shore line and the fifteen fathom contour), ranged from about 32.6‰ to 35‰, lowest along the south shore of

Fig. 36.— Chart of bottom salinity on the continental shelf between Cape Cod and Chesapeake Bay in July, and in the Gulf of Maine for August.

Long Island, and off Block Island, highest, as might be expected, along the outer edge of the shelf. In a general way, it corresponded to depth; but there was also an unmistakable increase, independent of depth, from northeast to southwest. Thus a bottom salinity of 34‰ was found at about the seventy fathom curve south of Nantucket, at about the forty-five fathom curve off Cape May, and at about the eighteen fathom curve off Chesapeake Bay; and 33.5‰ water at the forty, thirty, and ten fathom contours at the same localities. Bottom water fresher than 33‰ was restricted to a narrow coastal zone north of Delaware Bay; and the curves for this value and for 33.5‰ show evidence of water from the Bay, by swinging seaward off its mouth. But the outflow from Chesapeake Bay has no apparent effect on the curves, although it probably does reduce the bottom below what would otherwise obtain. The chart (Fig. 36) represents July conditions only; earlier as well as later in the season, the bottom water was much salter at the few localities where water-samples were taken (34.18‰ off Cape May, May 9; 35.17‰ in 60 fathoms, southwest of Nantucket August 22).

Salinity profiles. A profile (Fig. 37) running from the southern edge of the basin of the Gulf of Maine (Station 10058) across Nan-

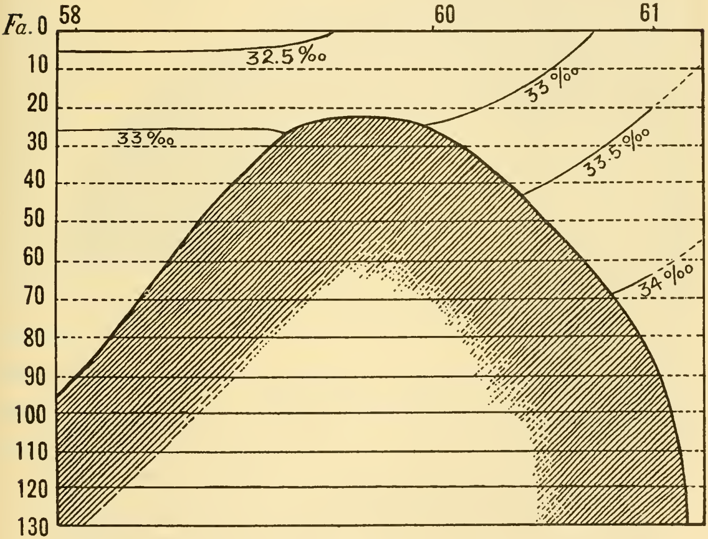

Fig. 37.— Salinity profile from the southern part of the basin of the Gulf of Maine (Station 10058) across Nantucket Shoals to the outer edge of the continental shelf south of Nantucket (Station 10061).

tucket Shoals (Station 10060) to the edge of the continental slope (Station 10061), shows that the water was much salter south than north of the Shoals, early in July. In the southern part of the Gulf there was comparatively little increase in salinity with depth below thirty fathoms, and the bottom salinity was about the same on the Shoals as at the same depth further north; but the surface shows the influence of the salter southern water by a steady, though slight, rise in salinity from Station 10058 to Station 10060, as well as in the fact that the

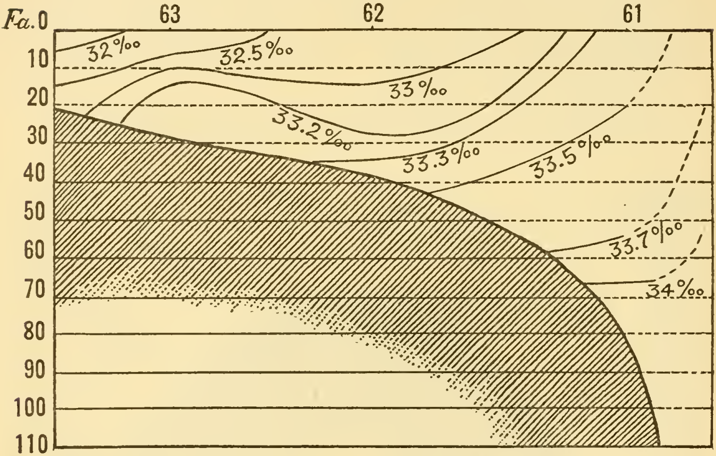

FIG. 38.— Salinity profile from the neighborhood of Montauk Point across the continental shelf (Stations 10063, 10062, 10061) to the edge of the shelf south of Nantucket.

average salinity for the upper ten fathoms was higher at Station 10060 (32.65‰) than at Station 10058 (32.5‰).

South of the Shoals there was a rapid rise in salinity, depth for depth, from north to south across the continental shelf. But the Shoals are an effective barrier to any active mixing of water on the two sides below about thirty fathoms.

The next profile (Fig. 38) runs across the continental shelf from Montauk Point (between Station 10083 and Station 10087) to the continental slope south of Nantucket Shoals (Station 10061). Its

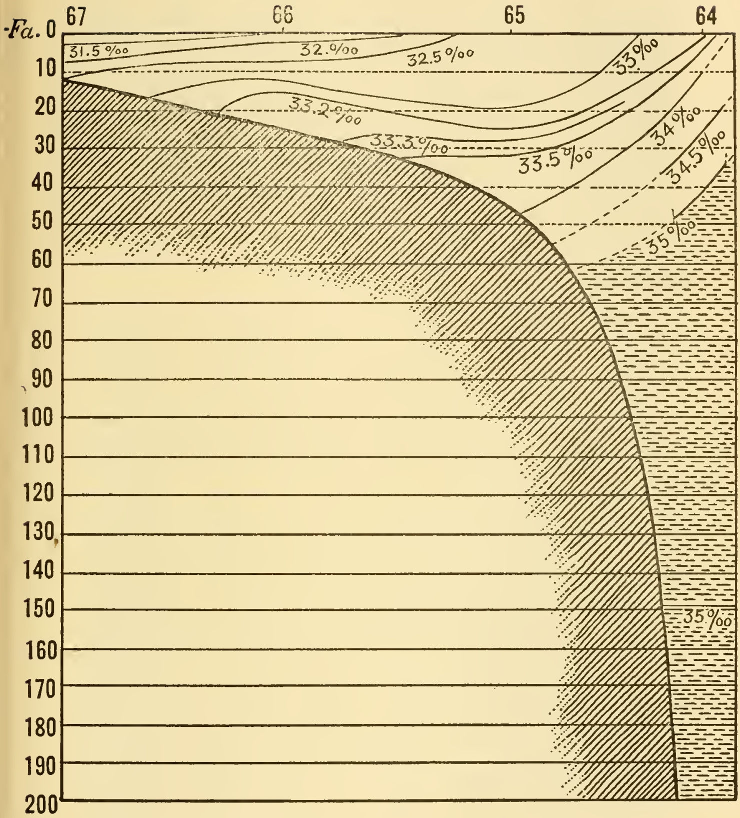

FIG. 39.— Salinity profile across the continental shelf from New York to the edge of the Gulf Stream in Lat. 39° 55′ (Stations 10067, 10066, 10065, 10064).

most striking feature, apart from the separation into comparatively fresh water on the continental shelf, and much salter oceanic water on the slope, is a succession of zones of comparatively uniform salinity alternating with zones in which there is a rapid change in salinity both vertical and horizontal. Next the shore there is first a mass of bottom water of 33.2‰, fifteen fathoms thick (Station 10063), separated by a zone of rapid transition from a much fresher though hardly less uniform surface zone of about 33‰ (Station 10062), some twenty-five fathoms thick. This, in turn, gives place to much salter water, over the edge of the shelf (Station 10061), where salinity increases only by .2‰ (33.41‰–33.62‰) from the surface down to fifty fathoms; below which there is a sudden rise. Since some of these masses of uniform water reappear in other profiles, it is convenient to designate them from the shore seaward, as A, B, and C.

On the profile from the neighborhood of New York to the slope, in about latitude 40° (Fig. 39), the salt ocean water is much more in evidence than it is further east, water of 35‰ bathing the slope nearly to the fifty fathom curve, although the surface water at the shore end is about the same salinity as in the last profile (Station 10067, 31.2‰). Two of the bands, which were noted in the preceding profile, reappear here, *i. e.*, A and B, with about the same salinities which characterized them further east. Band A is as well defined as in the preceding profile, occupies the same relative position on the shelf; and has the same salinity (33.2‰). But in the present profile the transition to the fresher water near shore is less sudden than it was further east. Band B is less clearly defined than in the preceding profile, and its salinity is less uniform, both vertically and transverse to the continental shelf, though of the same general value (about 33‰); nor does it so nearly reach to bottom, but overlies a layer of much salter water. Nevertheless the band is distinctly more uniform than the water immediately below, or on either side of it; hence its individuality still deserves recognition. But the third band, C, which characterized the outer part of the preceding profile, can not be distinguished in this one. As a whole the surface is fresher along this profile than the preceding; and this is true even of its off shore end, although the bottom water near the edge of the shelf is much salter than further east. And not only is water salter than 33.2‰ nearer the surface over the middle of the shelf, but water with salinity of 33‰ and higher washes the bottom to the fifteen fathom, instead of only to the twenty-five fathom curve. All this shows that off New York shore water was more in evidence on the surface, Atlantic water on

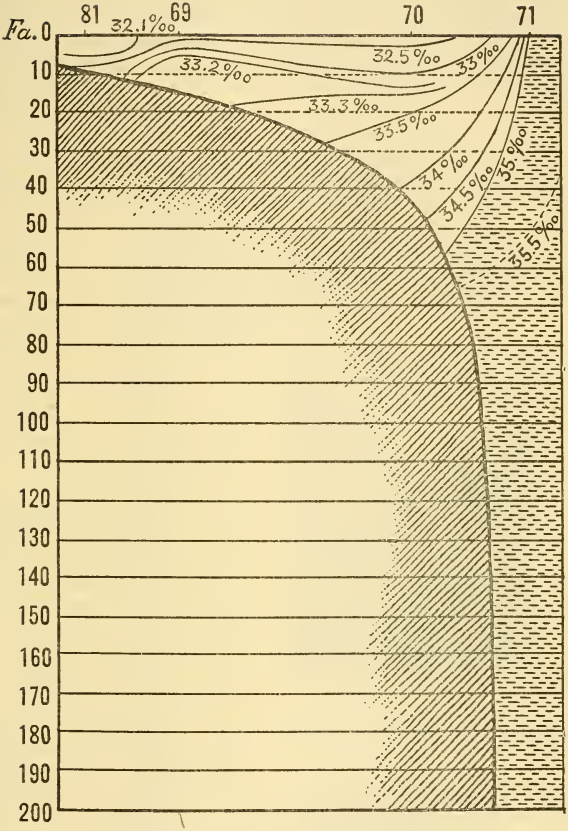

FIG. 40.— Salinity profile across the continental shelf abreast of Barnegat to the edge of the Gulf Stream in Lat. 38° 56′ (Stations 10081, 10069, 10070, 10071).

the bottom, than off Montauk or south of Nantucket Shoals; and that the transition between the two waters was very sudden. In the profile from off Barnegat to the continental slope in about latitude 39° (Fig. 40), water of 35‰ washes the slope below about sixty fathoms, and the curve of 35‰, which may be taken as an arbitrary division between coast and Gulf Stream water, is almost vertical. Generally speaking, too, the surface water was salter along this whole profile than in the preceding one, except at Station 10070; an exception explained by the fact that this part of the profile cut the southerly tongue of surface water fresher than 32.4‰, noted above (p. 187, Plate **2**). Neither band B nor C can be traced as far south as this profile. But Band A is still evident, with precisely the same salinity (33.2‰) as in the two preceding profiles, washing the bottom rather nearer shore than was the case further north, and gradually merging into the Gulf Stream water of 35‰ on its off shore side, instead of being limited seaward by a sudden transition zone. On the other hand there is a great difference in salinity between it and the surface water over it, and also between it and the zone of water closer to shore.

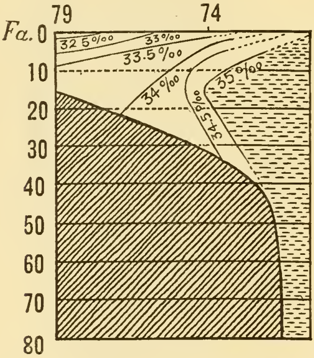

Fig. 41.— Salinity profile across the continental shelf south of Delaware Bay (Stations 10079, 10074).

The partial profile off Cape May is instructive chiefly because it shows no sign of band A; hence it is safe to conclude that the latter comes to an end north of Delaware Bay. The profile is otherwise so much like the preceding one, that I have not thought it necessary to reproduce it here. But the next one (Fig. 41), which is south of Delaware Bay, reveals an entirely new phenomenon, namely, a tongue of salt off shore water with salinity of 35‰ or more, intruding into the intermediate depths over the continental shelf, with fresher water both above and below it. Its landward end lies about over the thirty fathom curve, where the bottom water has a salinity of about 34.3‰, with 33.24‰ on the surface. Apart from the salt tongue, the salinity as a whole is higher than in the preceding profile, the bottom salinity in fifteen fathoms being 33.86‰ as against 33.14‰, with 34‰ as against 33.5‰ on the bottom at the twenty-five fathom curve. The shallower layers, too, are salter, depth for depth, than north of Delaware Bay.

A similar shoreward intrusion of 35‰ water into the intermediate

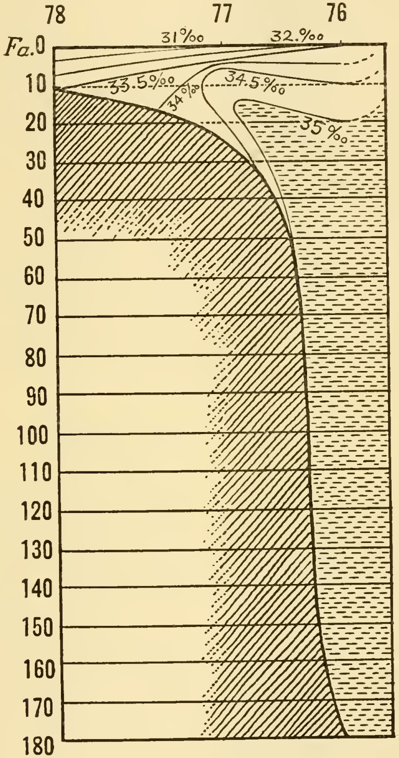

FIG. 42.— Salinity profile across the continental shelf to the edge of the Gulf Stream, abreast of Chesapeake Bay (Stations 10078, 10077, 10076).

depths over the shelf is also to be seen in the profile abreast of Chesapeake Bay (Fig. 42); and it has about the same extent and conformation there as further north, the curve of 35‰ rising from the sea floor at about the fifty fathom curve, with fresher water underneath it. But here the water near shore was much fresher down to five fathoms than in the preceding profile; the immediate surface layer fresher than any water we encountered further north, as might be expected from the volume of river water which debouches from the Bay in spring. And though this layer was very thin, the salinity rising from 29.25‰ on the surface to 33.5‰ on the bottom in ten fathoms at the shore end of the profile, its influence is unmistakable out to the edge of the continental shelf. At the outer end of the profile (Station 10076) the water was saltest at 50–100 fathoms (about 35.4‰), just as at the other deep water stations; below that level salinity decreased very slowly, as it does over the north Atlantic as a whole.

The change in salinity from north to south over the shelf north of Delaware Bay is illustrated by a profile following the forty fathom contour from Nantucket Shoals (Station 10060) to Station 10070 (Fig. 43). Below about ten fathoms there is a general increase in salinity, depth for depth, from northeast to southwest. But the surface water is freshest at the southern end of the profile (32.2‰), saltest at Station 10062 (32.86‰), and fresher once more (32.63‰) over the slope of Nantucket Shoals.

Salinity in the Gulf of Maine.

Surface Salinity. Early in July the surface salinity (Plate **2**) of Massachusetts Bay, immediately off Gloucester, was about 31.56‰, a rise of about .5 since the middle of May (1914b, p. 393), and it was 31.9‰ off Cape Cod (Station 10057, p. 205) with 32.4‰ over the southern part of the basin (Station 10058), and 33‰ on the southwest side of George's Bank (Station 10059). When we returned to the Gulf of Maine a month later, the water was slightly salter along the eastern shore of Cape Cod (32.05‰, Station 10085; 32.09‰, Station 10086), while a greater increase of salinity had taken place off Gloucester (to 32.03‰). And by the 25th of August it had risen to 32.16‰ in the mouth of Massachusetts Bay (Station 10106). The water immediately abreast of the Bay and along Cape Cod (Plate **2**) was 32–32.2‰, the curve for the latter value swinging eastward from the mouth of Vineyard Sound, and then northerly, toward Penobscot Bay.

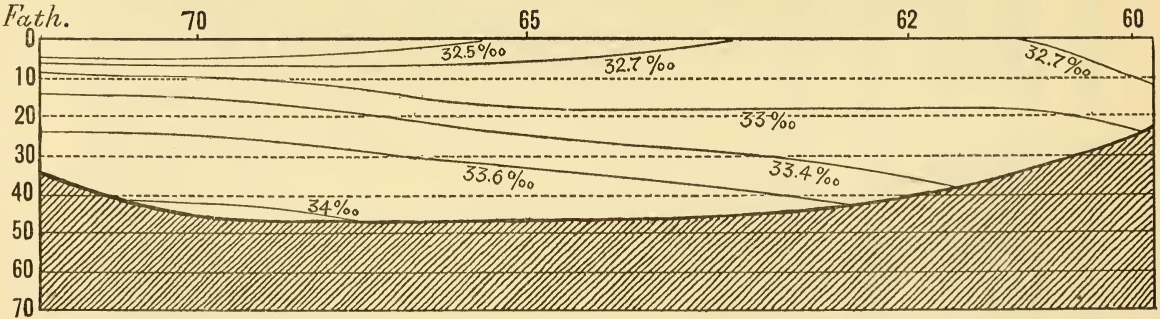

FIG. 43.— Salinity profile parallel to the shore, along the 30–45 fathom contour from Delaware Bay to Nantucket Shoals (Stations 10070, 10065, 10062, 10060).

Water fresher than 32‰ was restricted to a narrow zone close to shore, extending from just north of Cape Ann to Monhegan Island, broadest (twenty-five miles) off Cape Elizabeth.

In general there was a rise of surface salinity from west to east across the Gulf, the water being 32.5‰ some sixty miles off Cape Cod;

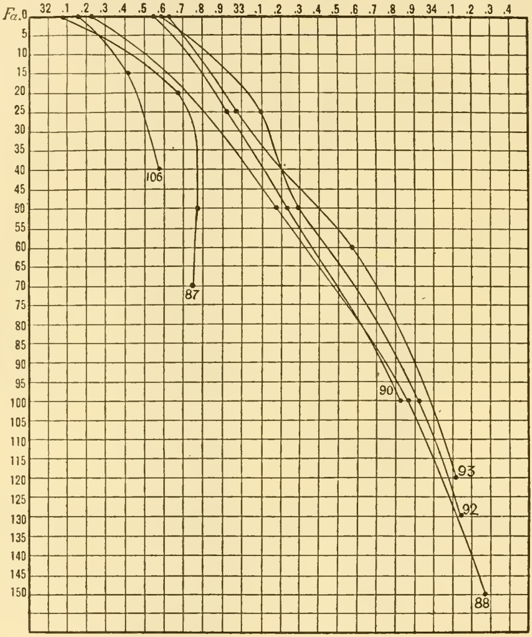

FIG. 44.— Salinity sections in the Gulf of Maine, from Massachusetts Bay to the eastern basin (Stations 10087, 10088, 10090, 10092, 10093, 10106).

32.6‰ in the centre of the Gulf, and 32.7‰ near the Nova Scotia coast bank. But the increase was far from uniform, the course of the curves being distorted by an outrush of comparatively fresh water (32.2‰ to 32.5‰) off the west mouth of Penobscot Bay, and by a band of water of the same low salinity extending thence along the coast of Maine to the Grand Manan Channel. The salinity was 32.5‰ or less over the coast bank west of Nova Scotia; and it is probable that the surface of the Bay of Fundy was even fresher than this. The curve for 34.4‰ shows that the direct effect of Penobscot water did not extend further south than Jeffrey's Bank (Station 10091), south of which it runs in an S, roughly parallel with the coast, crossing the southern end of the basin, and thence westward across Nantucket

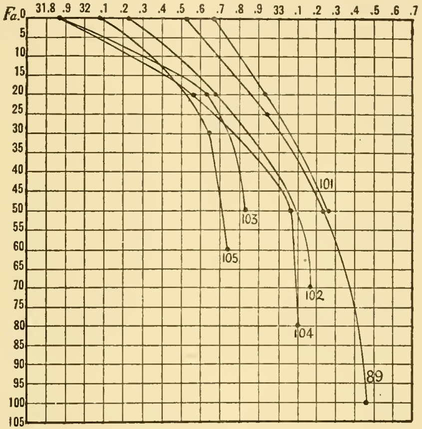

FIG. 45.— Salinity sections in the Gulf of Maine near Platt's Bank (Station 10089); along shore between Cape Ann and Penobscot Bay (Stations 10102, 10103, 10104, 10105) and near Matinicus Island (Station 10101).

Shoals. The surface of the eastern half of the Gulf as a whole was salter than 32.6‰; the curve for that value outlining a tongue some sixty miles broad, with an eddy-like curve from southeast to northwest. Water as salt as this lay close to the land east of Mt. Desert Island, and indented westward, as far as Matinicus Island, into the fresher Penobscot water. The curve of 32.6‰ probably crossed the mouth of the Bay of Fundy. At any rate it paralleled the western shore of Nova Scotia, where it was separated from the land by fresher water (32.45‰ on Lurcher Shoal).

The only record from George's Bank was considerably salter (about 33‰). And judging from the strong tidal currents of the Bank, from the few previous records (1914b) and from the proximity of the Gulf Stream, the general surface salinity over the bank is probably above 32.5‰.

The saltest surface water which we found in the Gulf was 32.79‰ on German Bank (Station 10045); but this is an abnormal value, caused by vertical circulation (p. 178). And though even salter water

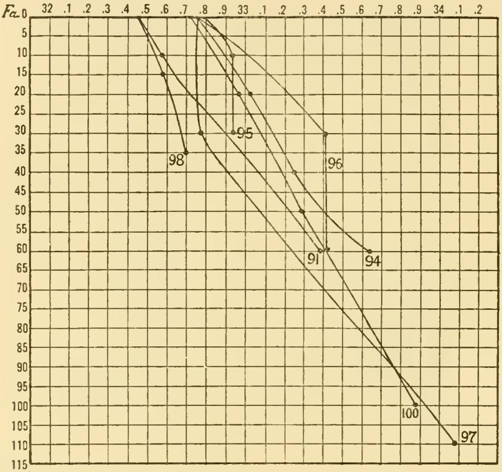

FIG. 46.— Salinity sections in the northeastern end of the basin of the Gulf of Maine (Stations 10097, 10100); on Jeffrey's Bank (Station 10091); German Bank (Stations 10094, 10095), near Lurcher Shoal (Station 10096) and off the coast of Maine near Grand Manan Channel (Station 10098).

may have spread from the south across George's Bank into the southeastern part of the Gulf in August, there is no actual evidence that such was the case.

Salinity sections. The waters of the Gulf of Maine were freshest at the surface, saltest at the bottom, just as in 1912 (1914a). In its central part (Stations 10088, 10090, 10092, 10093, Fig. 44), the rate of increase with depth was comparatively constant over the whole column of water; with a maximum difference of about 2.1‰ between surface and bottom salinity at the deepest Station (10088, surface 32.1‰; bottom 34.2‰); and this same type of curve likewise characterized the deep water off Mt. Desert (Station 10100, Fig. 46). The salinity curves at the Stations near shore, north and east of Cape Ann, (10101, 10102, 10103, 10104, 10105 Fig. 45), are of rather different type, the vertical increase in salinity being most rapid near the surface. In the northeast corner of the Gulf (Fig. 46), on the Nova Scotian Banks, and again off Cape Cod and on George's Bank, the salinity curves show unmistakable evidence of vertical tidal disturbance. Thus at Station 10098 the total vertical range of salinity, in thirty-five fathoms, was only about .2‰ (Fig. 46); off Lurcher Shoal (Station 10096, Fig. 46) there was a rise of .6‰ from the surface down to thirty fathoms (32.75‰–33.4‰); but below that depth the salinity was uniform down to the bottom in sixty fathoms. On German Bank the total range was only .1‰ (32.79‰–32.92‰), and on George's Bank (Station 10059) the water was practically uniform from surface to bottom. The upper layers in the northern end of the eastern basin (Station 10097) must likewise be disturbed by vertical currents, because the salinity was uniform from the surface down to thirty fathoms, with a sudden increase below that depth (Fig. 46). But there was no evidence of vertical mixing on Jeffrey's Bank.

In general the upper fifty fathoms of water was freshest off Cape Cod (Stations 10086, 10087), in Massachuetts Bay (Station 10106),

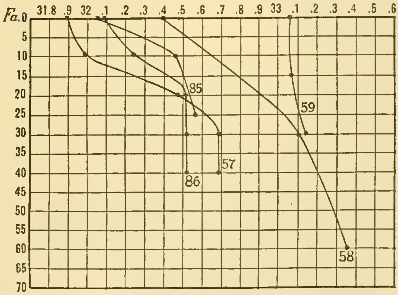

FIG. 47.— Salinity off Cape Cod in July (Station 10057) and in August (Stations 10085, 10086); in the southern part of the basin of the Gulf (Station 10058) and George's Banks (Station 10059) in July.

just north of Cape Ann (Station 10103), and close to the coast of Maine east of Mt. Desert (Station 10098); saltest in the centre of the Gulf and over the eastern basin (Stations 10092, 10093, and 10100), and over the edge of the Nova Scotian slope (Stations 10094, and 10096). And this is further illustrated by the following table of the mean salinity of the upper 50 fathoms:—

Station	Mean sal.	Station	Mean sal.
10058	32.9	10095[2]	32.9
10086[1]	32.4	10096	33.2
10087	32.6	10097	32.8
10088	32.7	10098[1]	32.5
10089	32.9	10100	33.
10090	32.9	10101	33.
10091	32.8	10102	32.7
10092	33.	10103	32.5
10093	33.	10104	32.6
10094	33.1	10105	32.5
		10106[1]	32.4

The mean salinity between 50 and 100 fathoms was lowest at Station 10089, highest in the eastern basin (Station 10093), as follows:—

Station	Mean sal.	Station	Mean sal.
10088	33.5	10093	33.7
10089	33.35	10097	33.5
10090	33.55	10100	33.6
10092	33.6		

Salinity on the bottom. The bottom salinity of the Gulf (Fig. 36) depended chiefly on depth, the bottom water of the basins being from 34‰ to 34.27‰. The bottom salinity of the coastal zone surrounding the whole Gulf was below 33‰ (32.5‰–32.9‰), the curve of 33‰ agreeing, roughly, with the fifty fathom contour of the bottom. But there were various local anomalies, already pointed out, especially the abnormally low bottom salinities of the several circumscribed sinks on the western side of the Gulf.

Salinity profiles. The profile from Massachusetts Bay to German Bank (Fig. 48, Stations 10106, 10087, 10088, 10090, 10092, 10093, 10094, 10095), shows that the water was salter in general, depth for

[1] Mean for 40 fathoms. [2] Mean for 30 fathoms.

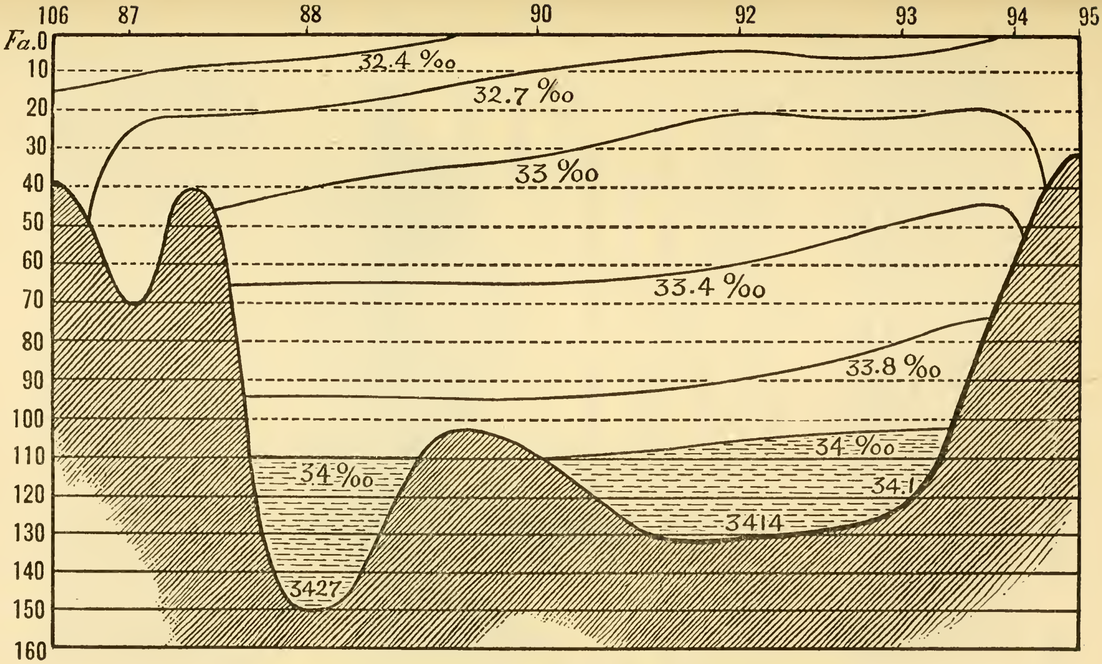

FIG. 48.— Salinity profile across the Gulf of Maine from Massachusetts Bay to German Bank in August (Stations 10106, 10087, 10088, 10090, 10092, 10093, 10094, 10095).

depth, at the eastern than at the western side of the Gulf, down to about 100 fathoms, equal salinities being found about 15–20 fathoms deeper on the Massachusetts Bay than on the Nova Scotia side. Below 100 fathoms there was much less variation in salinity from west to east, depth for depth, the curve of 34‰ following the 110 fathom level right across the western basin. At 130 fathoms the salinity was almost precisely the same (34.1‰) in the two basins.

The water was much fresher at the mouth of Massachusetts Bay

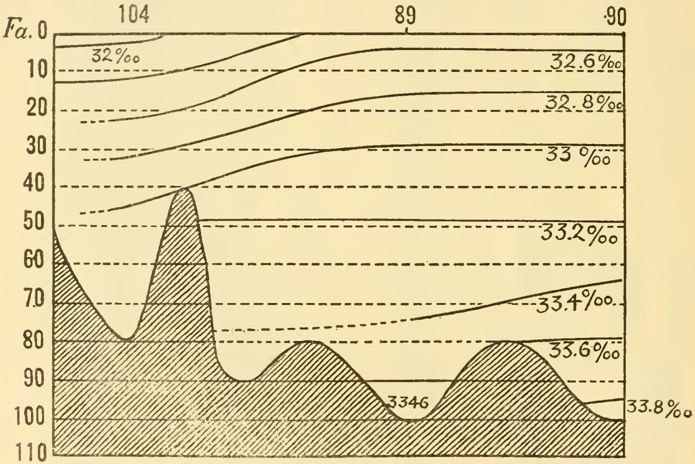

FIG. 49.— Salinity profile from the trough between Jeffrey's Ledge and the mainland (Station 10104) to the centre of the Gulf of Maine (Station 10090).

than further east, especially at the bottom, while the very sudden dip of the curve of 32.7‰ suggests that vertical circulation was active in the Bay. And this may well have been the case, as the tidal currents are of some strength in the neighborhood of Station 10106. The eastern end of the profile shows a sudden spreading of the curves over the coast bank, such as we found in 1912 (1914a), the range of salinity for the entire column of water on German Bank being only from 32.79‰–32.94‰. The only exception to the rule that salinity increased from west to east is afforded by Station 10093, where the salinity of the water between five and twenty fathoms was slightly lower than at Stations 10092 and 10094, on either side of it.

Successive profiles from near shore toward the centre of the Gulf, at right angles to the last, show that the water was fresher along the western coast than off shore. In the profile (Fig. 49), from Cape Porpoise, across the northern end of Jeffrey's Ledge, to Station 10090, the salinity curves all dip toward the land; but in the eastern half of the profile (Stations 10089 to Station 10090), they are practically

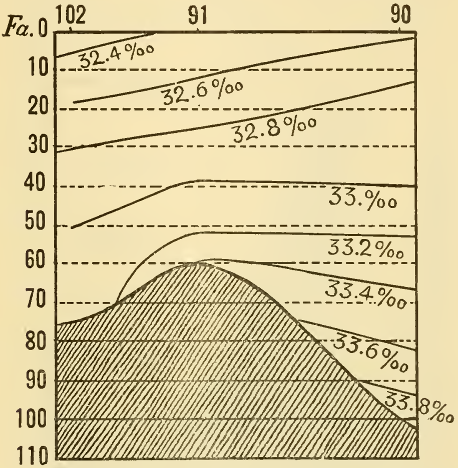

Fig. 50.— Salinity profile from Station 10102, off the mouth of Penobscot Bay, across Jeffrey's Bank (Station 10091) to the centre of the Gulf of Maine (Station 10090).

horizontal, *i. e.*, the salinity in the upper fifty fathoms was uniform horizontally; though below that depth the off shore water (Station 10090) was slightly saltest. The fact that the salinity was precisely the same (33.4–33.5‰) on the bottom in the sink where Station 10089 was located, as at seventy fathoms in the basin to the east of it, shows that its rim, which rises to a general level of about seventy-five fathoms, and is crowned by the much shallower Cashes Ledge, is an effective barrier to the entrance of the salt bottom water from the centre of the Gulf. And Jeffrey's Ledge evidently acts in the same way, for though it leaves an open entrance on the north to the trough west of it, the fact that the salinity was the same at eighty fathoms in the trough as at forty fathoms east of the Ledge, shows that little if any salt water flows in across the latter.

In the profile (Fig. 50) from the mouth of Penobscot Bay (Station 10102) to the centre of the Gulf (Station 10090) via Jeffrey's Bank

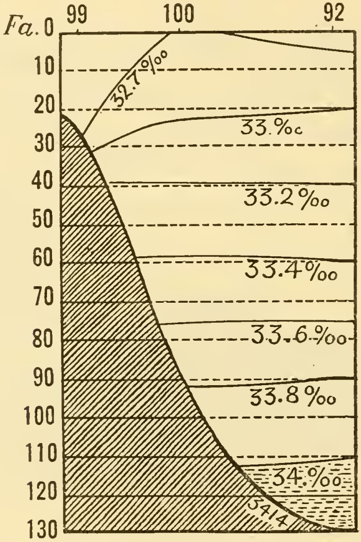

FIG. 51.— Salinity profile from the neighborhood of Mt. Desert Island (Station 10099) to the eastern basin of the Gulf of Maine (Stations 10100, 10092).

(Station 10091), the salinity curves all dip shoreward between the surface and forty fathoms. This is true for the whole column of water between Jeffrey's Bank (Station 10091) and the mouth of the Bay Station 10102). But between Station 10090 and the Bank, the reverse is the case below forty fathoms. The curve of 33.2‰ is especially interesting because while it runs almost horizontal at about fifty fathoms from Station 10090 to and across Jeffrey's Bank, it must then dip to bottom in about seventy fathoms, the bottom salinity at Station 10102 being only 33.17‰, suggesting a shoreward movement of salt bottom water across the Bank.

The next profile (Fig. 51) is parallel to the last, some 30 miles further east (Station 10099, 10100, 10092). Here the slope of the bottom is

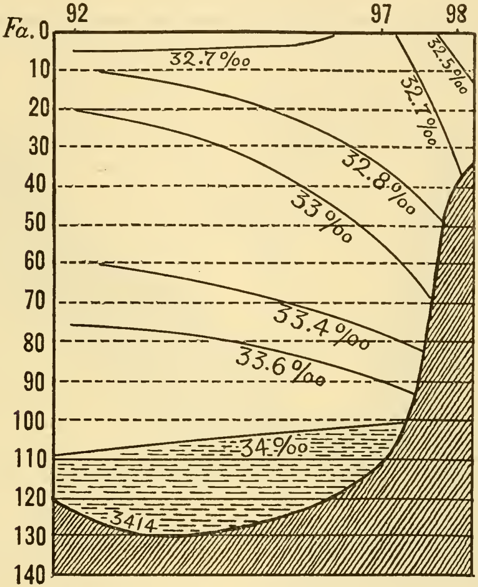

Fig. 52.— Salinity profile lengthwise of the northeastern part of the Gulf of Maine from south to north (Stations 10092, 10097, 10098).

an even one, consequently the salinity curves do not show the anomalies noted for the profiles further west; but they agree with the latter in dipping shoreward between the surface and thirty fathoms.

The water close to the surface was slightly salter at Station 10100 than at Station 10092, though the former is the nearer shore; but this does not invalidate the thesis of a general freshening near land, because the profile crosses the long-shore tongue of 32.7‰ surface water (Plate 2). Below forty fathoms there was practically no change in salinity, depth for depth, along the profile. Comparison between this profile and the one off Penobscot Bay (Fig. 50) shows that the off shore water was slightly salter off Mt. Desert, than off Penobscot Bay,

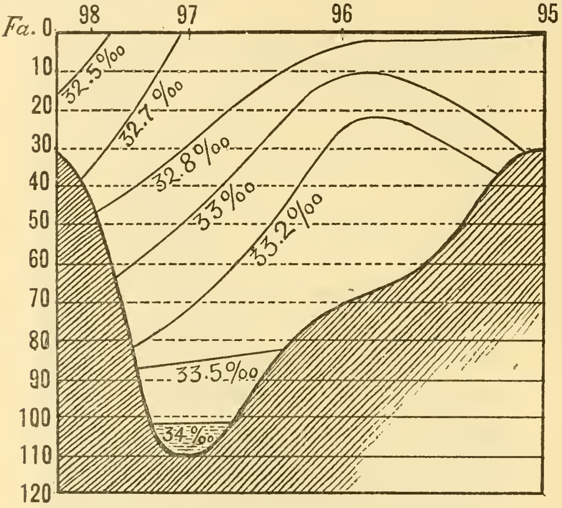

Fig. 53.— Salinity profile across the mouth of the Bay of Fundy, from the coast of Maine (Station 10098) to German Bank (Station 10095), crossing the basin (Station 10097).

the difference being greatest at 10–40 fathoms, where equal salinities are found 10–20 fathoms deeper at the former than at the latter.

A profile (Fig. 52) from the eastern basin (Station 10092) to the coast of Maine near the entrance to the Grand Manan Channel (Station 10098) shows an even more pronounced freshening toward the land, down to about ninety fathoms, the curve of 33‰ dipping from the twenty fathom level at Station 10092, to seventy fathoms on the shore slope. But below one hundred fathoms the dip of the curves is reversed, *i. e.*, the water was saltest, depth for depth, next the land, suggesting a movement of bottom water up the slope. The general rule that the salinity of the upper layers rose steadily passing off shore was broken at Station 10097; but this was probably due to local vertical circulation, as evidenced by the vertical uniformity of salinity for the upper thirty fathoms.

The profile crossing the mouth of the Bay of Fundy from the coast of Maine to German Bank (Stations 10098, 10097, 10096, and 10095, Fig. 53) shows the same comparatively fresh shore water off the coast of Maine, and the water was only slightly salter on German Bank, at the southern end of the profile. But the salinity was much higher in the centre of the profile, where 33‰ water came up to within ten fathoms of the surface, though the immediate surface was slightly fresher there than on German Bank. The course of the curves over the outer part of the Nova Scotia slope (Station 10096) is especially instructive because they reveal the existence of a zone of uniform water, between thirty fathoms and the bottom (sixty fathoms) the salinity of which agrees with the eighty fathom level over the basin (Station 10097). And this, of course, suggests an up-draught of bottom water over the slope. Vertical circulation was active in the shallow water at each end of the profile; slightly more so on German Bank than next the Maine coast, as shown by the fact that the difference between surface and bottom salinity in thirty fathoms on the latter was only .13‰, as against .23‰ in forty fathoms at Station 10098.

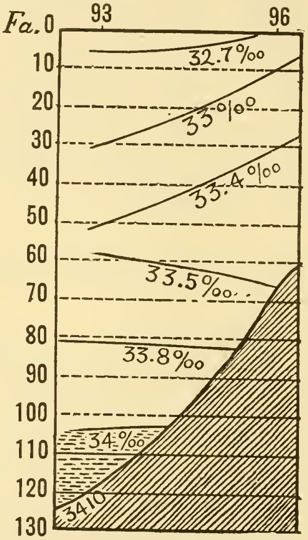

Fig. 54.— Salinity profile from the eastern basin of the Gulf of Maine (Station 10093 toward the mouth of the Bay of Fundy (Station 10096).

A profile from the basin (Station 10093) toward the mouth of the

Bay of Fundy (Fig. 54), shows that the upper layers at Station 10096 are salter than the water at corresponding depths further off shore. And this is true whether Station 10092 or Station 10093 be taken as the outer end of the profile, though the difference is slightly greater in the case of the latter. The uniform water between thirty and sixty fathoms at Station 10096 is slightly salter (33.4‰) than the mean (33.27‰) of the corresponding column of water at Station 10093. Station 10096 was likewise considerably salter as a whole than the water over the slope of German Bank (Station 10094), especially in the mid-depths; and though the latter was the salter of the two on the surface this does not invalidate the general statement, because its high surface salinity was due to local vertical mixing by tidal currents (p. 204). In short, the upper thirty fathoms of water was salter off the mouth of the Bay of Fundy (Station 10096) than on the coast bank to the south, the eastern basin, or for that matter, anywhere else in the Gulf; probably due to an updraught from the mid-depths off shore. And the profile is further interesting because the spreading of the curves for 33.4‰ and 33.5‰ over the coast slope at 50–80 fathoms suggests that vertical mixing, which in the Gulf is synonymous with tidal currents, was active on the bottom at Station 10096, though not on the surface.

Density, at the temperature in situ, Cape Cod to Chesapeake Bay.

The chart of density on the surface south of Cape Cod (Fig. 55), for the first half of July, is less significant in detail than the chart of surface salinity, because surface density was constantly falling, with the seasonal rise in surface temperature (p. 156). The off shore water was as a whole heaviest, the coast water lightest. But on our voyage south we encountered a secondary area of low density over the central part of the continental slope off New Jersey (Station 10070), as outlined by the curve for 1.0220, with heavier water (1.0227) between it and the coast, a phenomenon caused by the rapid warming of comparatively fresh surface water (p. 187) by warm southerly winds from the Gulf Stream, which prevailed at that time. And by the end of July the rise of surface temperature (p. 156) caused even lower densities next the coast (Station 10080, density 1.0215; Station 10081, density 1.02145). The density was lowest (1.0184) at the mouth of Chesapeake Bay, highest outside the continental shelf (Station 10071);

but as noted (p. 221) the water was even denser on George's Bank and in the Gulf of Maine. In general, the density rose from southwest to northeast, corresponding to the general decline of surface temperature (Fig. 1).

At all our stations south of Cape Cod the water was heaviest at the bottom, *i. e.*, it was in stable equilibrium, as is the rule everywhere,

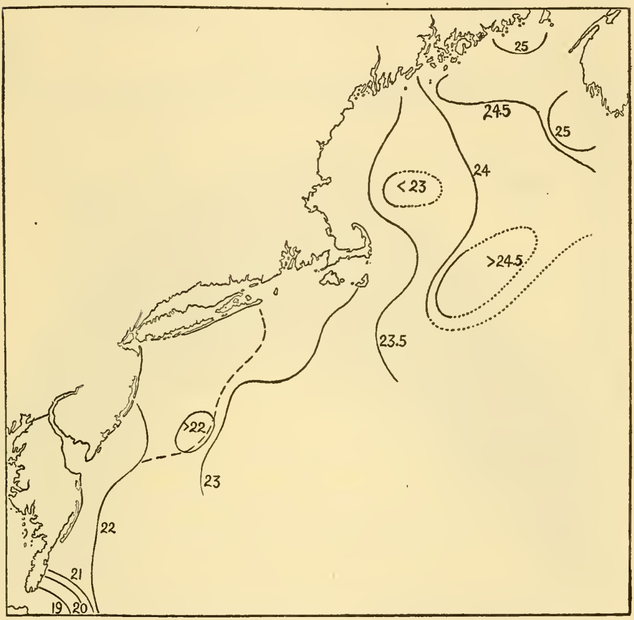

Fig. 55.— Chart showing surface density of the water south and west of Cape Cod in July, and of the Gulf of Maine in August. Curve - - - - -, July 29–Aug. 1.

in temperate regions in summer. But it varied so much, level for level, at different stations, as to suggest a potent cause for circulation. To facilitate comparison with salinity and temperature, density is reproduced here by corresponding profiles.

The first (Fig. 56), from the southern part of the basin of the Gulf of Maine (Station 10058), to the outer edge of the continental shelf (Station 10061) shows that there was very little difference in density, depth for depth, on the two sides of Nantucket Shoals, above the level of the latter (about thirty fathoms). Below that level the water was distinctly lighter on the south than on the north side of the Shoals; and the vertical stability of the water was very slight over the outer part of the shelf between the thirty-five and fifty fathom levels.

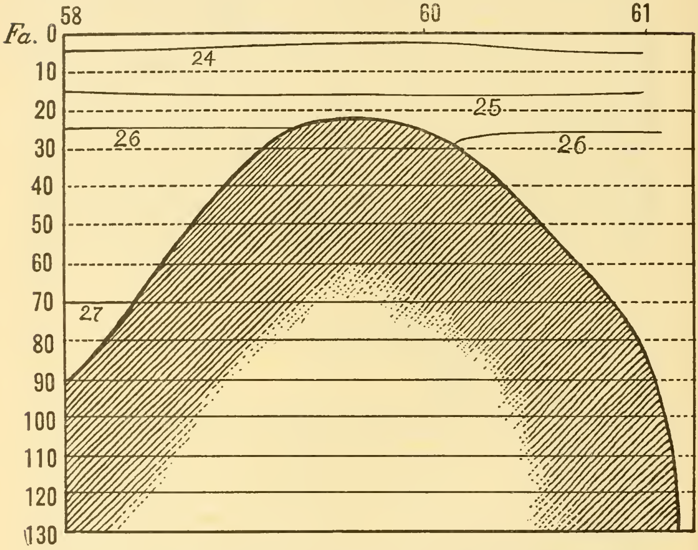

Fig. 56.— Density profile from the southern part of the basin of the Gulf of Maine (Station 10058) across Nantucket Shoals, to the continental slope south of Nantucket (Station 10061) July 8–10.

The next profile (Fig. 57) from Station 10063, off Nantucket, to the edge of the continental shelf (Station 10061), shows that down to about twenty fathoms the water was considerably lightest at the shore end. Below thirty fathoms the density curves dip seaward, especially at the outer edge of the shelf, coincident with the cold tongue (p. 165). But this condition must have been limited to a narrow east and west zone, for in the profile off New York (Fig. 58) the dip of the curves in the same relative position, is just the reverse, being steepest at the level (fifty fathom contour) where the slope of the bottom becomes rapid, *i. e.*, just below the cold tongue. At about thirty fathoms the density curves are generally horizontal, and they are probably horizontal below 100 fathoms. The next, off Barnegat

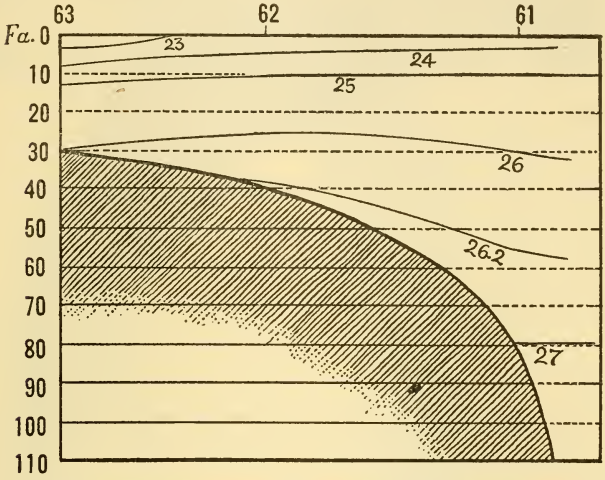

Fig. 57.— Density profile across the continental shelf southwest and south of Nantucket (Stations 10063, 10062, 10061) July 10–11.

(Fig. 59), shows a similar distribution of density, except that the surface, as well as the deeper water was densest at the seaward end, the dip of the curves being especially pronounced in the upper fifteen fathoms or so, and again at 40–50 fathoms over the continental slope.

A profile running from Station 10079 to Station 10074 (Fig. 60). shows that just south of Delaware Bay where the surface water was lightest next the coast, the reverse was true below about twelve fathoms, the bottom water being heaviest, depth for depth, next the land, while the seaward dip of the curve of 1.026, suggests a seaward

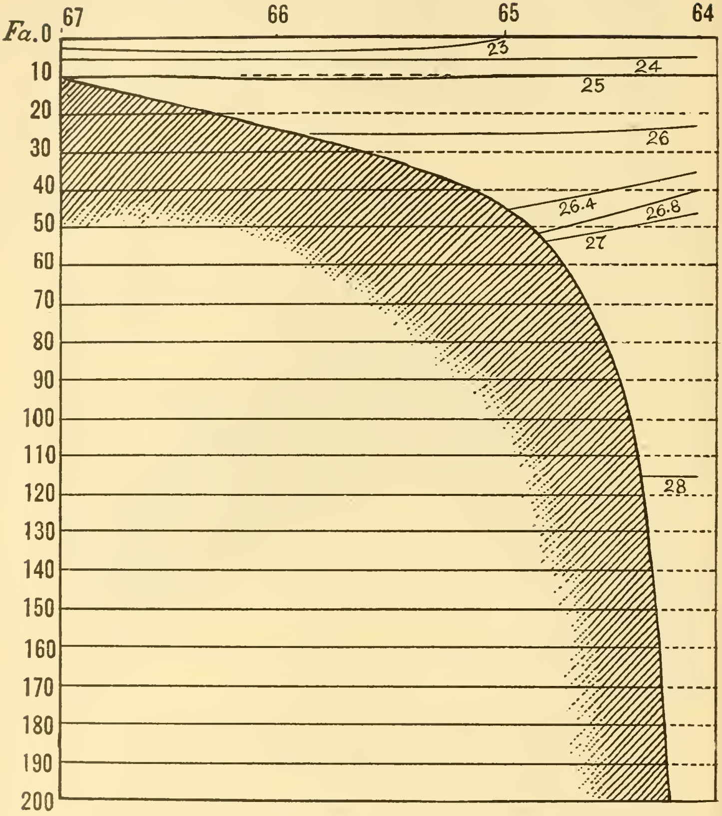

FIG. 58.— Density profile from New York to the edge of the Gulf Stream in Lat. 39° 55′ (Stations 10067, 10066, 10065, 10064) July 11–13.

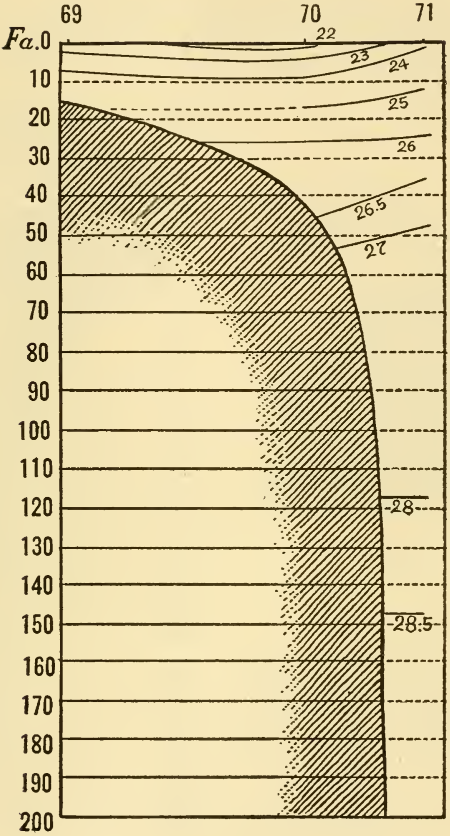

FIG. 59.— Density profile across the continental shelf abreast of Barnegat to the edge of the Gulf Stream in Lat. 38° 56′ (Stations 10069, 10070, 10071) July 19–20.

flow over the bottom. And the level at which density is uniform, horizontally (twelve fathoms) exactly coincides with the salt tongue (p. 198). The profile abreast of Chesapeake Bay (Fig. 61) shows a similar distribution of density over the inner part of the continental

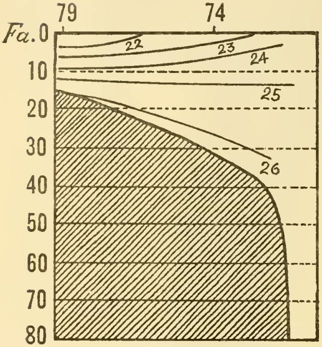

Fig. 60.

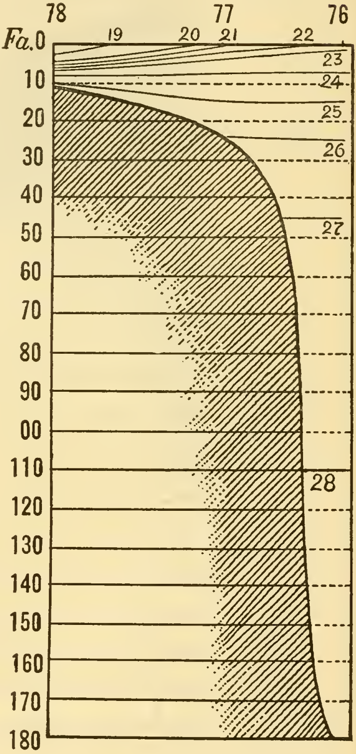

Fig. 61.

Fig. 60.— Density profile across the continental shelf south of Delaware Bay (Stations 10079–10074) July 22–30.

Fig. 61.— Density profile across the continental shelf abreast of Chesapeake Bay (Stations 10078, 10077, 10076) July 24–29.

shelf. But the seaward rise of density on the bottom is less rapid than it is further north; and density is uniform, horizontally, below twenty-five fathoms.

Density in the Gulf of Maine.

In the Gulf, in August (Fig. 55) the surface water was lightest close to shore north of Cape Ann (1.0231), off Cape Cod (Station 10085, 1.0231), and, in an isolated region, over the western basin (Station 10088, 1.0229); the latter was a local phenomenon, due to high surface temperature. Surface density was highest on German Bank (1.0254) and along the northern part of the coast of Maine (1.025), *i. e.*, in those regions where tidal currents cause the most effective vertical mixing of the water. And the surface was only slightly less dense off Lurcher Shoal, owing to its low surface temperature. We likewise encountered surface water of high density off Matinicus (Station 10101, 1.0248); And no doubt many other anomalies of this kind might be found in the Gulf, caused by local surface cooling by tide rips and vertical currents.

The surface density of most of the Gulf was 1.0236–1.0248, increasing from southwest to northeast; *i. e.*, considerably higher than over the continental shelf south of Cape Cod a month earlier; had the observations been taken simultaneously the discrepancy would have no doubt been greater, it being only reasonable to assume that the surface of the Gulf would have been cooler early in July than early in August, but with nearly the same salinity (1914a).

The table of density (p. 344) shows that the water was lightest at the surface, heaviest on the bottom, *i. e.*, was in stable equilibrium, everywhere in the Gulf. Where vertical and tidal circulation is active, as on German Bank, the stability was so slight as to offer little resistance to vertical overturning of the water. But where tides are weak, as for example off Massachusetts Bay, over the western basin, and in the trough west of Jeffrey's Ledge, the difference between surface and bottom density, and hence the vertical stability, is great. In the western parts of the Gulf in general there was a very rapid rise of density from the surface down to about 20–30 fathoms, corresponding to the rapid rise of salinity and fall in temperature in this zone; followed by a very much slower, though continuous increase, down to the bottom. But the density curves, like those for temperature are progressively straighter and straighter, passing across the Gulf from southwest to northeast. And in the northern end of the eastern basin, as well as on the Nova Scotian and Maine banks, the rise in density, whether great or little, was nearly uniform in rate, from surface to bottom; most nearly so where the stability of the water was slightest (*i. e.*, German Bank).

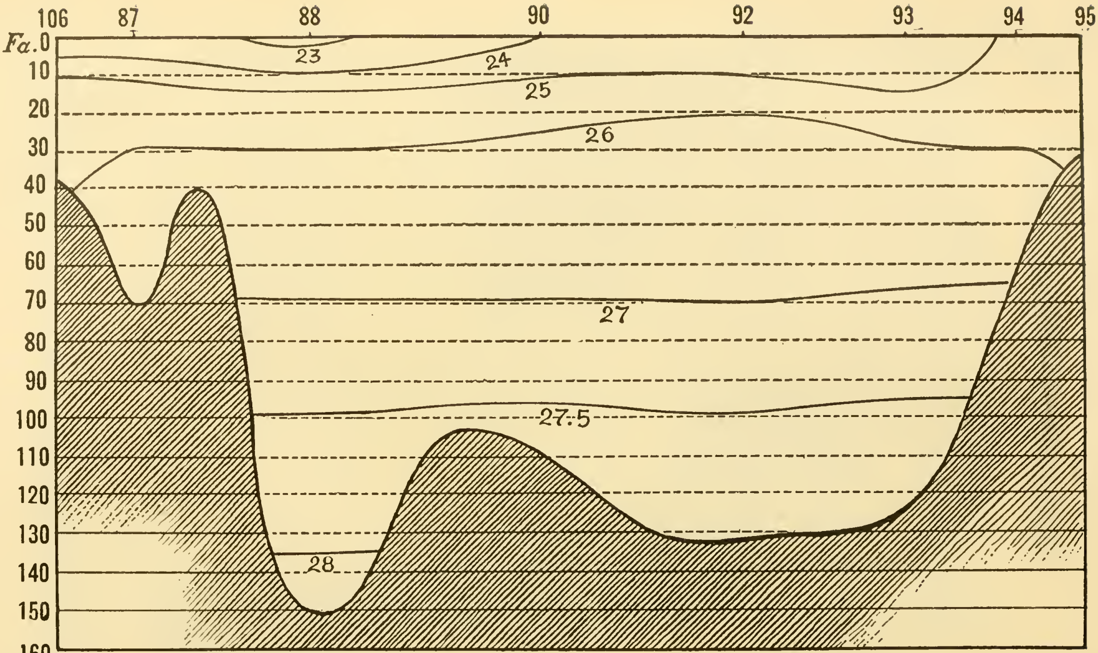

Fig. 62.— Density profile across the Gulf of Maine from Massachusetts Bay to German Bank (Stations 10106, 10087, 10088, 10090, 10092, 10093, 10094, 10095) August 9–20.

The density profile (Fig. 62) crossing the Gulf from Massachusetts Bay (Station 10106) to German Bank (Station 10095) shows that the water was nearly uniform horizontally, depth for depth, below seventy fathoms. In the mid-depths the water was densest at Station 10092. Over German Bank there is a distinct spreading of the curves reminiscent of, and due to the same cause, as the spreading of the temperature and the salinity curves in that region. And the same condition

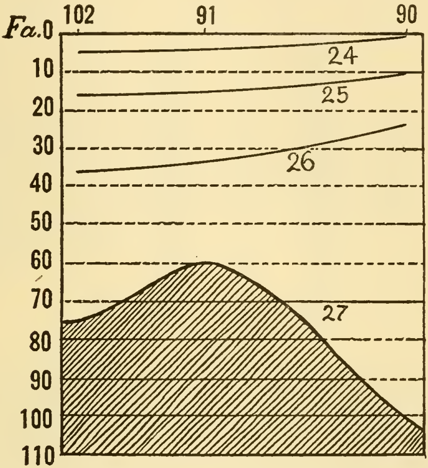

Fig. 63.— Density profile from the mouth of Penobscot Bay (Station 10102) to the centre of the Gulf of Maine (Station 10090) crossing Jeffrey's Bank (Station 10091) August 10–14.

prevails below twenty fathoms in Massachusetts Bay, just as described for salinity (p. 208).

A profile from Station 10102, near Penobscot Bay, across Jeffrey's Bank to the centre of the Gulf (Fig. 63) shows a slight rise in density passing off shore, the difference being greatest in the mid-depths. But a parallel profile further east would be exactly the reverse, the surface density being higher at Stations 10101, 10100, and 10098 than at either Station 10092 or 10093.

Color of the sea.

The observations on color, tabulated below, are interesting chiefly because there is very little precise information as to the color of the water over the continental shelf south of Cape Cod.

Color, in % of yellow, according to the Forel scale (Steuer, 1910).

Station	Color	Station	Color	Station	Color	Station	Color
10057	27	10070	5	10083	20	10096	20
10058	9	10071	2	10084	27	10097	—
10059	20	10072	9	10085	27	10098	20
10060	5	10073	2	10086	27	10099	27
10061	2	10074	5	10087	14	10100	27
10062	9	10075	20	10088	—	10101	35
10063	20	10076	2	10089	—	10102	20
10064	2	10077	9	10090	9	10103	—
10065	5	10078	14	10091	20	10104	20
10066	—	10079	14	10092	9	10105	20
10067	54	10080	14–20	10093	—	10106	—
10068	54	10081	9	10094	27		
10069	27	10082	—	10095	27		

The water was very green (27% yellow) along Cape Cod both in July and in August, and this was also the case on the western side of George's Bank (20%). But it was distinctly bluer (9% yellow) over the southern end of the basin of the Gulf and after crossing Nantucket Shoals the water grew visibly blue to the eye, being almost pure blue (2% yellow) at the 80 fathom curve south of Nantucket (Station 10061).

In general the water was greenest near land, bluest off shore, as might be expected, the water being greenest of all near New York (Stations 10067, 10068). The color was 20–27% yellow along the coast of New Jersey; that of the coast water south of Delaware Bay 14–20% yellow. The water was nearly pure blue (2% yellow) at all the stations outside the edge of the continental shelf.

The water of the Gulf of Maine was considerably greener, most so along Cape Cod (27% yellow), over German Bank (27% yellow), and along the coast of Maine between Mt. Desert and Penobscot Bay (27–35% yellow). The water was considerably bluer (9%) over the deep basins; but nowhere in the Gulf did we find the beautiful ultramarine water which washes the continental slope.

South of Cape Cod the general rule is that the water is bluest where saltest, greenest where freshest; though this does not exactly cover the case, because the water was bluer close off Chesapeake Bay than off New York, although the salinity was lower. But in the Gulf of Maine this rule did not hold either in 1912 (1914a) or in 1913, the greenest water being intermediate in salinity, while the saltest water was not the bluest.

Current measurements.

Measurements of surface and bottom currents with the Ekman Current meter (Ekman, 1905b) were taken at three stations between Cape Cod and Chesapeake Bay, with hourly readings for six hours at each station. The directions are the compass bearings (magnetic) toward which the current flows. Velocity in knots per hour is to the nearest tenth of a knot.

I. Station 10065, July 12.

High water at Fire Island Inlet at 2.05 P.M.

Hour	Depth	Duration	C. C. per sec.	Direction	Knots per hour
9 A.M.	0	4′ 58″	19.1	WNW.	.4
9 "	40	5′ 10″	10.2	NW. by N.	.2
10 "	0	5′	9.3	WNW.	.2
10 "	40	2′ 20″	22.1	W. by N.	.4
11 "	0	5′ 18″	10.7	W. by N.	.2
11 "	40	5′ 10″	3.2	NW.	Trace
12.30 P.M.	0	5′ 5″	26.9	NNW.	.5
12.30 "	40	5′ 45″	27.9	S. by E.	.5
2 "	0	4′	24.	NE.	.4
2 "	40	4′ 45″	24.9	S. by E.	.5
2.45 "	0	5′	33.3	NE.	.6
2.45 "	40	5′ 5″	15.1	S.	.3

II. Station 10072, July 21.

Low water Barnegat Inlet at 4 A.M.

1.46 A.M.	24	5′	10.	S. by E.	.2
2.15 "	4	5′	12.4	S. by W.	.2
2.30 "	0	5′	7.3	SSW.	.14
3 "	24	5′	7.2	WSW.	.14
3.15 "	4	5′	7.3	S. by W.	.14
3.20 "	0	5′	7.2	SSW.	.14
4 "	24	5′	7.3	NNW.	.14
4.15 "	4	5′	7.7	W.	.15
4.20 "	0	5′	27.3	SSW.	.5
5 "	24	5′	25.3	S. by W.	.5
5.15 "	4	5′	34.3	W. by S.	.7
5.25 "	0	5′	38.2	S. by W.	.74
6 "	24	5′	17.3	N. by W.	.3
6.15 "	4	5′	36.8	W.	.7
7 "	24	5′	14.1	N. by E.	.3
7.15 "	4	5′	36.3	W. by N.	.7
7.30 "	0	5′	36.3	W. by S.	.7
8 "	24	5′	13.2	NE. by N.	.3
8.15 "	4	5′	28.	WNW.	.54

III. Station 10074, July 22.

High water Cape May 11 A.M.
High water Barnegat 10.35 A.M.

7.45 A.M.	30	5′	5.9	S. by E.	.1
8 "	0	5′	30.	W.	.6
8.45 "	30	5′	2.8	?	Trace
9 "	0	5′	28.8	W.	.55
9.45 "	30	5′	9.7	SSE.	.2
10 "	0	5′	20.	NW. by W.	.4
10.45 "	30	5′	9.7	S. by E.	.2
11 "	0	5′	9.7	NNW.	.2
11.45 "	30	5′	16.3	SSE.	.3
12 "	0	5′	10.5	N. by W.	.2
1.10 P.M.	30	5′	7.7	S½W.	.15
1.20 "	0	5′	4.	NNE.	.1
2 "	30	5′	9.9	S.	.2
2.10 "	0	5′	18.3	ENE	.35
3 "	30	5′	5.6	SSE.	.1
3.10 "	0	5′	14.3	E½N.	.3

At Station 10065, over the 45 fathom curve, fifty miles south of Long Island, the first reading was taken about five hours before high water at Fire Island Inlet, the nearest shore station for which tidal data is available. The surface current ran northwesterly for the first three hours; and then veered to the north and northeast, in which direction it flowed, till the end of the set. Of course the observation does not show conclusively whether or not there was a dominant drift in any direction, because it did not cover the last half of the ebb; but it goes far enough to show that the flood current ran about northwest; the first half of the ebb to the northeast, the strength of the flood being .2–.6 knots, of the ebb .4–.7 knots per hour (Fig. 64).

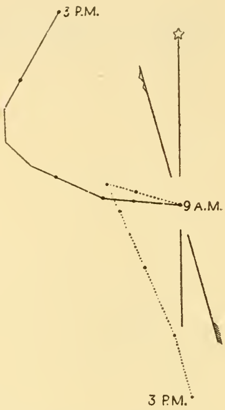

FIG. 64.— Surface current ———, and bottom current . . . . . . at Station 10065; hourly from 9 A.M. to 3 P.M., July 12. The distance between dots (.) shows the drift for each hour; 2.25 cm. = 1 sea mile. The compass arrows are true and magnetic.

The total drift for the part of the tide covered by the set is about 1.8 knots north. And it seems hardly probable that the last few hours of the ebb would wholly nullify this, the general trend of the coast in this region being such that it is safe to assume that the last part of the ebb flows about east, the first part of the flood westerly. And even if the late ebb ran southeast with a velocity of .5 knots, there would still remain a net northerly drift of nearly .5 knots. It is therefore fair to conclude that there was a slight dominant northerly movement of the surface water over this part of the continental shelf.

The bottom current turned an hour earlier than the surface current. During the last three hours of the flood the flow on the bottom was toward the northwest, with a velocity diminishing from .4 knot to zero. It then veered to the south by east, and south, running in that direction for three hours with the considerable velocity of .35–.5 knot per hour. The total set showed a net movement of water of about 1.4 knot toward the south-southwest; but it is a question whether there was any dominant flow on the bottom, for if the current veered to the southeast and east during the last of the ebb, with a northwest current throughout the flood, as is not unlikely, the net drift would be neutralized.

Fifty miles off Cape May (Station 10072) readings were taken at zero, four, and twenty-four fathoms, from 1–46 A.M. to 8–15 A.M., the time of low water being 4 A.M. at Barnegat Inlet (Fig. 65). The surface current ran southwest during the entire set, veering toward the west (S. S. W. to W. by S.) with velocities ranging from .15 knot at the beginning to .7 knot at the end, showing that the tide started to flood shortly before we began work. The total drift was about

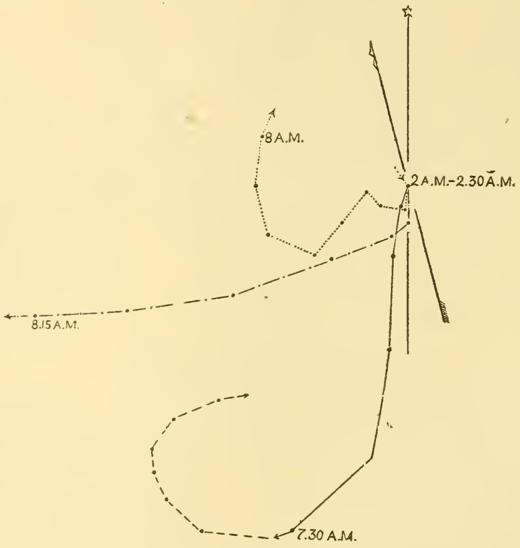

FIG. 65.— Surface current ———, 4 fathom current — · — · — ·, and bottom current. . . . , at Station 10072; hourly from 2 A.M. to 8 A.M., July 21. The surface current of Station 10074,. . . . , is combined with Station 10072 to show total drift for an entire tide. 2.25 cm. = 1 sea mile.

3 knots southwest. At four fathoms the current veered from S. by W. through west, to W. W., N. the velocity ranging from .14 knot to .7 knot, the net drift 3 knots west, *i. e.*, toward shore. The bottom current at twenty-four fathoms veered irregularly from S. by E., through S. W. west, and northwest to northeast, with velocities

ranging from .14 knot to .5 knot, greatest when the flow was southwesterly and northwesterly. The total drift was about 1 knot toward the northwest. These three sets were planned to cover the last half of the ebb, and the first half of the flood. But the observations show that the flood current had begun to run one to two hours earlier than the time of low tide at Barnegat. Hence, the set must have been confined to the flood, and therefore can not show whether there was any dominant drift. To remedy this defect it would have been necessary to continue the set for six hours more, but this was impracticable, owing to a sudden squall. Consequently a third set of current measurements was made the next day at Station 10074, so timed as to

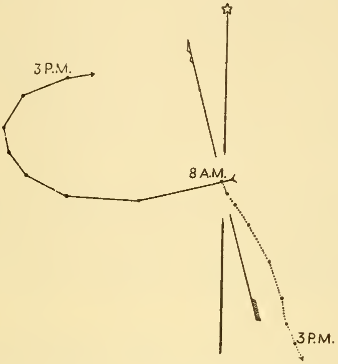

Fig. 66.— Surface current ———, and bottom current. . . ., at Station 10074, for each hour from 8 A.M. to 3 P.M., July 22. 2.25 cm. = 1 sea mile.

cover the last of the flood and most of the ebb (Fig. 66). The surface current at Station 10074 set westerly for the first two hours, *i. e.*, during the last of the flood. It then veered gradually through northwest, north, and northeast to east, in which direction it was running with a velocity of .3 knot at the end of the set. The velocities were .6 knot for the first two hours; .1 knot to .4 knot after that. The total net drift was about 1.5 knot to the northwest.

The bottom readings were less satisfactory than those on the surface, because of the weakness of the current. In general the flow was toward the south and south-southeast, varying irregularly between these two bearings, the total drift being about 1.2 knot toward the south by east. On combining the stations, omitting the first hour of 10074 to compensate for the advance of the tide during twenty-four hours, a southwesterly surface drift of 2.2 knots and a southwesterly bottom drift of about 1 knot results.

The last two hours of the ebb are still to be accounted for; the regular veering of the surface current suggests that it continues to swing toward the east and southeast, and general knowledge of similar tidal currents suggests a diminishing velocity. These two stations, then, taken together, indicate a dominant southwesterly current with a velocity on the surface, of two to three knots for an entire tide, *i. e.*, four to six knots in twenty-four hours. Of course the validity of this conclusion depends on whether a combination of these two sets of observations, as though they had been made at one station, is justified, and there is no apparent objection to so doing, either in the contour of the bottom, the course of the shore line, or in the amplitude of the tide at the two stations. Nor was there anything in the weather conditions to suggest that the surface current was a wind drift at either, because Station 10074 was occupied during a calm, and after a calm night; Station 10072 likewise after a calm night, and in a moderate breeze. And so far as the observations go, the velocity of the tidal currents was apparently about the same at the two stations, being about .7 knots per hour for the fifth hour of the flood at Station 10072, .6 knot at Station 10074. The bottom currents likewise suggest a slight southwesterly drift.

Circulation over the continental shelf, July, 1913.

Our current measurements, salinities, and densities allow a tentative reconstruction of the movements of the water over the continental shelf at the time of our visit. During the spring there must have been off shore surface currents opposite four main sources of fresh land water, *i. e.*, Long Island Sound, the Hudson River, Delaware Bay, and Chesapeake Bay, to produce the tongues of low salinity which we encountered there (Plate **2**). These currents must have been at their height at least a month earlier, *i. e.*, at the time of the greatest river freshets; the Delaware current reaching its maximum after the middle of May, because the salinity was higher off the Bay on May 9 (p. 188) than we found it (p. 198). The drift, as indicated by salinity, was easterly off the mouth of Long Island Sound, and there must have been a similar, but more pronounced off shore current opposite Chesapeake Bay, much as it is represented on the current chart of the North Atlantic (Soley, 1911), and surface density suggests that the fresh water from the Bay spreads out, fan-like, to the north, as well as over the heavier ocean water. The salter water which alternates with these comparatively fresh tongues is in part a contrast phenomenon; but the salinity curves immediately south of Delaware Bay can only be explained as due to an actual shoreward drift of water of high salinity (p. 187). And the current data at Station 10074 suggest, though they do not prove, that this salt tongue was swinging, eddy-like, toward the southwest. Just north of Delaware Bay, there seems to have been a similar eddy-like movement which, added to the southerly flow of coast water, produced the strong southwest current which was found at Station 10072. Surface salinities, like the current measurements at Station 10064 suggest traces of a northerly movement, or "banking up" of the ocean water south of Long Island, a process which had progressed so far by the end of August as to raise the surface salinity from about 32.8‰ (Station 10062) to about 34‰ (Station 10112).

Surface density, being practically the same off Cape Cod as over the outer part of the continental shelf south of Nantucket, does not indicate any general flow across Nantucket Shoals into the Gulf of Maine in July, or *vice versa;* nor does surface salinity afford any unmistakable evidence of a dominant current in that region, though the curve of 33‰ suggests a possible southeasterly drift. Salinities show that there must have been an indraught of ocean water into the eastern side of the Gulf, which is consistent with the fact that the surface density of the northern and eastern parts of the Gulf was very much higher than that of the ocean water outside George's Bank. To compensate for this tongue of ocean water, there was an outflow of land water off Penobscot Bay; and the salinity curves suggest a general southward drift of surface water along the western coast of the Gulf (Plate 2).

The salinity curves, and our actual current measurements, agree very well with the earlier data, as summarized in the U. S. Coast Pilot (1912). According to the latter the prevailing drift over Nantucket Shoals is easterly, which agrees so well with our salinity curves as to make it a fair assumption that there is actually a dominant easterly current in this region in summer. The few current measurements which have yet been made on George's Bank (U. S. Coast Pilot, 1912, Mitchell, 1881) indicate a similar easterly drift, veering northward near the eastern edge of the Bank. And although the observations are insufficient for any definite mapping of currents in a region where the tides are so strong, it is certainly suggestive that this northerly trend near the eastern end of the Bank corresponds with the salt tongues which were found in the eastern side of the Gulf in both 1912 and 1913. But an easterly and northeasterly movement of water on the Shoals and over George's Bank, does not mean that there is a general easterly long-shore current, both because there is no dominant drift at Nantucket light-ship (U. S. Coast Pilot, 1912, p. 10), and because the various records agree in crediting the coast waters south of Marthas Vineyard as a whole with a westerly, southwesterly, or northwesterly drift. In short, present indications point to the conclusion that the movements of surface water are tidal there, in the form of an irregular, perhaps intermittent eddy, which receives greater or less accessions of Gulf water on its northern side, and of ocean water along its southern and southeastern edge. The latter is an important factor in summer when it must influence hydrographic conditions on the banks profoundly, just as it does over the continental shelf further west (p. 198). And it exerts an unmistakable influence on the oceanography and plankton of the Gulf of Maine as well.

The outrush of comparatively fresh water from Long Island Sound, shown by the salinity curves, is substantiated by current records; and the northwesterly current over the forty fathom curve south of Block Island, represented on the current chart in the Coast Pilot, corresponds with our current records over the same part of the shelf a few miles further west. But the changes which take place in the surface salinity of this region at different seasons show that it is by no means a permanent phenomenon, probably being reversed in spring by the outrush of shore water.

The combined evidence of the various records of ocean currents, our own included, points to the conclusion that the dominant drift over the continental shelf, south of New York, is to the southwest; and this is certainly the prevalent opinion of practical navigators and hydrographers. But it does not necessarily follow that this drift is a simple, long-shore current, as has so often been suggested. On the contrary, surface salinity shows that it is interrupted by outpourings of comparatively fresh water off the rivers and bays, at least in spring and summer, and, conversely, by shoreward movements of salt ocean water. Furthermore little evidence was found of any appreciable southerly flow on the bottom, even in water as shallow as twenty-four fathoms, though there was an unmistakable southwesterly current on the surface. The correct explanation is that the movement of the surface waters over the shelf is chiefly a series of great eddies, receiving water, on the one hand from the Gulf Stream off shore, on the other, from the land. The accompanying chart (Plate **2**) shows an attempt to reconstruct the surface currents, for the summer months; but so intricate is the problem, and so scanty the reliable information yet at hand, that it is only tentative.

It is even more difficult to reconstruct the movements of the subsurface water, because we must rely almost wholly on the GRAMPUS observations. These current measurements do not prove any dominant flow on the bottom north or south of Delaware Bay (p. 230), and it is questionable whether any general flow can be deduced from them south of Long Island. But salinity, density, and temperature show that the bottom and intermediate waters over the shelf are far from being stagnant, though their movements, other than tidal currents, are probably slow as compared with the surface currents.

The density profile across Nantucket Shoals does not suggest any flow into, or out of the Gulf of Maine in this region at any depth; nor does the density of the bottom water of the Gulf suggest any influx of ocean water from the zone between fifty and 130 fathoms, via the Eastern Channel.

The seaward dip of the density curves south of Nantucket together with the cold tongue (p. 165) shows that the bottom water was flowing seaward down the shelf from the fifty fathom curve, indenting into and mixing with the ocean water over the slope (Fig. 10); and this agrees with the salinity curves. But south of Long Island, the fact that the density curves are just the reverse, together with the sudden rise of salinity immediately below the cold tongue, suggests that here the ocean water was sinking, obliquely, toward the land below the cold, fresh coast water. And to judge from the densities, a similar movement of water must have been taking place over the outer part of the shelf off Barnegat also.

The salt tongue which indents the fresher coast water in the mid-depths over the continental shelf between Delaware Bay and Chesapeake Bay (p. 198) is as interesting as the cold tongue off Long Island. Just south of Delaware Bay, there seems to have been an actual movement of surface water toward the coast (Fig. 60), gradually mixing with and sinking below the much fresher, hence lighter coast water. At twelve fathoms, *i. e.*, the axis of the salt tongue, the density was uniform, east and west; below twelve fathoms, the density gradient dipped from land to sea. Thus ocean water must have been coasting, as it were, down the density gradient, from near the surface over the 100 fathom contour to about twelve fathoms over the thirty-five fathom contour, with the heavier, though fresher, bottom water of the shelf moving seaward below it. Density points to a similar type of circulation off Chesapeake Bay. But this phenomenon must be transitory, because as the coast water grows warmer with the advance of the season its density on the bottom must fall as low as that of the salter water off shore.

The band of uniform salinity which we traced from Station 10063 to Station 10069 (p. 194) was not the result of vertical mixing; had it been temperature like salinity would have been equalized. Its origin is obscure.

Neither density, salinity, nor temperature indicates any general longshore movement of the bottom waters on the shelf.

Previous records of temperature and salinity Cape Cod to Chesapeake Bay.

The existence of a band of cold water between the Gulf Stream and the coast has been recognized since the days of the early voyages to these shores. By 1850 its general geographic limits were well understood (Maury, 1855), since which time a vast body of surface temperature readings has been taken over the continental shelf by vessels entering the ports of New York, Philadelphia, and Chesapeake Bay, as well as by various expeditions and government services. But most of these have never been published; and since, in any event, the general range of summer temperature is now well known, I need refer here to only a few of the more important sets of observations. The data obtained by the U. S. Fish Commission south of Marthas Vineyard between 1880 and 1882, (Tanner, 1884a, 1884b; Verrill, 1880–1884b), show the general rise of temperature passing off shore from the southern coast of New England. And records have constantly been kept at Woods Hole since that time, so that there are very satisfactory data of the temperature close to shore in that region. The more recent of these are summarized by Sumner, Osburn, and Cole (1913), who find that the monthly surface mean for a five year period, at the Woods Hole Station, is 31° in February, 43.9° in April, 68.8° in July, 69.7° in August, 48.2° in November. In Vineyard Sound the mean surface temperature, August, 1907, was 64.7°, November, 1907, 50.9°; March, 1908, 36.6°; June, 1908, 56.5°. The surface temperatures of the water close to the coast south of New York are likewise well known for all months in the year (Rathbun, 1887) owing to the extensive series of temperatures taken at various light-houses and light-ships, notably "Winter quarter Shoal," and "Five fathom bank" off Cape May from 1881–1885. At the former, on July 25, *i. e.*, about the time the GRAMPUS passed there, the temperature was 74° in 1881, 72° in 1882 and 1883, 69° in 1884, and 74° in 1885. Our records, a few miles away, July 21, were 74°–75°. But by July 30, a surface temperature of 76° close to the light-ship was noted. At "Five fathom bank" the temperature, on July 25, 1881, was 71°; 73° in 1882; 71° in 1883; 74° in 1885: on July 21, 1913, it was 73°–74°, a few miles to the east, rising to 77° close to the light-ship on July 31. Off Sandy Hook, July 19, the surface temperature was 71° in 1881 and 1882; 74° in 1883; 65.5° in 1884; 69° in 1885. On July 17, 1913, it was 68°–69°. On Nantucket Shoals, 40° 54′ N., 69° 49′ W., *i. e.*, some seventeen miles north of the present location of the light-ship, the surface temperature, July 10, ranged from 55° to 60° for the five-year period. On July 9, 1913, it was probably about 56°, *i. e.*, about the same; but the GRAMPUS did not visit this exact spot; and the surface temperature varies with the greater or less violent tides over the shoals.

The general summer temperature of the water over the outer part of the continental shelf is now well known for the region south of Martha's Vineyard, thanks to Verrill (1880–1884b) and Libbey (1891, 1895).

In July and August, 1881, the surface temperature south of Marthas Vineyard was slightly cooler than in 1913, from 63° over the forty fathom curve, to 66° over the fifty fathom curve, and 72° over the 100 fathom curve (Verrill, 1881, 1884b), whereas on July 11, 1913, a few miles further east, it ranged from 65°–67° between the forty and the seventy-five fathom curves. Over the 100 fathom curve, on the other hand, the 1913 temperatures are a little the lower (69°–70°, as against 72°). Unfortunately Verrill's data for 1882 are not directly comparable, because taken in August. But during that month the surface water outside the sixty fathom curve south of Marthas Vineyard was constantly warmer than 70°, *i. e.*, about as much warmer than the year before for that month, as 1913 was warmer than 1881 in July. In 1889 Libbey (1891) took an extensive series of surface temperatures south of Block Island and Marthas Vineyard, affording the most complete temperature survey of a limited locality yet attempted off the American coast. Any analysis of these records would require a study of diurnal warming and nocturnal cooling, to make them comparable with one another. But this is not necessary here, because, after all, they are not strictly comparable with our observations, having been taken from three to six weeks later in the season, and hence may be expected to be higher. They suggest that the surface water in that year may have been rather cooler than we found it, for Libbey (1891) found much the same temperature at the end of July that was observed in the first half of the month; *i. e.*, July 24, 1881, 62.8° at the 25 fathom curve south of Nantucket; 66°–67° over the outer half of the shelf; 68° at the 100 fathom curve.

A large number of surface temperatures have been collected by Dickson (1901) for the years 1896, 1897. In July 1896, according to his charts, the surface temperature from Marthas Vineyard to New York was between 60° and 68°, above 68° off New Jersey. By August it had risen to 68°, the greater number of the records having been taken, no doubt, along the direct steamship line from Nantucket light-ship to Fire Island light-ship. In 1897 the water was warmer, being upwards of 68° from Nantucket to New York. According to the British Meteorological office (Sumner, Osburn, Cole, 1913, p. 438) the mean surface temperature, some thirty miles south of Marthas Vineyard, is 67° in July, 69° in August: 66° and 70° respectively in Long Island Sound; 71° and 73° in the mouth of Delaware Bay; 75° for both months over the 100 fathom curve off Chesapeake Bay. Hautreux (1911) gives the average surface temperature, for a five-year period, off Fire Island light-ship, as 66.2° for both July and August. How closely the temperatures obtained in July, 1913, agree with Sumner's averages is illustrated by the fact that we had precisely the same reading off Fire Island light-ship; off Marthas Vineyard (Station 10063, 67°); off the edge of the continental slope abreast of Cape May (73°); and the difference off Chesapeake Bay was only 1°–2°. And they lie within the range for 1896, as given by Dickson, but are colder than his records for 1897. On the other hand the water was warmer off New York in 1913 than the five-year average given by Hautreux, 69° instead of 66.2°.

The summer temperatures outlined above are enough to show that 1913 may be considered a perfectly normal year; 1881, 1884, and 1889 were cooler, and 1897 warmer. And in view of the fact that in summer the surface temperature over the continental shelf depends largely on the wind, it is doubtful whether the very slight differences between these years have any general significance.

The general range of surface temperature over the continental shelf between Cape Cod and Chesapeake Bay, so far as known, may be summarized as follows: — in February, the coldest season of the year, the temperature of the water is very low indeed close to the coast and in the bays and sounds, 31°–36° near Woods Hole, rising, toward the southwest, to about 35° near New York (Rathbun, 1887); about 36° off Cape May, 37°–38° at Winter Quarter Shoal; and even south of New York, freezing temperatures may occur near shore during very cold weather. But such low temperatures are limited to a very narrow belt, the winter temperature over the continental shelf as a whole being 40°–45°, rising suddenly to about 50° over the continental slope. And, of course, the surface water is still warmer further to the east and southeast, *i. e.*, in the Gulf Stream. With the advance of spring the temperature of the shore water rises steadily, until by the first part of July, the water over the continental shelf ranges, in temperature, from 75° off Chesapeake Bay to 68°–70° south of Marthas Vineyard. During mid-summer the temperature is locally higher next the coast than it is over the shelf, often even higher than the surface water of the Gulf Stream in these latitudes. For instance, the temperature immediately off Chesapeake Bay, in July, 1913, rose to 80°; off New York to 75°; off Long Island to 70°–71°. And the summer warming of such enclosed waters as Woods Hole and Nantucket Sound outstrips the rise of temperature over the shelf, until, as the summer advances, the shoreward movement of Gulf Stream water may obliterate this difference by raising the surface temperature over the shelf as a whole to 70° or over. And Gulf Stream water, with its characteristic plankton, often floods Narragansett Bay and Vineyard Sound in late summer, though the extent to which this happens differs from year to year, depending on the direction of the wind. The surface temperature of the coast water reaches its maximum in August.

To the student of ocean circulation one phenomenon in this annual cycle is of great importance, namely, the fact that where the water cools most rapidly, and to the greatest degree, in autumn and winter, *i. e.*, close to the shore, there it warms up most rapidly in spring and summer.

A large number of subsurface temperatures have been taken in the waters south of Marthas Vineyard, beginning with a series of bottom readings, by the vessels of the U. S. Bureau of Fisheries, in 1880, 1881, and 1882; and continued by Libbey (1891, 1895), who took several thousand readings at intermediate depths in 1889, 1890, and 1891. But these were all made in summer and early autumn; and our knowledge of subsurface temperatures on the continental shelf at other seasons, and at any season elsewhere than in the region studied by Libbey and Verrill, is limited to a few bottom readings taken by the FISH HAWK (Tanner, 1884a, 1884b), BLAKE (Smith, 1889) and ALBATROSS (Townsend, 1901). Verrill's observations were located at successive points across the zone between the fifty and 150 fathom contours, and they are especially valuable, because they were taken before and after the extraordinary mortality of the tile fish, *Lopholatilus chamaeleonticeps,* of 1882 (p. 266). On July 21, 1880, the BLAKE ran a line across the continental shelf from Montauk Point, getting the following bottom temperatures: 24 fathoms, 60°; 43 fathoms, 49°; 71 fathoms, 51°; 129 fathoms, 51°; and 732 fathoms, 39.5°. Although these readings were taken with the Miller-Casella (maximum-minimum) thermometer, and hence register merely the coldest water at each station, which may not have been on the bottom, they show that the cold water on the shelf was separated from the even lower temperature of the abyss by a warmer belt at 75–130 fathoms, just as it was in July, 1913; and that this condition obtained as far east as the northeast end of George's Bank, where the bottom temperature, following down the continental slope, rose from 42° at seventy fathoms to 44° at 139 fathoms, and then fell to 40.5° at 300 fathoms. This "warm belt" was certainly distinguishable as late as August 17, 1880, when the FISH HAWK found bottom temperatures of 40°–48° in about thirty fathoms off Block Island. In September and October of the same year, the FISH HAWK took a considerable number of bottom temperatures on the shelf south of Block Island with deep-sea thermometers of the reversing type, finding about the same temperature (51°–53°) at 100–142 fathoms as in July, with colder water deeper down the slope (Verrill, 1880, Tanner, 1884a). But no readings were taken on the inner part of the shelf except in the very shallow water close to shore. The BLAKE records suggest that the water on the shelf south of Block Island was several degrees warmer, depth for depth, in 1880 than in 1913; but the discrepancy may be due to the fact that the observations were taken two weeks later in the former year.

The FISH HAWK temperatures for 1881 (reversing thermometers), again demonstrate the existence of the "warm belt" bathing the bottom at 70–100 fathoms, with lower bottom temperatures in the shallower water near shore (Verrill, 1881, 1884a, Tanner, 1884b), much the same distribution of temperature as in 1913. Thus on a line S 1/2 W from Marthas Vineyard, the bottom temperature rose from 42° at forty-four fathoms to 52° on the bottom between the sixty-seven and ninety-eight fathom curves, below which it fell slowly to 42° at 229 fathoms, as illustrated by the following table, constructed from Verrill's data.

Line S 1/2 W from Marthas Vineyard, July 16, 1881.

Fathoms	Bottom temperature
44	42°
46	45°
53	42.5°
63	49°
67	52°
98	52°
164	44.5°
199	44°
229	42°

The absolute temperatures of 1881 closely parallel those of 1913, *i. e.*, Verrill found a bottom temperature of 52° at seventy-seven fathoms, August 14, close to the location of Station 10061, where the bottom reading was 51.5° in seventy-five fathoms. Near Station 10062 Verrill's bottom reading was 42° in forty-four fathoms, 43.6° that of the Grampus in forty fathoms, five days earlier in the season.

The records for 1881 and 1913 are not directly comparable outside the 100 fathom curve because the former were made six weeks later in the season than the latter, at the one location visited in both years. And the seasonal difference shows its effect in higher temperatures for 1881. Thus, near Station 10064 Verrill's readings, September 8, were 47.5° and 45° at 182 and 216 fathoms, depths at which the temperatures, on July 11, 1913, were 45.7° and 43°. In October, 1881, the Fish Hawk took a series of temperatures off Delaware Bay, finding 51° on the bottom at about 100 fathoms (Verrill, 1882a; Tanner, 1884b). And on November 16, of the same year, she found the bottom temperature 56° in 31 fathoms, 55° in 56 fathoms and 48° in 157 fathoms, off Cape Charles (Tanner, 1884b).

In 1882 the bottom water on the continental shelf was decidedly colder than it was the year before (Tanner, 1884c; Verrill, 1882, 1884a). And even more important is the fact that Verrill found no trace of the warm belt at 75–100 fathoms. On the contrary the bottom readings grew colder and colder seaward from the seventy fathom curve, as follows: —

Bottom temperatures south of Marthas Vineyard, August 22, 1882.

Fathoms	Temperatures	Fathoms	Temperatures
65–70	49°	145–155	46°
89	48°–49°	171	43°
100	47°–48°	245	43°
116	48°	300	40°
124	47°		

And the fact that the temperatures of 1882 were taken when the water was at its warmest (a month later than those of 1881) suggests that the discrepancy for the two years would have been even greater had both sets of readings been taken at the same season. The only one of our stations directly comparable with the above is Station 10112, over the sixty fathom curve south of Marthas Vineyard, August 22, where the temperature was 58.9° at sixty fathoms, *i. e.*, nearly 10° warmer than in 1882. The deep waters of the Gulf of Maine were likewise unusually cold in 1882 (p. 244), and the remarkable mortality of fish which took place in the spring of that year has usually been accounted for by the abnormally low temperature (p. 266).

The only records available for the next year (1883) are a few scattered observations by the ALBATROSS (Townsend, 1901), unfortunately all outside the 100 fathom curve. They show that the temperature south of Marthas Vineyard was 48° at 131 fathoms in May, and 49° at 117 fathoms in September. In September, 1884, the ALBATROSS took a series of bottom temperatures south of Nantucket, extending from the eighteen fathom curve out to the continental slope, with the following results:

Bottom temperatures, south of Nantucket, September 26–28, 1884.

Fathoms	Temperature	Fathoms	Temperature
18	55.9°	58	52.9°
25	54.4°	78	51.9°
38	50.3°	98	50.9°
43	50.2°	122	48.8°
46	51.4°		

This series was taken a month later in the season than our 1913 stations, which perhaps explains the high temperatures on the inner part of the shelf in 1884. And the fact that our one Station (10112) at the end of August was considerably warmer than the 1884 records shows how difficult it is to compare scattered records, owing to fluctuating influences on the part of the Gulf Stream. Nevertheless the ALBATROSS temperatures are instructive because they show that in 1884 the cool water which bathes the shelf was once more separated from the cold water of the depths by a warm belt; *i. e.*, that the normal distribution of temperature was reëstablished.

We know nothing about the subsurface temperatures of the next four years. But in 1889 Libbey took no less than 1600 temperatures on the surface and at depths, over the region south of Marthas Vineyard and Block Island. These records are so arranged as to show the distribution of temperature in great detail for the region studied; and they are so extensive that I can only summarize them here. Full tables, with charts and profiles, have been published by the U. S. Bureau of Fisheries (Libbey, 1891). Libbey's profiles show a cold tongue projecting southward into the warm off shore layers, in the mid-layers, such as we found south of Marthas Vineyard (p. 165, figs. 9, 10). The course of the curve of 50° in most of his profiles suggests that the cold bottom water of the shelf was directly continuous with the cold water of the depths under the Gulf Stream, instead of being separated from it by a zone of warm bottom water. But his own tables show that the few bottom readings which he took in the zone bounded by the seventy and ninety fathom contours were warmer than the bottom water either in shallower or in greater depths. And although his profiles off Nantucket, (Longitude 70°–71°) even more strongly suggest a continuity between the cold bottom water of the shelf and of the deeper part of the slope, this is chiefly because a 10° interval between the curves is too great to illustrate the actual conditions, the temperatures on which his profile D (Longitude 70° to 70° 20′) was constructed showing that the coldest water on the shelf (42°, 50 fathoms) was underlaid by warmer water (45.3° to 47.4°). And the bottom temperature was even higher at ninety fathoms. In short, the cold coast water was separated from the cold water of the abyss by a warmer zone, in 1889, with a temperature of about 47°–51° at 70–100 fathoms. And the same was also true in 1890 (Libbey, 1895).

In 1889 the absolute temperature of the cold tongue was 46°–47° off Block Island, falling to about 42°–43° south of Nantucket, which agrees fairly closely with our observations at Stations 10065 and 10061, in July, 1913. But the facts that Libbey's temperatures were taken late in August, by which time the water was much warmer in 1913 (Station 10112), and that the cold tongue projected much further seaward in 1889 than in 1913, are good evidence that the water as a whole over the continental shelf was colder in that year. Judging from his profiles, 1890 seems to have been intermediate between 1889 and 1913.

Libbey continued his survey of subsurface temperatures in subsequent years; but the results have never been published, nor, except in a few instances, have the various bottom temperatures taken by the vessels of the U. S. Bureau of Fisheries on collecting trips south of Marthas Vineyard. Hence it is not possible to draw any comparison between 1913 and any year since 1890.

There are no records of subsurface temperatures for winter, or spring, except in the water close to the coast, *e. g.* at Woods Hole.

The temperatures taken in the Gulf of Maine by Verrill are summarized elsewhere (1914a); but the records obtained by the SPEEDWELL (Smith, 1887), the FISH HAWK (Verrill, 1882, 1884a, Tanner, 1886) and by Dawson, (1905), were omitted there. The SPEEDWELL took bottom and serial temperatures in various parts of the Gulf in the summers of 1877, 1878, and 1879; but those of 1877 are of little value, because taken with Miller-Casella thermometers, two instruments often differing by as much as 6° when used simultaneously at the same depth. In 1878 and 1879, however, the Negretti and Zambra reversing thermometers were employed. Sixteen serial temperatures, in July, August, and September, 1878, in depths greater than twenty-five fathoms, show that the water was slightly colder below about forty-five fathoms at the mouth of Massachusetts Bay, and off Cape Ann, than in 1913, and less uniform vertically; with bottom temperatures of 38.5° to 41.2°, instead of about 40.3° as in 1912; 41° or more as in 1913. And the bottom water of the western basin was 38.5°–39°, as late as August 31 in 1878. But in August the surface layers were decidedly warmer in 1878 than in either 1912 or 1913, as illustrated by the following serial temperatures in Massachusetts Bay.

	1878	1912	1913
		Station 10045	Station 10106
	Aug. 29	Aug. 31	Aug. 20
Depth	T°	T°	T°
0	64.2°	61°	61°
5	60	57	56
10	57	53	51.5
15	52.5	50	48.5
25	50.5	45	46
30	45	44.9	45
35	44	43.6	44
40	42.5	43.1	
45	41.5		

In 1879 the water was colder in the southern part of Massachusetts Bay than we found it in 1912, except on the immediate surface, as illustrated by the following pair of stations some eight miles northwest of Race Point: —

	1879	1912
Depth	Aug. 25	Aug. 31
0	61.2°	58.0°
5	49	55
10	44.5	52.7
15	43.5	47
20	43.5	45.9
25	43.5	44.6
30	43.5	44.3

and the difference can not be explained by differences in vertical circulation, the mean temperature being 46.7° in 1879, 49.9° in 1912. But by the end of September, 1878, the SPEEDWELL found the temperatures in this region very close to the GRAMPUS records of a month earlier, *e. g.*, 58°–59° at the surface, 44°–45° at thirty fathoms. There was even a greater difference between the two years in the deep water east of Cape Cod, especially in the mid-depths, as illustrated by a pair of stations within five miles of each other.

	1879	1912
Depth	Sept. 1	Aug. 29
0	60°	60°
10	52	55
20	47	50.9
30	43	48.5
40	41	44.3
50	40.8	44
60	40.7	42
70	40.6	41.7
80	40.6	41.3

The 1879 temperatures are not directly comparable with those of 1913, there being no pairs of stations at the same locality and date; but this side of the Gulf was even warmer in 1913 than in 1912 (p. 250).

The FISH HAWK records for August, 1882, are especially important, because in that year the subsurface temperatures were very low south of Cape Cod. They yielded the following results. Off Race Point, near Provincetown, the thirty-four fathom temperature was 39°–39.5°. A few miles further south, *i. e.*, along the shore off Cape Cod and Nauset light-houses, the bottom readings were:—

Fathoms	Temperature	Fathoms	Temperature
28	40°	61	37°
33	39°	83	38°
44	39°	90	38°
55	37°	110	38.5°

These records, taken with reversing thermometers (Tanner, 1884c), show that the deeper waters of the Gulf were considerably colder in the summer of 1882 than in any other year of which there is record; and, that in that year, as in 1913, the coldest water was not the deepest but in an intermediate zone at 50–70 fathoms. But the surface temperature of the Gulf in 1882 was apparently normal, just as it was south of Cape Cod, so far as the readings taken at various light-houses along the coast show (Rathbun, 1887).

In 1904 Dawson took a few subsurface temperatures at the mouth of the Bay of Fundy, finding water of 44.6°–48.4° in July, at fifteen fathoms; 48° to 52.1° in the middle of August, which agrees very well with our results. And Dawson seems the first to notice how the shoals and banks lower the surface temperature of the Gulf by causing vertical circulation (Dawson, 1905, p. 15).

Observations on salinity previous to 1913 are very scanty and many of them unreliable. Libbey (1891) took a large number of specific gravities in 1889, in the waters south of Marthas Vineyard, with the ordinary floating hydrometer. And although this instrument, as now universally recognized, is not sufficiently accurate to satisfy the demands of modern oceanography, his surface records agree fairly well with those of 1913, when reduced to salinity by Knudsen's (1901) tables. Thus on August 19, 1889, the surface salinity south of Block Island rose from 33.5‰, over the thirty fathom curve to 34‰ at the 100 fathom curve; in 1913 it was 34‰ near by, over the sixty fathom curve. Apparently, then, his instruments do not require the correction which Clark (1912) found necessary to apply to those used on the Albatross. But his subsurface readings yield salinities as high as 38.5‰ at 100 fathoms, 39‰ or more at 500 fathoms. Such values as these are, of course, out of the question in the North Atlantic, where the 500 fathom salinity is known to be about 34.9‰ (Murray and Hjort, 1912) being equalled only in the eastern half of the Mediterranean and in the Red Sea, and a similar error runs through Libbey's whole series of subsurface densities. As just pointed out it can not be charged to the instruments, and in absence of information as to how soon the observations were made after the samples were collected, there is no means of judging whether it can be laid to evaporation of the samples. But whatever its origin, it is useless to attempt any reconstruction of the density curves along his profiles. Had this been possible, it would have thrown light on the origin of the cold tongue which Libbey suspected was a "mechanical intrusion of cold water from the surface of the continental platform, reinforced by the specific gravity of the water" (1891, p. 407), as was certainly the case in 1913.

In the neighborhood of Woods Hole, Sumner, Osburn, and Cole (1913) took a considerable series of hydrometer readings, checking them from time to time by titration. And though from their very nature they can not claim the accuracy of the latter method, yet their averages must be very close to the truth. They found the mean salinity of Vineyard Sound in July and August about 32.2‰ which agrees very well with our record of 32.29‰ off the entrance to Vineyard Sound (Station 10084). Dickson's (1901) charts show the water immediately south of Marthas Vineyard as 32‰ in July, 1897, with the salinity 33‰ and higher over the 100 fathom contour. In August of the same year, the coast water between Delaware Bay and Nantucket Shoals was below 32‰ bounded seaward by a zone of water with salinity between 32‰ and 33‰ over the outer part of the continental shelf. These charts, taken at their face value, suggest that the salinity was considerably lower in 1897 than in 1913, for in July of the latter year water fresher than 32‰ was confined to a small area off the mouth of the Hudson River, and along the south shore of Long Island. But the records on which they are based are so few that it is a question whether there actually was any such difference between the two years. And Schott represents the salinity of the water over the continental shelf between Cape Cod and Chesapeake Bay as 32–33‰ (1902, taf. 33). Further information as to the salinity of our coastal zone is contained in the Bulletins of the International Conseil for the exploration of the sea. In August, 1907, and February, 1908 (1909), the water along the coast of Nova Scotia was 32‰ or less; the curve for 32‰ touching Cape Cod in the latter month. And the curves for May of that year afford the interesting information that 32‰ water spread seaward in an obtuse wedge, abreast of the Gulf of Maine, and that water of that same salinity bathed the coast as far as New York. Unfortunately there were no data from the continental shelf south of New York in that year, but in May, 1909 (1910), when there were no records for the northern part of the shelf, 34‰ water was found over the shelf opposite Cape May, just as was the case in May, 1913 (p. 188). And in August, 1909 (1911), 34‰ water lay close to land south of Cape Cod, agreeing with the GRAMPUS station in this region in August, 1913. In November, 1909, the curve of 34‰ salinity followed the southern edge of George's Bank: but the Bulletins contain no more recent records for the continental shelf.

So far as the rather meagre data show, salinity, like temperature, was normal in 1913.

OCEANOGRAPHY OF THE GULF OF MAINE IN THE SUMMERS OF 1912 AND 1913.

The surface water next the coast between Cape Ann and Penobscot Bay was 1°–4° warmer in 1913 than the year before. But from Penobscot Bay to Mt. Desert and again off the Grand Manan Channel the readings were about 2°–3° below those of the preceding year. And this was also the case on German Bank (48° in 1913, 50° in 1912).

The readings at corresponding stations, tabulated below, show how closely the surface temperature agreed in the two summers, in the central and southwestern parts of the Gulf:—

10024	61°	10027	59°
10089	61.5°	10092	60°
10002	63°	10045	61°
10087	62°	10106	61.2°
10028	59°	10012b	65°
10093	60°	10105	64°

The area which was warmest in 1913 (Fig. 1) was not visited in 1912. Conversely less attention was devoted to Massachusetts Bay and to the coastal zone in general in 1913 than in 1912. But so far as the observations in the Bay go, the surface temperature, month for month, was about the same there in the two years.

The subsurface temperatures of 1913 did not differ anywhere in the Gulf from those of 1912 by more than 5°. August stations in Massachusetts Bay in the two years, at nearly the same locality

(Stations 10044, 10045, 10106) agree very closely with each other, the curves being practically parallel, and it is probable that the same was also true of the waters immediately off the mouth of the Bay, for while the temperature as a whole was higher there in 1913 (Station 10087) than at the same locality in 1912, the greatest difference was only about 1° in the intermediate depths, while the two were alike below forty fathoms.

The water immediately north of Cape Ann (Stations 10104, 10105) was 2°–5° warmer in 1913 than in 1912 (Stations 10011, 10012b) down to 50–60 fathoms; below fifty fathoms the two sets of observations hardly differ at all. Here again we are confronted with the difficulty that the 1913 stations were occupied a month later than those of 1912, hence the higher temperature of the former might be explained as due to seasonal warming during the last part of July and August. However, the waters off Cape Elizabeth were also slightly warmer (.5°–3.°) in 1913 than in 1912, though studied only fourteen days later in the season, which suggests that the upper layer of the coast water from Cape Ann to Cape Elizabeth was actually warmer in 1913 than in 1912.

Near Monhegan Island the temperature was about the same below fifteen fathoms in 1913 (Station 10102) as it was a week earlier in 1912 (Station 10021), though over 5° warmer on the surface.

The mean temperature on Jeffrey's Bank was about 1° higher in 1913 than in 1912 (50° as against 48.7°); and the fact that the vertical range of temperature was much greater there in 1913 than in 1912 shows that vertical circulation was less active. A few miles further east, however, the 1913 temperatures (Station 10101) are 1.5°–3° lower than those of 1912 (Station 10038) at all depths.

The 1913 temperatures are likewise consistently lower than those of 1912 off the northeast coast of Maine (Station 10098) and over the coastal bank off Nova Scotia, the observations having been taken at about the same date. For example, the Station of 1913, off Lurcher Shoal (10096) was 2° colder on the surface; 2.5° colder in the mid-depths; 3° colder at sixty-five fathoms than the water a few miles further south in 1912 (Station 10031). And German Bank was 1.5°–2.5° colder in 1913 than in 1912.

Our discovery that in 1913 the basins were coldest in the mid-depths, with warmer water below, was totally unexpected, because in 1912 they were coldest on the bottom; or the temperature was at least vertically uniform below about fifty fathoms. In the western basin the water was 2° warmer at the surface, 1° warmer at fifty fathoms, 3° warmer at 100 fathoms in 1913 than in 1912 (Stations 10088, 10007). The higher temperature in the upper layers in 1913 was probably due to the fact that the observations were made a month later than in 1912. But this will not account for the difference at fifty fathoms and below.

Off Cape Cod the 1912 temperatures were 3.5° lower on the surface, 3°–7° higher in the mid-depths, than those of 1913. But this is the type of difference which might be expected from the advance of the season (the 1912 Station, 10043, was three weeks later than that of 1913), being the first step in the equalization of temperature which is complete, down to forty fathoms, by November (1914b). And I doubt whether there was any more temperature difference between the Cape Cod waters of 1912 and 1913 than can be explained on this ground.

Off Platt's Bank the stations for the two years were made at so nearly the same season (August 7, 1912 and August 10, 1913) that no seasonal difference need be allowed for. The upper thirty-five fathoms proved to be almost exactly the same in 1913 as in 1912, except for the immediate surface, which was 2° colder, a difference which may be due to the fact that in 1912 (Station 10023) the temperature was taken in the afternoon of a very warm and calm day; in 1913, at daybreak. But below thirty-five fathoms, the water was about 1° warmer in 1913.

Our stations of 1913 in the eastern basin were made at almost the same localities, and within a few days of the dates of those of the year before. On its western side the water was warmer down to ten fathoms in 1913 than in 1912; but the difference was so slight that it is a question whether it is anything more than evidence of diurnal warming, one station having been occupied in the daytime, the other at night. And the two were almost precisely alike below eighty fathoms. But the temperatures of 1913 are 2–3° colder in the mid-layers. The east side of the basin was warmer in 1913 than in 1912, down to thirty-five fathoms, the greatest difference being almost 4° at twenty fathoms. But below that level it was 3° colder all the way down to the bottom. And this is also true of its northern end (Stations 10097, 10026), the extreme variation being 2°, at 100 fathoms.

The range of salinity on the surface was smaller in 1913 (31.8‰–32.8‰) than in 1912 (31.06‰–32.84‰); but this is probably chiefly due to the fact that in 1913 most of our work was carried on in August, by which time the salinity of the coast water may be expected to be higher than a month earlier. But seasonal difference does not explain the higher salinity of 1913 off Penobscot Bay, for there our observations were made at practically the same season in the two years. Comparison of the charts for the two years (Plate **2**, and 1914a, Plate **2**) shows how much further northwestward toward Penobscot Bay the salt tongue of off shore water extended, and, conversely, how much less evident was the outrush of comparatively fresh water from the bay, in 1913. But east of Mt. Desert the surface water next the coast was fresher in 1913 than in 1912.

Over the Nova Scotia coast bank, near Lurcher Shoal, likewise, the surface salinity was higher in 1912 (32.84‰ at Station 10031) than in 1913 (32.75‰ at Station 10096); but on German Bank the reverse was the case (32.70‰ at Station 10029, 32.79‰ at Station 10095). Over the eastern basin the surface salinity was slightly higher in 1912 than in 1913, the readings at three pairs of stations being: —

Station	10027	1912	32.66‰
	10092	1913	32.59
	10028	1912	32.75
	10093	1913	32.61
	10036	1912	32.75
	10097	1913	32.75

And in 1913 the surface salinity was nowhere so high in the Gulf as it was off Lurcher Shoal in 1912 (32.84‰).

The subsurface salinity for the two years was about the same in Massachusetts Bay, in August, for, though there was much less difference between surface and bottom in 1913 (Station 10106) than at the same locality in 1912 (Station 10045), the mean for the entire column is almost precisely the same (32.4‰).

The observations off the mouth of the Bay were taken a month later in 1913 than in 1912. And while the salinity was considerably higher above forty fathoms, lower below that depth, in 1913 than in 1912, the mean salinities for the two years differs by only about .1‰ (Station 10002, July, 1912, 32.54‰; Station 10087, August, 1913, 32.63‰), no more than can be charged to the general rise of salinity which takes place after the spring freshets from the rivers have passed (1914b). In the western basin the observations for 1913 (Station 10088) were intermediate in date, as well as in geographic location, between the two stations of 1912 (10007, 10043); and they were likewise intermediate in salinity all the way from surface to bottom, *i. e.*, it was about the same in this general region in the two years. The same is also true of the deep water off Platt's Bank, where the stations were occupied within six days of the same date.

In the eastern basin, the water was considerably less salt in 1913 than in 1912, although the two sets of observations were taken within a few days of the same dates. On its western side (Station 10027, 1912; Station 10092, 1913) the difference was greatest in the mid-depths (.35‰ at fifty fathoms), very slight at surface and bottom; but further east (Station 10028, 1912; 10093, 1913), it was uniform (.3‰–4‰) all the way from twenty fathoms down to the bottom. And the 120 fathom salinity at Station 10028 in 1912 (34.54‰) is almost .3% higher than any salinity in 1913. In the northern end of the basin, on the coastal bank near Lurcher Shoal, and off the northeastern coast of Maine the water was also slightly salter at all depths in 1912 (Station 10036) than in 1913 (Station 10097), though the two sets of observations were taken at nearly the same season, and the geographic locations were almost identical. But on German Bank the reverse is true, the water being about .05‰–.1‰ salter at all depths in 1913 than in 1912. The salinity of the coast water between Cape Ann and Cape Elizabeth was about the same in August, 1913, as it was two to three weeks later in 1912, correspondingly salter than the July salinities of that year (1914a). Off Monhegan, where the observations for the two years were taken at practically the same date, the water was slightly fresher on the surface, slightly salter at sixty fathoms, in 1913 (Station 10102) than in 1912 (Station 10021).

Thus, in brief, the Gulf was colder and fresher in its eastern, warmer, but of about the same salinity, in its western half, in 1913 than in 1912.

In the preceding lines the differences between the two years have been emphasized. But the most important general conclusion is that these differences are really very slight; and that the general distribution of salinity, highest in the east, lowest in the west, was the same in 1913 as in 1912

Origin of the coast water.

In few parts of the world is the coast water so sharply defined by salinity, temperature, and color, from oceanic water, as it is over the coastal shelf between Nova Scotia and Cape Hatteras. And not only are the physical differences great, but the transition from one type to the other is often surprisingly sudden.

The general characteristics of the coast water, as they impress the voyager, have been so well described by Schott (1912), and are a matter of such common knowledge, that it suffices to state here that water with a mean annual surface temperature below 59°, and mean salinity below 34‰ may be so classed, as distinguished from the warm and saline ocean waters of the Gulf Stream. This cold, comparatively fresh water, which bathes the whole breadth of the continental shelf between Nova Scotia and Chesapeake Bay, out to about the 100 fathom curve, except when temporarily obscured or dispossessed by Gulf Stream water, and which fills the Gulf of Maine, has usually been explained as coming from the north, or from the abyss of the Atlantic. According to the first of these theories, the coast water is a branch of a current flowing from the north and northeast. Almost all the ocean atlases show something of this sort; and it has been accepted in one form or another in almost all the textbooks on physical geography and oceanography (for example, Maury, 1855; Reclus, 1873; Attlmayer, 1883; Thoulet, 1904, Krummel, 1911; Schott, 1912; the German marine observatory, Deutsche Seewarte, 1882; the current chart of the U. S. Navy by Soley, 1911; and the British Admiralty current chart). The mere coldness of the coast water suggests a northern origin, as does its comparatively low salinity; while the fact, long ago emphasized by Verrill and others, that it supports a boreal littoral fauna, contrasting sharply with the warm water fauna carried northward in the sweep of the Gulf Stream is evidence in the same direction. The continuity, too, of the cold zone all along the coast as far north as Newfoundland, with gradually decreasing mean temperature from south to north; and its sharp limitation seaward by the Gulf Stream, argue for a northern origin. And when we add to this the southwesterly drift which has been noted at many points along the coast between Nova Scotia and Cape Hatteras, it would require very strong evidence to prove that northern currents do not enter, in greater or less degree, into the composition of our coast water.

Up to 1897 the Labrador Current, a polar stream which has borne an unsavory reputation among mariners ever since its discovery in 1497 by John Cabot, was generally accepted as the source of this northern water, being so represented in practically all of the early atlases and textbooks; while Libbey (1891, 1895) expressly describes the cold water on the continental shelf south of Nantucket as one of its branches. And this view is still widely held, for example, the U. S. Navy Department states that the Labrador Current flows from the Grand Banks past Nova Scotia, southward in a narrowing belt as far even as the coast of Florida (Sumner, Osburn, and Cole, 1913,

p. 35); and Engelhardt (1913, p. 9, chart B), thinks it certain that the Labrador Current bathes our coast at least as far as New England.

But in 1897 a new light was thrown on the subject by Schott, whose analysis of the currents on the Grand Banks led him to conclude that the chief source of our cold coast water was not the Labrador Current, but water flowing out of the Gulf of St. Lawrence via Cabot Straits. And his work was founded on so large a body of temperatures, and current records taken by vessels at anchor on the Banks, that it may well serve as the starting point of our modern knowledge of the relationship of the Labrador Current to the Gulf Stream in that region. The most important feature of Schott's work, from the present standpoint, is his failure to find any evidence that the Labrador Current, as such, flows southwest across the Grand Banks, although it follows their eastern edge southward to the southern extremity. It is true, he says, that a small amount of polar water turns westward, and flows along the southern coast of Newfoundland; but it enters the Gulf of St. Lawrence. And though movements of polar water toward the southwest across the banks have been observed, he maintains that they are too small in amount, and too irregular in occurrence, to be anything more than local surface currents caused by the frequent strong northeast winds.

This is perhaps an extreme view, for as Krümmel (1911) points out part of the polar water which flows around the south coast of Newfoundland, joins the outflow from the Gulf of St. Lawrence. And Krümmel furthermore maintains that there must be a general tendency for the polar water to flow southwestward across the Grand Banks, and thus to reach the coast of Nova Scotia directly, instancing the fact that icebergs, coming south with the Labrador Current, have occasionally been known to drift southwest from the Grand Banks. But Capt. C. E. Johnston (1913), whose experience as commander of the U. S. Revenue Cutter on ice patrol duty on the Banks in 1913 and 1914 has given him unusual opportunities to study the currents in that region, states that the "currents on the Grand Bank....are almost wholly tidal. In a general way they flood to the northward and ebb to the southward. Winds drive them to the eastward or westward, sometimes overcoming the strength of the tidal current"; and we can hardly suppose that there is any constant movement of polar water southwestward around the southern edge of the Grand Banks, for although bergs have occasionally been known to drift for long distances in that direction (Krümmel, 1911), the general movement of the ice, after reaching the southern point of the Bank, is just the reverse, *i. e.*, toward the east and northeast, as graphically described by Captain Johnston (1913).

At present it seems safe to say that although there may be sporadic movements of Labrador Current water from the Grand Banks toward Nova Scotia, there is no constant current in that direction; and that the increment of polar water which reaches our coasts in that way, plus the polar water which joins the Cabot Current at Cabot Strait is too small in amount to have much effect on temperatures and salinities off New England. And it certainly has very little influence on the plankton west of Nova Scotia, where true polar organisms, such as characterize the plankton of the Labrador Current, are seldom recorded.

The existence of an outflow from the Gulf of St. Lawrence via Cabot Straits has been recognized by oceanographers for many years (Maury, 1855); but Schott (1897) seems to have been the first to emphasize its importance. Fortunately we now have considerable data as to its volume and physical characters, thanks to the tidal and current observations, temperatures and densities, taken by the Tidal Survey of Canada under the direction of Dr. W. B. Dawson (1896–1913). These establish a constant outflow along the south side of Cabot Straits, with velocities as high as 1–2 knots per hour between Cape North and St. Paul Id., termed the "Cape Breton current" by Dawson, but for which the earlier name, "Cabot Current" is appropriate; and an inflow along the north side of the Strait. The Cabot Current has sometimes been explained as polar water, entering the Gulf via the Straits of Belle Isle, and flowing southerly along the west coast of Newfoundland. But Dawson's (1907) survey of the Straits of Belle Isle proved that no great volume of water enters the Gulf from that quarter, there being very little balance of inflow over outflow, if any, in summer, though with a possibility of rather greater influx in early spring. The distribution of temperature in the Gulf likewise shows little or no effect of polar water, for in summer polar temperatures are not found within the Straits of Belle Isle (Krümmel, 1907, Dawson, 1907). And there is no evidence that such water as does enter via the latter flows southerly along the Newfoundland coast, but just the reverse, because the current along this coast is from south to north caused by the water which enters the Gulf along the north side of Cabot Straits. To enter further into Dawson's very interesting results is not necessary since the Gulf of St. Lawrence concerns us here only in its relation to the coastal water further south. What is important is that his work demonstrates beyond a doubt that the water which flows out through Cabot Straits is not polar, but true coast water. True, the Cabot Current contains small amounts of polar water, both from the Straits of Belle Isle, and from the Labrador Current via the south coast of Newfoundland, but this is modified past recognition in the general circulation of the Gulf. (For an excellent summary of Dawson's results, and of the general circulation of the Gulf of St. Lawrence, see Nature, April 18, 1901, p. 601).

The amount of outflow through Cabot Straits must be considerable for the Cabot Current is at least thirty miles broad abreast of Cape North, with a velocity of from .5 knot to 2 knots per hour on the surface (Dawson, 1913, p. 12). Its temperature is particularly characteristic in summer when the water is coldest (31°–33°) at about fifty fathoms, with warmer water (37°–40°) below at 100 fathoms, 39°–40° at 150 fathoms, while the surface warms to 58°–60° (Dawson, 1913, p. 37). And the discovery, by the ALBATROSS in July, 1885 (Townsend, 1901) of a corresponding layer of minimum temperature, at about the same depth, off the east coast of Nova Scotia, ranging from about 32° opposite Cape Breton to 35° off Halifax, and 39° off Cape Sable, with warmer water at greater depths, shows its influence along that part of the Coast. Surface temperature likewise indicates that the Cabot Current flows toward the southwest over the continental shelf (Schott, 1897); and so does salinity, for as Dickson (1901) has shown, water with a salinity of 32‰ or less, is continuous along the coast from the Gulf of St. Lawrence to the Gulf of Maine in spring and summer, though often separated from the equally fresh water over the Newfoundland banks by a salter wedge. And this salt wedge is normal for the whole year, according to Schott (1902, plate 33), though it may be temporarily obscured, as, for example in August 1897 (Dickson, 1901); and, finally, a southwesterly current has often been observed by mariners off the Nova Scotian coast. But although a southwesterly long-shore movement of St. Lawrence water is incontestable, it is by no means clear how far it can be traced as a recognizable current. According to Schott (1897) it makes its effect felt in the form of low temperatures to the neighborhood of New York. But according to the statement in the Nova Scotia and Bay of Fundy Pilot (British Admiralty, 1903), based on many years data of greater or less value, obtained by mariners, no true southwesterly current can be distinguished beyond Cape Sable, the movements of the surface water over George's Bank being wholly governed by tide and wind. And the work of our own coast survey, mentioned above (p. 231) has failed to reveal any dominant movement of water from northeast to southwest over George's Bank. According to the British

Admiralty (1903) there is a northerly drift into the east side of the Gulf of Maine; and our own records of salinity show that an indraught of comparatively saline water does take place more or less constantly into the eastern side of the Gulf. But it must be slow, or intermittent, for Dawson's (1905) measurements of currents failed to show any dominant drift along the west coast of Nova Scotia. And the organisms which it carries with it are good evidence that Gulf Stream as well as St. Lawrence water enters into its makeup. In short, it is extremely doubtful whether the Cabot Current can be traced, as an observable or measurable drift beyond Nova Scotia. Consequently the southwesterly currents noted south of New York (p. 230) require some other explanation.

In 1907, Pettersson offered a totally different explanation for our cold coast water, namely, that it was not northern water flowing southward, but water welling up from the Atlantic abyss. And although few, if any oceanographers have adopted this view in its entirety, both Schott (1912) and Krümmel (1911) believe that there is more or less upwelling along our coast, particularly in winter. And Clark (1914) maintains that the cold water off Nova Scotia must be abyssal in part, to account for the distribution of crinoids.

Upwelling, whether on a large or a small scale, must obviously largely depend on the prevailing direction of the wind; consequently along our coast, where off shore winds prevail in winter, winds parallel to the coast in summer, it might be expected to be seasonal. And for this reason our data for 1913 can only be expected to show its presence or absence in summer. But they are worth analyzing, because the occurrence of upwelling in this region has so far been deduced from theoretical grounds, rather than from actual observation, previous knowledge of subsurface salinity on the continental shelf being practically *nil.* If abyssal water had been flowing up the continental slope in any considerable amount at the time of our voyage, salinity and temperature would necessarily reveal its presence, just as they do in parts of the oceans where there is a well-marked updraught of bottom water, next the coast. Perhaps as useful an index as any in the warm months, in temperate zones, is surface temperature, for in regions of active upwelling, the constant access of cold water from below retards seasonal warming, and consequently causes the surface to be abnormally cold. And unless the updraught should extend along the whole coast line, a most improbable supposition, the cold region would be surrounded by warmer surface water, north and south as well as off shore, just as it is off the coast of California (McEwen, 1912), and off the southwest coast of Africa (Schott, 1902, taf. 8). Subsurface temperatures would reveal upwelling by continuity between the cold water near the surface and in the abyss; and surface salinity in regions of active upwelling, is about the same as the salinity of the layer from which the updraught comes, as is very clearly illustrated by the salinity curves off the coast of Morocco (Schott, 1912, pl. 33).

I have already pointed out (1914a) that the salinities and temperatures of the Gulf of Maine in 1912 do not suggest upwelling, except locally on a small scale; and the records for the winter of 1912–1913 and for the summer of 1913 all support this view. If abyssal water enters at all into the complex of the Gulf of Maine it must be in such insignificant amount that it has no appreciable effect on its temperature or salinity. However, this semi-enclosed basin may well differ hydrographically from the waters over the shelf south and west of Cape Cod.

In weighing the evidence of temperature, we must first consider whether the surface over the continental shelf is abnormally cold, as it has usually been characterized, most recently by Clark (1914). So firmly grounded is this idea, that the waters of the Gulf of Maine have often been called "Arctic." But, as I have already pointed out (1914a, 1914b) the observations in the Gulf of Maine during the summers of 1912 and 1913 and the winter of 1912 and 1913, corroborate Verrill's early contention that its temperature is nearly normal for its geographic location. It is, of course, much colder than the Gulf Stream; its surface temperature 7°–9° lower than the average for its latitude (Krümmel, 1907). But the waters of its deeps are no colder than the mean annual air temperature over the part of its watershed from which blow the chilling winds of winter, with their accompanying snowfall (1914a, p. 97). And the bottom temperature of its eastern basin in 1913, was almost precisely the same as the mean annual temperature of the air at Yarmouth, on the neighboring Nova Scotian coast (43.3° as given by the Nova Scotian Coast Pilot, British Admiralty 1903, p. 11), and about a degree warmer than the mean for the year at St. John, New Brunswick, on the Bay of Fundy. And as Tizard (1907) has pointed out, the coast water is warmer off New York in summer than off England, and even in November its surface temperature is no lower than west of Ireland, though the latter is commonly described as warmed by the Atlantic Current. In short, as Schott (1897) and others have insisted, it is more because of its contrast with the Gulf Stream than because of its absolute temperature that the coolness of our coast water has so impressed itself on students and laity alike. It is true that the surface temperature falls very low in winter near the coast, cooling to about 39° over the zone between Marthas Vineyard and New York (Sumner, Osburn, and Cole, 1913), with even lower winter temperatures in enclosed sounds and bays, for instance, 31.2° in February at the Woods Hole Station of the Bureau of Fisheries (Sumner, Osburn, and Cole, 1913, p. 48, average of three years). But this only happens where surrounding islands give the waters more or less the hydrographic character of lakes. And the zone over which the surface temperature falls below 40° in the coldest month (February) is nowhere more than thirty-five miles broad, south and west of Cape Cod, with a steady rise of surface temperature from the land seaward. The cold water is also correspondingly shallow, bottom water colder than 40° being probably limited seaward by the fifty fathom contour in this region. In short, the water is coldest just where it might be expected to be influenced most by the icy northwest winds of winter. And so far as the scanty winter data show, this is true all along the coast as far as Chesapeake Bay.

Air temperatures 10°–15° F. below freezing, such as are common in winter in southern New England, are surely enough to account for considerable cooling of the adjacent water. How closely the winter temperature of our coast water depends on the influence of the land is illustrated by the fact that Gloucester Harbor, which opens freely to the deeps off Massachusetts Bay, is 1°–2° warmer than the more enclosed waters of Woods Hole in winter, although a degree of latitude further north, and bordering a colder ocean area. Gloucester Harbor in turn, is colder than Massachusetts Bay; for example, its surface temperature fell to about 34° during the winter of 1912–1913, the lowest reading a few miles outside being 37°. And Boothbay Harbor, seventy-five miles north of Gloucester, which bears something the same relation to the land as Woods Hole, being shut in by numerous islands, is colder than either Gloucester or Woods Hole (about 30° F. in February), reflecting the very cold winter climate of northern New England; and likewise colder than the water off shore. (The mean temperature for December and March, at Mt. Desert Rock, is about 38° and 36°; at Boothbay, 37° and 32.2°). These comparisons of surface readings apply just as well to the whole of the upper 30–40 fathoms, for our winter work (1914b) has shown that the temperature of the Gulf of Maine is practically uniform, vertically, to at least that depth from December to March. The fact that in summer the water is coldest at the bottom of such partially enclosed sinks as the trough between Jeffrey's Ledge and the mainland, *i. e.*, just where outside influences of any kind must be least active, is further evidence that it is winter cooling by the air that is responsible in the main for the cold water. And this same process equally well explains the general persistence of low temperature in summer near shore below twenty fathoms or so, solar warming progressing but slowly below that depth, consequent on the progressive increase in the vertical stability of the water.

And how closely mean air and water temperatures agree, for bays and sounds, is illustrated by Long Island Sound, where the mean surface temperature for the year (52°–53°) is practically the same as the mean air temperature for the year at New York. The mean surface temperature in Massachusetts Bay is about 50°–52°; the mean air temperature at Boston about 4.9°. In short, the temperature of the coast water between Cape Sable and Chesapeake Bay is not abnormally low, considering its relation to the land mass to the west, and the winter climate of the latter. Hence it gives no direct support to the upwelling theory.

Neither is there anything in the surface temperature curves to suggest such upwellings as those off California, off Morocco, and off South Africa, for though the surface temperature is much lower over some of the coast banks, and in the northeast corner of the Gulf of Maine as a whole, than elsewhere, subsurface temperatures, salinities, and tidal currents prove that their cold surface is the result of violent vertical circulation, accompanied by correspondingly high bottom temperatures. Furthermore, the mean temperature is lowest where there seems to be the least possibility of abyssal upwelling, *i. e.*, in partially enclosed basins next the coast.

The rapid rise of surface temperature during July and August is in itself a strong argument against the view that upwelling can have been active at that time; and so is the great annual range of surface temperature (30° for the Gulf of Maine, nearly 40° off New York, with an even greater extreme range, Murray, 1898); for any considerable upwelling of cold abyssal water would necessarily check the former, and consequently lessen the latter. It would be hard to reconcile our subsurface temperatures with an upwelling over the upper part of the continental slope at the time of our visit, whatever may have been the case earlier in the season, because if such a process had been taking place, the cold water over the shelf would have been continuous with the cold water at greater depths further off shore, instead of separated from the latter by the warm bottom zone, which was found south of Cape Cod and Long Island; and which probably extended to Chesapeake Bay. And the considerable difference in temperature between the surface and the water a few fathoms down is almost as conclusive evidence in the same direction, because any constant accession of cold water from below would have made the temperature more uniform, vertically.

The evidence of salinity supports that of temperature, for although Schott (1912) believes that the low salinity of the coast water suggests upwelling, a more rational explanation of this phenomenon is that it results from the large amount of river water which enters the sea between Chesapeake Bay and Newfoundland, as maintained by Tizard (1897). I have already pointed out (1914a), that the river water which enters the Gulf of Maine would be sufficient to raise the level of the latter half a fathom per year, were it an enclosed basin, evaporation being more than offset by rainfall. And even larger amounts of fresh water come from the rivers west and south of Cape Cod; *e. g.*, the Connecticut, Hudson, Delaware, and the watershed draining into Chesapeake Bay. There is therefore no more need to call upon upwelling to account for the low salinity of our coast water, than for that of the Baltic, of the Gulf of St. Lawrence, or of the waters off the mouths of the Niger and Amazon rivers. Furthermore, while upwelling would lower the salinity of the surface water below that of the Gulf Stream, it could not possibly reduce it to the comparatively fresh state of the coast water (32‰ to 33‰), because the deeper layers of the Atlantic, from which any updraught must come, are far salter than this (34.9‰, Murray and Hjort, 1912). In short, low surface salinity does not indicate upwelling in this case, though it does not necessarily preclude the possibility that such a process might be taking place to a small extent. Unfortunately our salinity profiles across the continental shelf do not establish the upper limits of the water of the abyss as well as the temperature profiles, for they leave a bare possibility that the fresh coast water may have been connected with the abyssal water of 34.9‰ by a continuous zone of bottom water fresher than 35‰ (p. 344). But although the data are not absolutely conclusive, for want of bottom salinities at the crucial depth (75–100 fathoms), it is very much more probable that the bottom water at this depth was salter (above 35‰), just as it was warmer (p. 164), than the water below it. And this was certainly the case south of Nantucket in August, when the salinity of the bottom water, in sixty fathoms, was 35.17‰ (p. 193). If our salinity profiles are correct in this respect, it is impossible to reconcile them with active upwelling. Density, likewise, argues against the existence of an updraught of abyssal water over the continental shelf, in summer, because, as the profiles show (p. 233), the tendency must have been just the reverse. And the very considerable difference in density between surface and deep water off the coast must be a bar to upwelling, even though it may not absolutely prevent it, as it does in stratified waters where the layers of different densities are sharply defined (Sandstrom, 1908; Wedderburn, 1908).

It is not to be expected that our work could conclusively settle such a complex problem. But considering that the evidence of temperature, salinity, and density agree, and that it is hardly conceivable that one or other of them would not have revealed upwelling, it is safe to say that no widespread vertical movement of this sort was taking place over the continental shelf in July, 1913. And the fact that the cold water over the shelf south of Marthas Vineyard is usually separated from the cold water of the abyss by a zone of warmer bottom water in summer, suggests that this conclusion holds good for that season normally. It is true that during one summer, 1882, the whole shelf is known to have been bathed by cold water; but it is as likely that this resulted from an unusual accession of northern water or from abnormal winter cooling, as from upwelling.

Upwelling may be more important in winter, for, as Krümmel (1911) and Schott (1912) point out, the prevailing north and northwest winds, which often rise to storm strength, would have more tendency to produce this type of circulation, than the southwest, long-shore winds of summer. Furthermore, density is not so effective a barrier to upwelling in winter as in summer, because its vertical range is much smaller then. Nevertheless, it is probable that upwelling caused by off shore winds would be from a comparatively shallow depth, say 100 to 200 fathoms, both because the direction of the wind is not constant but often reversed, and because the abyss water must be considerably heavier than coast water even in winter. And gravity would similarly resist any upwelling which the effect of the rotation of the earth might tend to produce along the inner edge of a current moving parallel to the coast. Upwelling of this latter type may play a very important part in the movements of ocean waters, as pointed out by Ekman (1905a) and recently by McEwen (1912); but until the movements of the bottom water of the North Atlantic are better understood, discussion of this theoretic aspect of the case may well be postponed.

The real explanation of the low temperature of the coast waters is to be found neither in upwelling, nor in a northern current, but in the land climate of eastern North America. On this side of the North Atlantic the relation between land climate and ocean temperatures is exactly the reverse from what it is off the west coast of Europe, because the winds as a whole, and the great majority of cyclonic disturbances, drift from the land out over the sea, instead of from sea to land. Hence the coast water must necessarily borrow its temperature, in large degree, from the land climate, instead of tempering the extremes of the latter, as is the case in the favored continent of Europe. Granting this, and the principle is so important, and so obvious, that it is remarkable that it has not been emphasized more strongly in the past, the fact that the water is coldest next the coast, and in enclosed troughs, with a steady rise of temperature, depth for depth, passing off shore, is at once explained, for the cold winds of winter would necessarily be most effective as cooling agents near shore. And they would become progressively less so, further and further from land, being warmed by the absorption of heat from the sea water over which they blow. The change from our torrid summer to frigid winter, with its prevalent off shore winds, sufficiently explains the rapid cooling of the coast water in autumn and winter. Conversely, solar warming and the warm land winds of spring and summer are the only agencies which could produce the very rapid warming of the surface, which characterizes our coastal zone at that season; for if the change were due to flooding by Gulf Stream water, salinity would rise correspondingly, something which does not happen until the surface water has warmed by some 25°–30° F, if at all (p. 188). The change in land climate, with latitude, is an obvious explanation for the rise in surface and subsurface temperatures over the continental shelf from north to south. Still another continental influence, which must play a part in chilling the coast water is the low temperature of the river water, and the river ice which enters the sea in spring; but this can hardly have as much effect south of Cape Cod as supposed by Tizard (1907).

The Gulf of St. Lawrence affords an excellent example of the degree to which winter cooling takes place, and of the rapidity with which the temperature falls in autumn, in an enclosed basin under the influence of the rigorous climate of eastern North America, for its low temperature is certainly due to local causes (Krümmel, 1907). Were the Gulf of Maine as nearly enclosed as the Gulf of St. Lawrence, it would reproduce the temperature of the latter even more closely than is now the case, the northern part of the former being separated from the southern part of the latter by only forty miles of latitude.

In short, the Gulf of Maine is warmed, not cooled, by the combination of northern and Gulf Stream water which enters it; and this is even more true of the coastal waters south and west of Cape Cod. This does not mean that more or less northern water does not enter into the composition of the coast water; on the contrary, such water enters into the Gulf of Maine in amounts varying from year to year. But by the time it has flowed so far south as this, it has been so warmed by mixing with warm off shore water, that it is no longer cold enough to chill the coast water below the temperature which would be given it by the land climate alone. And the northern water has even less effect on salinity than on temperature south of Nova Scotia, because the volume of fresh water which empties into the Gulf of Maine, and over the shelf beyond Cape Cod, is sufficient to lower the salinity of the coast water nearly to that of the water which flows out of Cabot Strait (p. 259).

The upper layers of the Gulf Stream can not be neglected in studying coast waters. It has long been known that Gulf Stream water drifts northward almost every summer, flooding the surface even to the southern shores of New England. And salinity profiles suggest that it was a shoreward movement of the surface waters of the Stream, dipping below the fresher coast water, which raised the salinity of the bottom water of the shelf southwest of Nantucket so considerably during July and August (p. 193). In the Gulf of Maine, too, Gulf Stream water is probably of more importance than is usually realized, its entrance being an annual phenomenon, signalized by the tropical organisms it bears with it (p. 336).

The evidence marshalled in the preceding pages shows that our coast water is not of any one origin; it does not even have any one predominant source, as has been so often assumed, but is really very complex and variable in its composition. The constituents which enter into it are northern water, chiefly from the Gulf of St. Lawrence, and hence itself coastal, not polar, plus a possible small component of polar Labrador water; river water from the land; water of high salinity from the upper layers of the Gulf Stream; water from the mid-layers off shore, and possibly Atlantic abyssal water, besides rain water. In just what proportions these components mix, is for more detailed studies to show. But temperature and salinity suggest that it is St. Lawrence water which is the most important off Nova Scotia. In the Gulf of Maine, St. Lawrence water, land water, and water from the upper 100 fathoms off shore play more equal rôles, now one, now another having the upper hand with the succession of the seasons;

and there is no actual hydrographic evidence that abyssal water enters at all into the Gulf. Between Cape Cod and New York, the chief components of the coast water are the surface and upper layers of the Gulf Stream, which is far more important here than in the Gulf of Maine, and river water, northern water being hardly appreciable, except perhaps in exceptional years (p. 266). Salinities and temperatures do not afford any actual indication of upwelling here in summer (p. 260). South of New York the problem of upwelling assumes more importance, because of the prevailing direction of the winter winds; though no evidence of it was found in summer. But the questions to what degree it is effective in winter and whether it floods the shelf, or is limited to the waters outside the slope can not yet be answered.

Oceanography of the Gulf of Maine and of the North Sea.

A brief comparison between the Gulf of Maine and the North Sea is pertinent because the latter is now the best known water-area, both physically and for its plankton, on the globe. (For an excellent summary of the hydrography of the North Sea, see Knudsen, 1909). Both also support fisheries, which differ more in extent than in kind.

The salinity of the North Sea as a whole, 34‰ to 35‰, is considerably higher than that of our Gulf. At the west end of the English Channel, and off the north coast of Scotland, the two sources from which ocean water enter, it is above 35‰. On the other hand, there is a coast-belt fresher than 34‰, near Denmark; and of course the surface grows much fresher passing through the Skagerrak into the Baltic. The salinity of the North Sea further differs everywhere from that of our Gulf in being practically uniform from surface to bottom, the result of strong currents; and in changing very little from season to season.

The Gulf of Maine agrees very closely in mean surface temperature (about 48°) with the central parts of the North Sea (48.2°); and Massachusetts Bay (50°–52°) corresponds with its southern part (50°). This generalization can be extended also to the upper ten fathoms of the whole of the North Sea, and to the whole column of water (about twenty fathoms) in its southern half. The coldest winter temperature of the North Sea ranges from 37.4° near Denmark to 42° near Scotland — in the central part it is 39°–40°; which is slightly warmer than the Gulf of Maine, where the winter temperature as a whole is about 36°–37°. On the other hand the North

Sea is rather cooler as a whole than our Gulf in summer, its warmest water, off the coast of Belgium, being about 62.5°; with the greater part of its surface area 55°–60°. But nowhere in the North Sea are the surface temperatures of summer as low as they are in the northeast corner of the Gulf of Maine. At fifty fathoms the temperatures of the North Sea and of the Gulf are about the same, though the range is somewhat greater in the latter, the extreme limits being from 38°–48°. And they also agree closely in greater depths, which, in the North Sea, are limited to a small area at its northern entrance. Thus the 100 fathom temperature of the North Sea is between 41.9° and 44.6°; the temperature of the Gulf between 38° and 46° at that depth.

The surface density, at the temperature *in situ*, like the salinity, is considerably higher, as a whole, in the North Sea than in the Gulf of Maine. In summer the densities of the two overlap, that of the Gulf ranging, from about 1.0227 to about 1.0254; the North Sea from about 1.0247 to 1.0266. But during the rest of the year the density probably does not rise as high anywhere in the Gulf as in the North Sea. And in May the difference is great, for at that season, owing to the inrush of fresh river water, the surface density of the western side of the Gulf of Maine falls below 1.023, whereas in the North Sea it ranges from 1.0263–1.0273. Subsurface densities, likewise, are lower in the Gulf, for, while the temperature is not very different from that of the North Sea, the salinity is much lower.

In short, there is nothing in the temperatures to cause any faunal difference between the two bodies of water, but the difference in salinity is so great that it might well have some influence. And it would not be surprising to find that the density was an important factor in determining the fish fauna of our Gulf by governing the flotation of pelagic eggs.

The coast water as a biological environment.

The hydrographic facts outlined in the preceding pages have a twofold interest: first for their bearings on the general problems of oceanography; secondly for their relation to the animal population which the coast waters support. As a biological environment, the different parts of the continental shelf differ greatly, though all are characterized by relatively low temperature and salinity. The Gulf of Maine, except for its uppermost layers, is a region of great physical uniformity from season to season. Below say sixty fathoms the extreme range of temperature over the entire Gulf, throughout the year is probably not over 10° (38°–48°); at 100 fathoms the extreme range is about 8° (38°–46°). And the deep parts of the western half of the Gulf are still more uniform; the extreme temperature variation at all depths below sixty fathoms, being not more than 4° in the basins and troughs next the western shore. Salinity, too, is surprisingly uniform in the deeper parts of the Gulf. In short, the fauna which occupies these depths enjoys an environment whose physical factors are practically unchanging from year's end to year's end.

But quite the opposite is true of the surface layers of the Gulf, where there are violent seasonal fluctuations of both temperature and salinity. Along the western shore, and in Massachusetts Bay, the surface temperature rises from about 36° in winter to 63° or 64° in summer, *i. e.*, a range of almost 30°. And though the annual range is smaller along the eastern side, it is still considerable. The salinity, too, oscillates between wide limits, and the changes are very sudden in spring. For example, north of Cape Ann, the range is from about 32.8‰ in February to about 29‰ early in May.

In addition to these regular seasonal changes, the Gulf is subject to sporadic invasions, on the one hand by water from the Gulf Stream, with its characteristic fauna, on the other by St. Lawrence water. But these are not extensive enough to cause much change in the Gulf as an environment, though they do alter the *facies* of the plankton by the addition of either southern, or northern organisms, as the case may be.

South and west of Cape Cod there are no parts of the continental shelf where the water is as uniform, from season to season, as it is in the deeps of the Gulf of Maine. On the contrary, the entire water mass over the shelf is subject to violent fluctuations, both seasonal and sporadic. These are most violent, of course, near the surface and next the coast. For example, the surface temperature off New York ranges from about 38° to over 70° during the year; the salinity from about 31‰ to possibly 34‰. And even as deep as sixty fathoms the temperature may rise from below 45° to nearly 60° in a month (p. 349), the salinity from 33.5‰ to 35.1‰ in the same short period. And this general statement is true all along the coast, at least as far as Chesapeake Bay. Thus any bottom animal may be subjected to great and sudden changes. At the edge of the shelf, where the water is deeper (75–125 fathoms), conditions are more uniform. And this is a particularly interesting zone zoölogically, as Verrill (1880, 1884a) long ago pointed out, because it is the only place where the bottom is normally bathed by water varying only a few degrees, either way, from 50°. Deeper down the slope the bottom water is constantly colder; nearer the shore it is so for at least part of the year. Along this zone, too, salinity is much more constant than it is nearer the shore, as well as higher, and probably with but little seasonal change. Added to these hydrographic advantages, is the abundant food supply which usually characterizes the contact-zone between warm and cold waters, the importance of which was long ago realized by Verrill (1881). The result is that the bottom fauna of this zone is remarkably rich, both in species and in individuals, and largely of southern origin (Verrill, 1880, 1881, 1884b). But its biological advantages are partly compensated for by its dangers, for at least once within the memory of man its inhabitants have suffered widespread destruction, the surface, for some hundred of miles, being strewn with the dead bodies of the tile-fish (Lopholatilus), as so graphically described by Collins (1884) and Verrill (1882, 1884b) and often commented upon by subsequent writers (Murray, '98, Murray and Hjort, 1912, Sumner, Osburn, and Cole, 1913). And at the same time the invertebrate bottom fauna was practically obliterated (Verrill, 1884a, p. 656; 1884b). Verrill believed that this was due to an off shore movement of the cold bottom water on the shelf, under the influence of violent northerly storms which swept the coast during the late winter and early spring of 1882. And whether this was the true cause, or whether an unusual accession of northern, or of abyssal, water was to blame for the lowered temperature observed by Verrill in that year (p. 239), the occurrence serves to illustrate the fluctuations to be expected along the meeting zone of cold and warm waters. And it was evidently not a unique, though no doubt an unusual occurrence, for in July, 1884, the Albatross encountered great numbers of dead cephalopods floating on the surface, over the 100 fathom curve, further south (Lat. 37° 47′, Tanner, 1886). Conversely the failure of various northern littoral animals to extend their ranges beyond Cape Cod, is probably due to the excessive summer warming, partly due to solar heat, but also to sporadic flooding by Gulf Stream water.

THE PLANKTON.

General account of the macroplankton.

The plankton work of the cruise had two main objects: — first, a qualitative survey of the various species, which must precede any quantitative study to make the latter valuable; and, secondly a faunistic examination of the plankton as a whole, at each station, to illustrate the geographic occurrence of associations of species.

When the work in Massachusetts Bay in May, 1913, was finished the vernal diatom swarm had largely disappeared, and copepods, which had been very scarce during the preceding month, had reappeared in the shape of swarms of nauplii and older larvae; while by June, hauls off Gloucester yielded an almost pure Calanus plankton. Much this same condition obtained early in July, surface hauls off Gloucester, on July 7th, yielding a rich harvest of *Calanus finmarchicus*, with great numbers of the large blue copepod *Anomalocera pattersoni*, together with young schizopods, and a few other boreal organisms; while the importance of this region as a spawning ground for food fish was attested by the presence of numerous gadoid fry in the nets.

The hauls off Cape Cod (Station 10057) revealed the same type of macroplankton that occupied the greater part of the Gulf during the summer of 1912, namely, swarms of *Calanus finmarchicus*, a few *Euchaeta norvegica*, many small schizopods (Thysanoessa), Euthemisto and Hyperoche among amphipods, the pteropod *Limacina balea* (p. 303); *Sagitta elegans* (p. 299); the Medusae *Staurophora mertensii* and *Melicertum campanula;* the siphonophore *Stephanomia cara* (p. 315); and the ctenophores *Beroe cucumis* and *Pleurobrachia pileus*. Although open nets alone were used, their contents clearly showed that the plankton was bathymetrically stratified. Thus it was the surface hauls alone that yielded any considerable number of copepod nauplii and eggs; and while the haul at 15–0 fathoms caught swarms of Calanus, and many schizopods, and hyperiids, but only a few Sagittae, the haul from thirty fathoms contained almost no schizopods, hyperiids, or pteropods, but on the other hand brought back great numbers of Sagittae; and Euchaeta was taken in the deep haul only; *i. e.*, Calanus, schizopods, hyperiids, and pteropods were mostly above fifteen fathoms, Euchaeta, and Sagittae below that depth, Beroe, Pleurobrachia, and Stephanomia more evenly distributed horizontally.

Over the southern part of the basin of the Gulf (Station 10058) the plankton was qualitatively much the same — but quantitatively very different, for Calanus was not nearly so abundant in the haul from forty fathoms; the net, however, yielded many *Euchaeta norvegica*, with few *Calanus hyperboreus;* and fully one half the catch consisted of Stephanomia bells and denuded stalks (p. 316); there were also more fish fry than were found nearer shore.

At the Station on the northwest side of George's Bank, a rather surprising discovery was made, namely that the surface water was full of campanularian hydroids (Obelia) broken from their attachments, and many of them entirely regenerated. A similar phenomenon was noted on George's Bank during the winter of 1912–1913 (1914b, p. 414). It is interesting faunistically as showing how the strong tides of the region, by keeping the detached hydroids afloat, mechanically introduce an exotic element into the plankton. So far as I can learn, nothing of the sort has been observed elsewhere, at least on so large a scale. The place of Calanus was taken by another copepod, *Temora longicornis*, while the bulk of the deep haul consisted of Sagittae (*S. elegans*). The net also yielded many young Cyanea, and several caprellids, no doubt shaken loose from the hydroids.

In the waters over Nantucket Shoals (Station 10059) Calanus was again the prevalent organism, with but few Sagittae; near the lightship, however, (Station 10060), Sagittae about equalled Calanus in bulk; and this Station was also notable for swarms of young Euthemisto (p. 281), of pteropods (*Limacina balea*, p. 304), and of the free medusae of Obelia.

We saw fragments of Gulf weed on the surface south of Nantucket light-ship, and at Station 10061, over the eighty fathom curve, the influence of the Gulf Stream was made evident by the presence of Salpae, Phronima, and the amphipod Vibilia, though the bulk of the plankton still consisted of *Calanus finmarchicus*, with such other boreal forms as *Euchaeta norvegica*, Euthemisto, *Sagitta elegans*, and *Limacina balea*. The plankton over the shelf south of Marthas Vineyard and Block Island (Stations 10062 and 10063) consisted chiefly of swarms of young and old Euthemisto (p. 281), with smaller numbers of copepods (Calanus and Centropages, p. 287), Sagittae and an occasional *Pleurobrachia pileus*. And here for the first time large numbers of fish fry, a striking feature of the tows further south, were encountered. When the deep water outside the shelf south of Long Island (Station 10064) was reached the boreal plankton was replaced by a warm water assemblage, for while the 175 fathom haul still yielded many Euthemisto, the rest of the catch consisted of such typical Gulf Stream species as small "black fishes" (Myctophidae), swarms of Salpae of several species (p. 275), Doliolum, Phronima, Vibilia, Saphirrina and other species of copepods not taken in the cold waters nearer shore (p. 296); and such typical warm water coelenterates as *Rhopalonema velatum, Physophora hydrostatica,* and *Agalma elegans* (p. 316). But the haul from twenty-five fathoms yielded little except hundreds of colonies of *Agalma elegans,* with only a few Salpae; and the surface water was practically barren. Along this part of the coast Gulf Stream fauna was confined to the waters outside the continental shelf, for as we ran shoreward once more a typical Calanus plankton in great abundance was encountered, together with other boreal organisms, over the forty fathom curve (Station 10065).

Cape Cod is often spoken of as the dividing line between warm and cold water faunae on our coast; but at the time of the cruise it was not until we neared New York that any decided change in the character of the plankton of the coast water was noted. East of this, and in the Gulf of Maine (p. 285), copepods, chiefly Calanus, everywhere played an important rôle, though occasionally overshadowed by the extraordinary abundance of some other organism, for example, the hydroids on George's Bank, and the swarms of Euthemisto south of Block Island. But they were a very insignificant part of the plankton south of New York and were occasionally entirely lacking in the hauls. Near New York (Stations 10067 and 10068) the water was filled with swarms of *Pleurobrachia pileus* to the exclusion of almost everything else, except on the immediate surface, where the no. 20 net brought back a considerable number of small copepods (*Centropages typicus*). A few miles further south (Station 10069) large numbers of Salpae (p. 277) were seen on the surface close to land. At this Station, too, swarms of the large warm water ctenophore, *Mnemiopsis leidyi,* which has never been known to enter the Gulf of Maine, but which is common along shore as far as Cape Cod later in the summer, were noted for the first time. Other interesting coelenterates, common near the surface at this Station and further south, are the well-marked southern variety of the large hydromedusa, *Aequorea groenlandica,* and the pale southern Cyanea (p. 315). But all these warm water forms seem to have been limited to a shallow surface zone, because the haul from fifteen fathoms yielded great numbers of *Pleurobrachia pileus,* but no Salpae or Mnemiopsis, and only a few Aequorea which were probably caught near the surface. Besides the Pleurobrachia there were about twenty *Aglantha digitale*

(p. 316) besides a few Sagittae (p. 298), Euthemisto, one large *Tomopteris helgolandica*, and many fish fry of several species. We fully expected to find Salpae more abundant on our line seaward opposite Barnegat; but this was not the case, for, though great numbers of Mnemiopsis and Salpae were noted on the surface for some thirty miles from the land, both then disappeared, and at Station 10070, over the forty fathom curve, the hauls yielded no Mnemiopsis, and only seventeen specimens of Salpa, though the latter represented no less than six species. And Salpae were nearly as scarce at about the same relative position on the shelf off Cape May (Station 10072), none being seen on the surface, and the total catch only about thirty (p. 275). But the water there was full of Mnemiopsis, which clogged the nets; and the haul from fifteen fathoms yielded swarms of Pleurobrachia, many fish fry and one unmistakable warm water species, the small hydromedusa Niobia (p. 317).

The Gulf Stream station off Cape May (Station 10071) yielded much the same plankton that was found in the edge of the Stream off New York (Station 10064), as might have been expected from the high temperature and salinity of the water (p. 163). Little was to be seen on the surface except a few bits of Sargassum; and the surface nets yielded practically nothing. But the hauls from 175 and 190 fathoms brought in masses of Salpae of four species, notably *S. cylindrica* (p. 277); and such other warm water organisms as Phronima, *Agalma elegans, Diphyes serrata,* young myctophids, Leptocephali, *Sagitta inflata,* Rhizophysa, several southern pteropods (p. 302), and the oceanic schizopod *Nematoscelis megalops.* The only members of the list from this Station which are regular inhabitants of the coast water north of New York are a few copepods (Calanus and Metridia), which shows how little the coast water influences the plankton outside the continental shelf.

The plankton of the coast water was composed of much the same constituents south of Delaware Bay as off Barnegat. At Station 10073 the surface water was very barren, the total yield of the surface nets being only a few small Doliolum, one Pleurobrachia, two Sagittae, seven or eight copepods, a few small appendicularians, and fish eggs. But at fifteen fathoms the net was clogged by Mnemiopsis, while Geryonia, Diphyes, Cuboides, Sapphirina, several species of warm water pteropods (p. 302), and two specimens of the Leptocephalus of the conger eel gave it a more southern aspect than that of the shallow water further north. The hauls over the forty fathom contour, some fifty miles further south (Station 10074) contained an even larger proportion of warm water animals, and loggerhead turtles, sharks, and pilot fish were seen on the surface. And the deep haul contained many oceanic species, *e. g.*, Criseis, Corolla, Firoloides, Liriope, Aglaura, Rhopalonema, *Agalma elegans*, and the tropical hydromedusa Niobia, which, owing to its asexual budding, comes into the oceanic category so far as its dispersal is concerned. But there were also many neritic forms, *e. g.* fish eggs and fry, stomatopod larvae, gammarids, young crabs, and the ctenophore Pleurobrachia. Five miles nearer land the water was crowded with copepod larvae and the ctenophore Mnemiopsis, though still with an occasional Agalma, Doliolum, and Liriope. The swarm of Mnemiopsis, which revealed its presence by its phosphorescence (for we ran through it at night) as well as by an occasional use of the dip net, was some twenty miles broad. But as land was approached it gave place to hosts of Salpae, which filled the surface waters at Station 10075. At this Station we noted an occasional Cyanea, and Aequorea, and many large specimens of *Beroe forskalii*, besides schools of menhaden (Brevoortia) and porpoises (Tursiops).

The final Gulf Stream Station (10076) lay abreast of Chesapeake Bay. And though the plankton consisted chiefly of the same oceanic forms which were encountered further north, the presence of stomatopod larvae, Aequorea, considerable numbers of small copepods, and eel grass (Zostera) instead of Sargassum floating on the surface, showed as clearly as did the salinity (p. 200) that the influence of the fresh water from the Bay was felt over the whole breadth of the continental shelf. And perhaps this also explains the fact that all the hauls at this Station were scanty, and contained a large proportion of debris.

As the mouth of the Bay (Station 10077) was approached the macroplankton grew even more scanty, though there was a decided increase of microplankton (p. 334); and Beroe was once more found in considerable numbers, together with the neritic hydromedusa Laodicea, while a new element of shore origin was added by swarms of larvae of the blue crab (Callinectes) on the surface. The few oceanic elements were now much in the minority; but even near the mouth of the Bay (Station 10078), the nets yielded a few Liriope and an occasional siphonophore (Diphyes).

The stations on the run northward to Cape Cod all lay close to land, hence yielded chiefly neritic plankton. The swarm of Callinectes larvae extended for about thirty-five miles along the coast, being no doubt recruited from the various bays and inland sounds, as well as from the Chesapeake itself; but it had disappeared by the time Station 10079 was reached, and it is interesting to note that its disappearance coincided with a decided rise in the salinity of the surface water (Plate 2). On the other hand Mnemiopsis, together with a few Aequorea, Cyanea, and Pleurobrachia, was again numerous at this Station, and there was a great increase in the number of Salpae (p. 275), which were but sparsely represented at the stations off the mouth of Chesapeake Bay. The hauls at Station 10079 likewise yielded such oceanic genera as Doliolum, Criseis, and Firoloides. Immediately north of Delaware Bay (Station 10080) we once more found swarms of small Salpae (p. 275) and Mnemiopsis, the nets coming in full to the brim. But both of these genera must have been limited to a very shallow surface zone, because a net working about a fathom down caught very few of either. Deeper down, about ten fathoms, the water was occupied by a swarm of Pleurobrachia. Stations 10080 and 10081 illustrate how much more varied the plankton was near shore along this part of the coast than in the Gulf of Maine, for no Pleurobrachia, and very few Mnemiopsis were taken at the latter only about forty miles north of the former and about the same distance from land, with about the same temperature and salinity. But the deeper water layers must have swarmed with small Salpae, for the haul at ten fathoms yielded a perfect Salpa soup; and the surface hauls caught great numbers of Callinectes larvae, which were not represented at all at Station 10080.

By August 1, Salpae, which were first met in numbers off Barnegat, on the voyage south, had spread northward as far as the Hudson trough (Station 10082) where they formed the bulk of the surface tow. But the haul at twenty fathoms yielded very little except Pleurobrachia. When the shore of Long Island (Station 10083) was approached, the Salpae, and the Pleurobrachia swarm, were replaced by a rather scanty copepod plankton.

The remainder of the work was carried on in the Gulf of Maine. And no sooner had the Grampus rounded the southern angle of Cape Cod (Station 10085) than the boreal plankton, with which we are familiar from previous work in the Gulf, was encountered. Stations 10057 and 10086 were located at the same geographic position off Highland light, and the only apparent change which had taken place during the interval of four weeks which separated them was that the Staurophora, Stephanomia, and Beroe, which had been prominent in the tow early in July were no longer found. Off Massachusetts Bay we found a typical Calanus plankton, with *Euchaeta norvegica*, northern schizopods, *Sagitta elegans*, Euthemisto, *Limacina balea*, Pleurobrachia, Melicertum, *Tomopteris helgolandica*, Euchaeta, and hosts of

Gulf of Maine plankton.

Species	Stations																			% of stations for each species
	10086	10087	10088	10089	10090	10091	10092	10093	10095	10096	10097	10098	10099	10100	10101	10102	10103	10104	10105	
Calanus finmarchicus	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	100
Pseudocalanus elongatus	?	×	×	×	×		×		×	×	×	×	×	×	×	×	×		×	80
Metridia lucens	×	×	×	×	×		×	×		×	×	×	×	×	×	×	×	×	×	80
Anomalocera pattersoni			×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	80
Euchaeta norvegica		×	×	×	×	×	×	×		×	×			×	×	×		×		70
Meganyctiphanes norvegica			×				×	×			×			×	×		×			40
Thyanoessa inermis		×																		
Euthemisto compressa	×	×	×	×	×	×	×	×	×	×	×			×	×	×	×	×	×	90
" bispinosa				×	×	×	×	×	×	×	×					×				50
Hyperoche kroyeri	×	×	×								×	×		×				×		40
Limacina balea	×	×	×		×	×	×	×	×	×	×		×	×	×	×	×	×		80
Tomopteris helgolandica		×	×	×		×		×	×	×	×		×	×	×		×			60
Sagitta elegans	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	100
Phialidium languidum			×	×	×	×			×	×	×	×	×	×	×	×	×		×	80
Staurophora mertensii				×	×	×		×						×			×	×		40
Pleurobrachia pileus	×	×		×					×	×	×	×	×	×			×			50
Total species per stations	8	11	12	12	11	10	10	11	10	12	14	8	8	14	11	10	12	9	7	

larvae of the red fish (*Sebastes marinus*). And the assemblage over the western basin was the same, with the addition of the schizopod, *Meganyctiphanes norvegica*. Off Penobscot Bay (Stations 10091 and 10100) there were swarms of *Limacina balea*, a pteropod represented at most of the other Gulf Stations by small numbers only; at several stations the nets brought back numerous specimens of Staurophora (p. 273), and at Stations 10091 and 10092 the surface waters were swarming with young amphipods (Euthemisto), as well as with young stages of *Calanus finmarchicus*, in the proportion of about one of the former to four of the latter. The accompanying table showing the occurrence of fifteen of the more characteristic and faunistically important species, illustrates the extreme uniformity of the plankton of the Gulf. At fourteen of the nineteen stations in the Gulf ten or more of these fifteen species are represented; and at only three stations were less than eight found; the poorest even (Stations 10098, 10099, 10105) had half of the species. Two forms, *Calanus finmarchicus*, and *Sagitta elegans* were taken at every station; and a third, *Pseudocalanus elongatus* was probably also universal (p. 291). *Euthemisto compressa*, *Anomalocera pattersoni*, *Limacina balea* and *Phialidium languidum* occurred at 80–90% of the stations and *Euchaeta norvegica* at every station where the haul was deeper than forty fathoms. And no subdivision of the Gulf into faunal regions is possible for any of the species, except that in a general way neritic forms, *e. g.*, *Tomopteris helgolandica*, Staurophora, and Phialidium, and the various metazoan larvae which are always more or less in evidence in the tows near shore, occurred less regularly at the stations in the centre of the Gulf.

The only region which showed a decided variation from the general plankton type just described was German Bank (Station 10095) where the copepods were largely replaced by a swarm of *Pleurobrachia pileus*. But this was an impoverishment, rather than a different plankton type, for Pleurobrachia is widely though irregularly distributed over the Gulf in summer; and when it swarms, seems to obliterate or devour almost everything else in the water.

In 1913, as in 1912, we found a few pelagic organisms of unmistakably oceanic and warm water origin in the Gulf, *e. g.*, Salpa, two copepods, *Euchirella rostrata*, and *Pleuromamma robusta*, and a chaetognath, *Sagitta serratodentata;* but the Gulf Stream component was smaller than in the previous year; while on the other hand, three cold water species, which, though not truly polar, are at least at home in low temperatures, *i. e.*, *Calanus hyperboreus*, *Euchaeta norvegica* and *Eukrohnia hamata*, were more abundant than in 1912, and a fourth, the copepod *Metridia longa,* which is more typically arctic than any of the preceding, is recorded from the Gulf for the first time. Northern species, however, were not uniformly more abundant than in 1912, the reverse being true of *Clione limacina* (p. 305).

Distribution of Salpa and Doliolum.

Identified by W. F. Clapp.

Table of occurrence.

Station	Depth	Date	S. fusiformis v. echinata		S. tilesii		S. democratica		S. zonaria		S. cylindrica		S. confoederata		Doliolum	
			agg.	sol.	agg.	sol.	agg.	sol.	agg.	sol.	agg.	sol.	agg.	sol.	ooz.	blast
10061	30–0	7/10/13			Chain 9				2							
10064	175–0	7/11/13	m.	56					33	13					2	
10065	20–0	7/12/13							23	1						
10069	Surface	7/19/13					Swarm m.	m.								
10070	0												1			
10070	20–0	"	2	2	2	1	2	4		1			1		1	
10071	0		1	1				1					1			
10071	190–0	7/20/13	1	m.			1		f.		m.	m.				
10072	15–0	7/21/13					×	×	23							
10073	Surface	"											f. chains			
10073	15–0	"						f.								m.
10074	Surface	7/22/13			f.			3					chains m.			
10074	20–0	"						3	29				11		1	f.
10075	8–0	7/23/13					swarms m.	m.								
10 miles E. off Hog Id.	Surface	7/29/13					m.									
10076	20–0	7/24/13			1				14				23			
10076	120–0	"		f.	2	2	f.	f.	1	2						
10077	20–0	"			1		m.	m.							1	
10078	8–0	7/29/13					f.	f.								
10079	0						swarms m.	m.								
10079	10–0	7/30/13					swarms m.	m.								12
10080	Surface	7/31/13					swarms m.	m.								
10080	12–0						m.	m.								
10081	10–0	"					m.	m.								
10082	0						m.	m.								
10082	15–0	8/1/13					m.	m.								
10096	30–0	8/12/13			6											
10064	25–0								f.							
10076	0												chains m.			

f. = few = 25 + m. = many = 100 +

Judging from the general distribution of the various species of Salpa in northern waters (Apstein, 1909) their occurrence in numbers was expected only where the surface temperature was high. And this proved to be the case. Salpae were more or less abundant at all the stations south of New York and over the outer edge of the continental shelf (Fig. 67). By the first of August they had extended their range to the waters off New York (Station 10082). And although they had

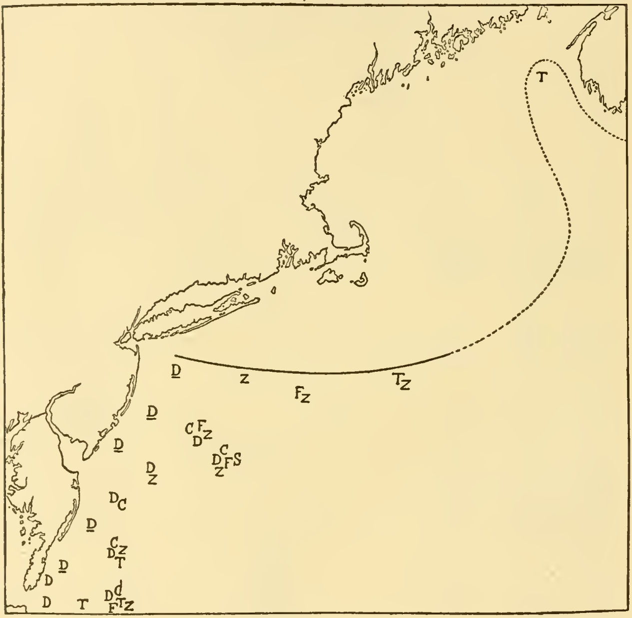

FIG. 67.— Distribution of Salpa. D, S. democratica; D, S. democratica swarms; T, S. tilesii; F, S. fusiformis; C, S. confoederata; S, S. cylindrica; Z, S. zonaria. The curve is the probable northern limit of Salpae at the time of our cruise.

not then reached the south shore of Long Island (Station 10083), they do so more or less regularly later in the season. The only Salpae encountered in the Gulf of Maine were a few specimens of *S. tilesii* which were taken on the eastern side (Station 10096). And I may note that great numbers of this species were taken by fishermen in Massachusetts Bay in the ensuing November and December. The commonest species was *S. democratica.* It was not taken over the edge of the shelf south of Nantucket and Long Island. But it swarmed on the surface off Barnegat (Station 10069); and was taken at all the stations further south, though it was far less abundant in the Gulf Stream than at certain localities near land, *e. g.*, Stations 10069, 10075, 10079, 10080, 10081, and 10082. But it was not universally common over this part of the shelf, there being regions of scarcity off Delaware Bay and off Chesapeake Bay (Stations 10070, 10072, 10074, 10078). All the captures were from temperatures higher than 65°. Salinity was about the same (32.1‰–32.4‰) at several of the poor Stations (10070, 10072) as at several rich ones (10069, 10079, 10080, 10081); and the total range of salinity occupied by the species was very great (32.27‰ to 35.25‰). The unequal quantitative distribution of *Salpa democratica* is, I believe, an index of the abundance of the food supply, not of the amount of Gulf Stream water. During the early summer the surface temperature rises sufficiently to make the coast water a favorable habitat for the Salpae which are dispersed over this part of the continental shelf by the constant mixture between land and Gulf Stream water, and wherever they find a plentiful food supply, they reproduce with marvelous rapidity. Examination of the intestinal contents of *S. democratica* supports this view, for the specimens taken at Stations 10069, 10077, 10081 contain large amounts of diatom and peridinian debris. *Salpa democratica* occasionally swarms in the Gulf of Maine, for example, off Chatham in September, 1912 (1914a), though not encountered there in 1913.

The five other species of Salpa do not agree in distribution with *S. democratica*, for they were all absent in the coastal belt south of New York, (Stations 10069, 10075, 10078 off Hog Island, 10079, 10080, 10081 and 10082), *i. e.*, just where *democratica* was most abundant (p. 275). *Salpa zonaria* was second to *democratica* in the number of stations at which it was observed, but unlike the latter, it was most abundant at the edge of the Gulf Stream and over the outer part of the shelf (Stations 10064, 10071, 10072, 10074); absent close to land.

Salpa fusiformis was even more restricted to the edge of the Gulf Stream, being most abundant in the deep hauls at the Stations where Gulf Stream water was purest (10064, 10071), much less so off Chesapeake Bay Station (10076). It was not found anywhere over the continental shelf, except a few specimens at Station 10070.

Our only capture of *S. cylindrica* was at the most typical Gulf Stream Station (10071), where it was numerous, far outnumbering all other Salpae put together. And the few chains of *S. confoederata* which were seen, or collected, it was nowhere abundant, were restricted to Gulf Stream Stations (10071, 10076) and to the outer part of the shelf (10070, 10073, 10074). *Salpa tilesii*, on the contrary, was not taken at all at Stations 10064 and 10071, but was found in adulterated Gulf Stream water at Station 10076, and was more or less common along the edge of the continental shelf (Stations 10061, 10070, 10077); and in the eastern part of the Gulf of Maine (Station 10096).

Salpae as a whole were far less numerous along the inner edge of the Gulf Stream in July, 1913, than they were in July, 1908 (1909, p. 198), when they were more abundant on the surface south of Nantucket than I have ever seen them.

The hyperiid amphipods.

Hyperiid amphipods often form a large part of the macroplankton in boreal waters and are of considerable importance as food for pelagic fishes. The species so far captured in the Grampus hauls, all of which are easily recognizable, are *Hyperia medusarum, Hyperia galba, Hyperoche kröyeri, Parathemisto oblivia, Euthemisto compressa, Euthemisto bispinosa, Phronima atlantica, Phronima sedentaria, Tyro atlantica,* and *Vibilia jeangerardi.* Their occurrence, in the summer of 1913, is shown in the following table (p. 279).

(The identifications follow Bovallius, 1887–1889, and Sars, 1895. For previous records off the New England coast, see Holmes, 1905, and Rathbun, 1905).

The most widely distributed hyperiids in the coast water, as well as the most abundant numerically, were the two species of Euthemisto, *compressa* and *bispinosa* (Fig. 68). This genus as a whole (the relationship of the two species to each other will be considered later) was generally distributed over the Gulf of Maine (Stations 10058, 10087 to 10105); it was present on George's Bank (Station 10059), in the waters over Nantucket Shoals (Station 10060), over the outer part of the continental shelf, south of Block Island and Long Island (Stations 10062, 10063, 10065, 10066); and in the mixed water at the inner edge of the Gulf Stream (Stations 10061, 10064, and 10076). But we did not find it in Gulf Stream water proper (Station 10071, 10073), in any of the tows in the comparatively fresh water off Chesapeake Bay (Stations 10077 and 10078), or at any of the stations near shore between New York and the Chesapeake (Stations 10067, 10068, 10079–10083), except in one instance (Station 10075).

Table of hyperiids.

Stations	Hyperia galba	Hyperia medusarum	Hyperoche kröyeri	Euthemisto compressa	Euthemisto bispinosa	Vibilia	Tyro	Phronima sedentaria	Phronima atlantica
10057	......	......	16	2					
10058	14	4	17	f.					
10059	5	2	......	f.					
10060	......	......	......	m.	m.				
10061	......	......	......	m.	m.	1		1	
10062	......	......	......	......	m.				
10063	......	......	......	f.	m.				
10064	......	......	......	m.	m.	10	......	5	7
10065	......	......	......	2	m.	3			
10066	......	......	......	1	13				
10069	......	......	......	3	1				
10071	1	......	......	......	......	14	1	7	4
10074	......	......	......	2	2				
10075	......	......	......	4					
10076	......	......	......	f.	f.	21			
10080	......	......	......	......	......	......	......	1	
10085	......	......	3	1					
10086	......	......	4	m.					
10087	1	......	1	f.					
10088	5	1	1	f.					
10089	......	......	......	f.	f.				
10090	......	......	......	m.	m.				
10091	......	......	......	f.[1]	f.				
10092	1	......	......	m.	m.				
10093	......	......	......	f.	f.				
10095	......	......	......	m.	f.				
10096	......	1	......	m.	f.				
10097	......	......	1	6	2				
10098	......	......	6						
10100	......	......	6	m.					
10101	......	......	......	f.					
10102	......	......	......	m.	2				
10103	......	......	......	f.					
10104	3	......	5	m.					
10105	......	......	4	f.					
10112	......	......	......	m.	m.				

m. = 50+. f. = 20+

[1] and a swarm of larvae, probably this species.

The distribution of the two species is not exactly the same, though roughly parallel, for while *compressa* was taken at practically every station where *bispinosa* occurred, it alone occurred off Cape Cod and on George's Bank, near the coast south of New York (Station 10075)

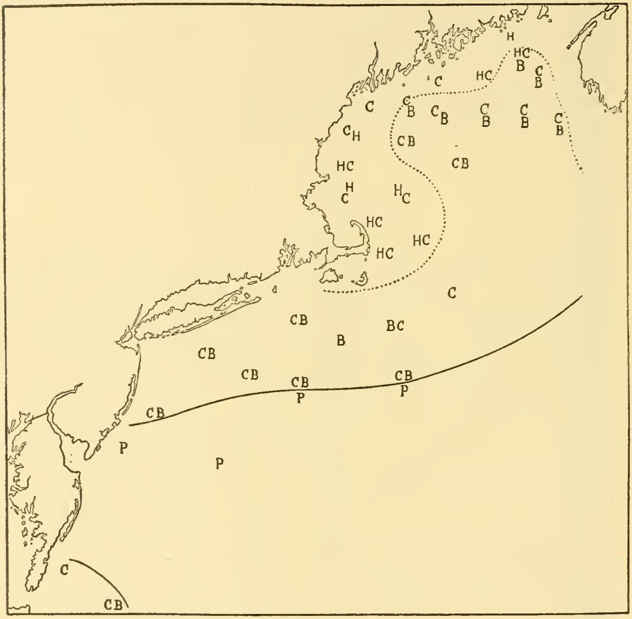

FIG. 68.— Distribution of hyperiid amphipods.
B = Euthemisto bispinosa; C, E. compressa; H, Hyperoche; P, Phronima. The curve —, is the probable southeastern limit to Euthemisto, the dotted curve, ..., the northern limit of E. bispinosa in the Gulf of Maine, at the time of the cruise.

off Massachusetts Bay (Stations 10087, 10088), and, in general, in the coast water north of Cape Ann (Stations 10100, 10101, 10103, 10104, 10105). Of course horizontal hauls can not afford an accurate idea of its abundance, but they do show that it swarmed on the surface over the eastern basin of the Gulf of Maine (Station 10092); and the swarms of larval Euthemisto which were taken on the surface off Penobscot Bay (Station 10091) probably belong to this species. Secondary centres of abundance for *compressa* in the Gulf were at Station 10102, and German Bank (Station 10095). The only place south of Cape Cod where it was taken in large numbers was on the south side of Nantucket Shoals (Station 10060). *Euthemisto bispinosa* was most abundant, in July, over the outer part of the continental shelf south of Nantucket and Long Island (Stations 10060, 10061, 10062, 10063, 10065); with a second centre of abundance in the eastern part of the Gulf of Maine (Stations 10092, 10093). Late in August young *bispinosa* swarmed in the water southwest of Nantucket (Station 10112) where the large specimens were about evenly divided between that species and *compressa*.

The hauls throw some light on the bathymetric occurrence of the two species. To begin with, it was seldom that the surface hauls contained more than a few representatives of either, though made by night as well as by day. But, as just pointed out, there were swarms on the surface at Stations 10062, 10091, 10092, and 10093. Judging from the stations where two or more intermediate hauls were made at different depths *E. compressa*, like *Calanus finmarchicus*, was most abundant above say forty fathoms in coastal waters, as illustrated by the counts of specimens at three representative stations in the Gulf of Maine and on Nantucket Shoals.

Stations	Fathoms	P. compressa specimens
10061	40–0	29
	70–0	3
10092	35–0	19
	85–0	6
10097	30–0	3
	80–0	0
10104	15–0	35
	50–0	8

And this difference is an actual one, not the accidental result of different nets, etc., because, as pointed out (p. 327) sometimes one net, sometimes another, was used for the deepest haul; and other things being equal, it is the net which worked the deepest, not the shallowest, which would be expected to yield the largest catch, because of the longer column of water through which it fished on its way down and up.

Off Chesapeake Bay (Station 10076) the numbers in the deep and shallow hauls were more nearly equal. In the edge of the Gulf Stream, south of Long Island (Station 10064) *compressa* was ten times as numerous in the haul from 175 fathoms, as in the twenty fathom haul.

Euthemisto bispinosa like *compressa* was more abundant in the deep than in the shallow haul at Station 10064. And it was likewise several times as numerous in the shallow as in the deep haul in the eastern part of the Gulf of Maine (Station 10092). But it was about equally numerous in the two hauls at Station 10061; and off Chesapeake Bay it was most numerous in the deep haul.

Station	Fathoms	Specimens of bispinosa	Station	Fathoms	Specimens of bispinosa
10061	40–0	56	10092	35–0	111
	70–0	67		85–0	29
10064	20–0	5	10097	30–0	1
	175–0	11		80–0	1
10076	20–0	0			
	120–0	17			

The quantitative relationship of the two species to each other is shown in the following table, which gives the relative number of each species in a sample at stations where both were taken.

Stations →	10060, 20–0 F.	10061, 40–0 F.	70–0 F.	10063, 25–0 F.	10064, 20–0 F.	175–0 F.	10065, 20–0 F.	10066, 0 F.	10069, 10–0 F.	10076, 20–0 F.	120–0 F.	10089, 25–0 F.	10090, 75–0 F.
Euthemisto compressa	58	29	3	10	4	42	10	1	3	10	6	28	39
Euthemisto bispinosa	52	56	67	200	5	11	75	13	1	0	17	18	40

Stations →	10091, 0 F.	10092, 0 F.	35–0 F.	85–0 F.	10093, 0 F.	85–0 F.	10095, 20–0 F.	10096, 0 F.	30–0 F.	10097, 30–0 F.	80–0 F.	10102, 20–0.	10112, 20–0.
Euthemisto compressa	1	30	19	6	25	1	30	10	22	3	0	75	10
Euthemisto bispinosa	1	2	111	29	50	8	9	0	6	1	1	2	100

Thus the two species were about equally abundant over Nantucket Shoals (Station 10060), in the centre of the Gulf of Maine (Stations 10090 and 10091), and in the upper layers near the edge of the Gulf Stream south of Long Island (Station 10064). But *compressa* preponderated off Barnegat (Station 10069) and at all the stations near shore in the Gulf of Maine where both were taken, (Stations 10089, 10095, 10096, 10097, 10102), as well as on the surface over the eastern basin (10092); *E. bispinosa* over the outer part of the continental shelf south of Nantucket and Long Island, in the deep haul off Chesapeake Bay, and in the deep hauls in the eastern basin of the Gulf of Maine. When *bispinosa* outnumbered *compressa*, its preponderance was usually greatest in the deep hauls.

Both species were living at a wide range of temperature, with a maximum of about 69° (Station 10066, surface). And swarms of *bispinosa* were taken in water as warm as 67° (Station 10062, surface); but *compressa* was not common in water warmer than 62° (Station 10092), and most of its captures must have been from considerably colder water. The lowest temperatures for both was about 42° (deep hauls in the Gulf of Maine); and *bispinosa* must have been living in numbers in this cold water, because plentifully represented in one of the deepest hauls in the Gulf as well as in the shallower ones (p. 282).

The range of salinity was likewise very wide for both species, with an upper limit of 35.2‰ (the deep haul at Station 10064) and a lower limit of about 31.5‰ (surface, Station 10066). But it was only once that either was taken in water fresher than 32‰, and the freshest water in which they were abundant was 32.8‰ for *bispinosa* (surface, Station 10062), 32.6‰ for *compressa* (surface, Station 10092).

The data outlined above suggest that both *compressa* and *bispinosa* belong to the coastal, not oceanic waters, of which *compressa*, at least, is almost as regular an inhabitant as *Limacina balea*, Calanus, or indeed any of the typical boreal plankton animals. Both species, it is true, were found in large numbers, and of unusually large size, in the deep water under the edge of the Gulf Stream; but the fact that this was only where the surface of the stream was considerably diluted with fresh water, and that both were absent in the Gulf Stream water proper (Station 10071, 10073) shows that neither of them is a regular inhabitant of the stream. They thrive below the inner edge of the stream, not because of temperature or salinity, but because of the abundant food supply.

Hyperoche kroyeri was taken only in the Gulf of Maine where it occurred at twelve stations, all near shore, as follows:—

Station	Fathoms	Specimens	Stations	Fathoms	Specimens
10057	15–0	10	10088	80–0	1
	30–0	6	10097	80–0	1
10058	40–0	17	10098	18–0	6
10085	20–0	3	10100	40–0	7
10086	20–0	4	10104	50–0	5
10087	15–0	5	10105	50–0	3
	30–0	1			

The numbers of specimens concerned are so small that they do not show anything about bathymetric distribution.

The few captures of *Hyperia medusarum* are likewise from the Gulf of Maine, and so are most of the *Hyperia galba*, which is consistent with the distribution of their medusan host Cyanea. But one specimen of *H. galba* was taken in the Gulf Stream (Station 10071, 190–0 fathoms).

The remaining hyperiids were all taken either in the Gulf Stream, or where Gulf Stream water was in evidence: they are all visitors from the south, or at least from the warmer parts of the Atlantic, and do not belong to the permanent plankton of the coast water.

Vibilia was taken at all the stations outside the continental shelf, and twice over the outer part of the shelf; curiously enough, however, it was not encountered in the Gulf Stream tongue south of Delaware Bay. The depths of the captures are:—

Station	Fathoms	Specimens	Station	Fathoms	Specimens
10061	70–0	1	10071	20–0	2
10064	175–0	10		190–0	12
10065	20–0	3	10076	20–0	2

Thus most of the specimens came from deep hauls, none from the surface.

Tyro was taken only once, in the Gulf Stream, one specimen, twenty fathoms, Station 10071.

The two species of Phronima were likewise restricted to the Gulf Stream, and to the outer edge of the shelf, except for a single specimen of *sedentaria* near Cape May (Station 10080). Though the two agree geographically *sedentaria* was living deeper than *atlantica* as shown in the following table of captures.

Station	Depth	Sedentaria	Atlantica
10061	40–0	1	
10064	20–0		7
	175–0	5	
10071	20–0		4
	190–0	7	
10080	12–0	1	

The only *sedentaria* taken in shallow water was dead and very fragmentary; those from the deep hauls were all alive, and most of them inside their "houses" (Doliolum shells). The *atlantica* were all free, and alive. Neither was taken on the surface, which agrees with the rarity of Salpae and Doliolum on the surface, in the Gulf Stream (p. 278) at the time of our visit. When Salpae swarm at the surface of the stream, as they occasionally do (1909b), Phronima appears there too.

Copepods.[1]

Copepods were by far the most important constituent of the plankton in the Gulf of Maine (p. 274), where they were extremely abundant; and the hauls revealed a rich copepod plankton over the shelf south of Cape Cod. But on the run west and south, these little crustaceans gave way to other organisms (p. 269), the copepods in the hauls south of New York being counted by individuals, instead of by hundreds of cubic centimeters. And in some of the southern hauls, *e. g.*, at Stations 10068, 10069, 10078, no copepods at all were detected, something never experienced in the Gulf of Maine. The geographic occurrence of the various copepods is listed in the following table.

[1] Identified by Dr. C. O. Esterly.

Table of the numbers of individuals of several species of copepods in the quantitative hauls (column of water .1 square meter) in the Gulf of Maine, from samples counted by Dr. Esterly.

Stations →	10087	10089	10090	10092	10095	10096	10097
Calanus finmarchicus	3750	1650	3750	8800	375	3000	2800
Calanus hyperboreus				80			
Pseudocalanus elongatus	360	1050	375	2600	2400	3000	5600
Euchaeta norvegica			15			20	30
Centropages typicus	90		75				
Temora longicornis				40	150	60	
Metridia lucens	900	225	60	160	105	240	280

Stations →	10098	10099	10100	10101	10102	10103	10105
Calanus finmarchicus	500	1200	5400	3000	2250	2000	1350
Calanus hyperboreus			270				
Pseudocalanus elongatus	3200	600	4500	3200	600	1200	975
Euchaeta norvegica							
Centropages typicus							150
Temora longicornis	80	300	1800	1200		160	
Metridia lucens	60	60	450	300	180	80	225

TABLE OF COPEPODS IN THE HORIZONTAL HAULS.[1]

STATIONS →	10057	10058	10059	10060	10061	10062	10063	10064	10065	10066	10067	10068
Calanus finmarchicus	s.	m.	1	m.	s.	....	m.	....	s.	3	....	....
Calanus hyperboreus	....	2	....	....	....	....	....	....	....	....	....	....
Pseudocalanus elongatus	....	....	×	....	....	....	....	....	....	....	....	....
Rhincalanus nasutus	....	....	....	....	....	....	....	30	....	....	....	....
Euchirella rostrata	....	....	....	....	....	....	....	70	....	....	....	....
Euchaeta norvegica	f.	f.	....	....	m.	....	....	....	....	....	....	....
Euchaeta media	....	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta minor	....	....	....	....	....	....	....	6	....	....	....	....
Undeuchaeta major	....	....	....	....	....	....	....	....	....	....	....	....
Centropages hamatus	....	....	....	1	....	....	....	....	....	....	....	....
Centropages typicus	....	....	....	....	....	s.	1	....	m.	s.	m.	....
Temora longicornis	....	....	m.	s.	....	....	....	....	....	f.	....	....
Metridia lucens	f.	f.	....	....	....	....	....	35	....	....	....	....
Metridia longa	f.	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma robusta	....	....	....	....	....	....	....	400	....	....	....	....
Pleuromamma xiphias	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma rotundum	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma sp.?	....	....	....	....	....	....	....	....	....	....	....	....
Anomalocera pattersoni	....	....	....	....	....	....	....	....	....	....	....	....
Scolecithrix persecans	....	....	....	....	....	....	....	2	....	....	....	....
Candacia armata	....	....	....	....	....	....	....	....	....	....	....	....

STATIONS →	10069	10070	10071	10072	10073	10074	10075	10076	10077	10078	10079	10080
Calanus finmarchicus	....	....	6	....	....	4	....	6	4	....	1	6
Calanus hyperboreus	....	....	....	....	....	....	....	....	....	....	....	....
Pseudocalanus elongatus	....	....	....	....	....	....	....	....	....	....	....	....
Rhincalanus nasutus	....	....	12	....	....	....	....	7	....	....	....	....
Euchirella rostrata	....	....	....	....	....	....	....	1	....	....	....	....
Euchaeta norvegica	....	....	....	....	....	....	....	....	....	....	....	....
Euchaeta media	....	....	....	1	....	....	....	....	....	....	....	....
Undeuchaeta minor	....	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta major	....	....	1	....	....	....	....	....	....	....	....	....
Centropages hamatus	....	....	....	....	....	....	....	....	....	....	....	....
Centropages typicus	....	m.	....	....	....	11	3	60	....	....	m.	7
Temora longicornis	....	....	....	....	....	....	....	....	....	....	....	....
Metridia lucens	....	....	10	....	....	....	....	10	....	....	....	....
Metridia longa	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma robusta	....	....	2	....	....	....	....	....	....	....	....	....
Pleuromamma xiphias	....	....	1	....	....	....	....	....	....	....	....	....
Pleuromamma rotundum	....	....	....	....	....	....	....	15	....	....	....	....
Pleuromamma sp.?	....	....	40	....	....	....	....	....	....	....	....	....
Anomalocera pattersoni	....	7	3	....	....	....	....	....	2	....	....	10
Scolecithrix persecans	....	....	....	....	....	....	....	....	....	....	....	....
Candacia armata	....	....	....	....	....	40	....	m.	6	....	....	....

[1] The occurrences of Pseudocalanus are chiefly from the quantitative hauls, p. 291.

Stations →	10081	10082	10083	10085	10086	10087	10088	10089	10090	10091	10092	10093
Calanus finmarchicus	1	....	s.	s.	s.	s.	m.	s.	s.	s.	s.	s.
Calanus hyperboreus	....	....	....	....	....	....	....	....	....	....	....	....
Pseudocalanus elongatus	....	....	f.	....	....	m.	f.	s.	m.	....	×	....
Rhincalanus nasutus	....	....	....	....	....	....	....	....	....	....	....	....
Euchirella rostrata	....	....	....	....	....	....	....	....	....	....	....	....
Euchaeta norvegica	....	....	....	....	....	f.	f.	f.	m	f.	m.	f.
Euchaeta media	....	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta minor	....	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta major	....	....	....	....	....	....	....	....	....	....	....	....
Centropages hamatus	....	....	1	....	....	....	....	....	....	....	....	....
Centropages typicus	....	15	m.	....	....	f.	m.	....	f.	1	6	....
Temora longicornis	....	....	4	....	....	....	....	....	....	....	f.	....
Metridia lucens	....	....	20	....	m.	×	5	×	1	....	m.	....
Metridia longa	....	....	....	....	....	....	5	....	2	....	2	....
Pleuromamma robusta	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma xiphias	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma rotundum	....	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma sp.?	....	....	....	....	....	....	....	....	....	....	....	....
Anomalocera pattersoni	40	....	....	....	....	....	55	×	f.	×	m	f.
Scolecithrix persecans	....	....	....	....	....	....	....	....	....	....	....	....
Candacia armata	....	....	....	....	....	....	....	....	....	....	....	....

Stations →	10095	10096	10097	10098	10099	10100	10101	10102	10103	10104	10105
Calanus finmarchicus	m.	s.	s.	s	s.	s.	s.	s.	s.	s.	s.
Calanus hyperboreus	....	....	....	....	....	m.	f.	....	f.	....	....
Pseudocalanus elongatus	s.	s.	s.	s.	m.	s.	s.	m.	s.	....	m.
Rhincalanus nasutus	....	....	....	....	....	....	....	....	....	....	....
Euchirella rostrata	....	6	....	....	....	....	....	....	....	1	....
Euchaeta norvegica	....	m.	m.	....	....	m.	×	×	....	f.	f.
Euchaeta media	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta minor	....	....	....	....	....	....	....	....	....	....	....
Undeuchaeta major	....	....	....	....	....	....	....	....	....	....	....
Centropages hamatus	....	....	....	....	....	....	....	....	....	....	....
Centropages typicus	....	f.	....	....	....	....	....	....	....	f.	m.
Temora longicornis	f.	f.	f.	f.	f.	f.	m.	f.	f.	....	....
Metridia lucens	f.	m.	m.	f.	f.	f.	m	m.	f.	f.	×
Metridia longa	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma robusta	....	....	....	....	....	1	....	....	....	....	....
Pleuromamma xiphias	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma rotundum	....	....	....	....	....	....	....	....	....	....	....
Pleuromamma sp.?	....	....	....	....	....	....	....	....	....	....	....
Anomalocera pattersoni	f.	f.	f.	×	....	1	1	f.	60	f.	f.
Scolecithrix persecans	....	....	....	....	....	....	....	....	....	....	....
Candacia armata	....	....	....	....	....	....	....	....	....	....	....

f. = few, 20 + m. = many, 100 +
s. = swarm, 1000 + × = the species occurred.

Calanus finmarchicus was, by far the most widespread and abundant species in 1913, as in 1912, very numerous in the Gulf of Maine in every haul from ten or more fathoms (Fig. 69). This was generally the case in the waters south of Nantucket also, as far as the edge of the continental shelf (Station 10061), except for Station 10062, where

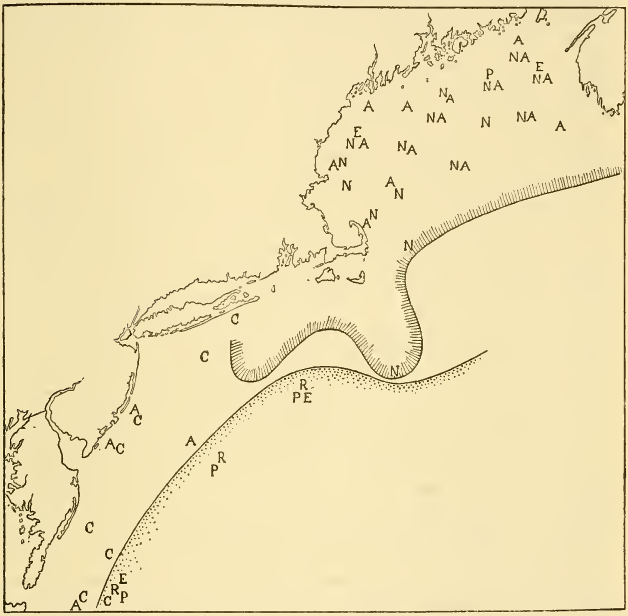

FIG. 69.— Distribution of copepods, July–August, 1913.
N, Euchaeta norvegica; A, Anomolocera pattersoni; R, Rhincalanus nasutus; P, Pleuromamma; E, Euchirella. ||| Southern limit to abundant Calanus finmarchicus; C, occasional Calanus finmarchicus. ⁝⁝⁝ Northern limit to Rhincalanus, Pleuromamma, and Euchirella.

it was wholly lacking, its place being taken by swarms of *Centropages typicus*, and of the amphipod Euthemisto. But it was represented by occasional specimens only, in the hauls off New York (Stations 10066, 10067) and further south; and only one specimen was detected in the hauls on George's Bank (Station 10059). It was also notably lacking in the Gulf Stream water (Stations 10064, 10071), except for a few specimens at Station 10076 abreast of Chesapeake Bay. Calanus appears to be uniformly rare, or absent, in the bays and sounds of the southern coast of New England in summer: but it swarms in Narragansett Bay in winter (Williams, 1906). Calanus was rare on the surface, even in the Gulf of Maine, except at Stations 10085, 10093, 10096, 10097, 10100, 10101, and immediately off Gloucester, July 8, where it swarmed at that level. Four of these stations were occupied in daylight, three after dark; which shows that its absence on the surface, in the regions where it swarms in deeper water, does not depend altogether on sunlight, though the latter may be one of the factors which confine it to deeper levels. And Calanus certainly did not come to the surface off Cape Cod during the night of August 5, for surface hauls taken at 2 A.M., and at practically the same locality at 8 A.M. (Station 10086), yielded very few Calanus, although the deep haul caught thousands. Stations 10057, 10061, 10087, 10090, 10092, 10102, 10104 where hauls were taken at three levels, surface, intermediate, and deep, show that Calanus was not usually equally abundant at all depths, the yields of hauls at 15–20 fathoms being very much larger than those at 50–85 fathoms. The numbers of specimens per haul were far too large for counting; but the shallower catches were usually two to four times as large in bulk as the deep ones, a difference too great to be charged to the difference in mouth area between the four foot and the Helgoland nets. And this source of possible error was further checked by occasionally alternating the two nets. The only exceptions to this rule were Stations 10093, 10097, and 10100, all in the eastern half of the Gulf, where Calanus was about equally abundant in deep and shallow hauls, *i. e.*, just the stations where it was abundant on the surface.

Calanus finmarchicus was taken through a very wide range of temperature, from about 42° (the deep hauls in the Gulf of Maine) to 76° (surface, Stations 10079 and 10080). But it was not abundant in water warmer than 62° (surface hauls, eastern part of the Gulf of Maine), and the great majority of the species was living in much cooler water (42°–50°). The lowest salinity for Calanus was 31.8‰ (surface, Station 10103), the highest may have been as high as 35‰ (Station 10074, 20–0 fathoms haul). But it is by no means certain that the specimens taken at that Station came from such salt water, the net having passed through water as fresh as 33.2‰. The vast majority were living in water of 32.7‰ to 33.4‰, in the intermediate depths of the Gulf of Maine. Calanus was wholly absent in pure Gulf Stream water, as exemplified by Station 10071, and the deeper layers at Stations 10064 and 10076; and it was likewise lacking in the very fresh water at the mouth of Chesapeake Bay. The possibility that the density of the water may determine the bathymetric distribution of copepods, by its effect on flotation, just as is the case with fish eggs, must be taken into account in geographic studies. The Calanus swarms in the Gulf of Maine were living in water of about 1.024 to 1.027. The lowest density in which adults were found abundant was 1.0239 (Station 10093, surface) though larval stages swarmed in water of 1.0231 (Station 10085, surface); the highest, for swarms, was about 1.027 in the deeper parts of the Gulf. None of the physical factors just outlined offer an obvious explanation for the scarcity of Calanus in the waters south of New York in July, for the subsurface salinities, temperatures, and densities of many of those stations were well within the range occupied by the species in the Gulf of Maine. What the limiting factor is, is one of the numerous questions raised, but not answered, by our cruise. Most of the specimens were large adults, as was the case in the summer and autumn of 1912. But the catch off Cape Cod on July 9 (Station 10057) was larval stages; and young stages swarmed in Massachusetts Bay during the early spring of 1913. (For an account of the biology of *Calanus finmarchicus* in Norwegian waters, see Damas, 1905).

The results of the quantitative hauls give a rough idea of the absolute abundance of Calanus in our Gulf (p. 286). Taken at their face value, they show that the numbers of Calanus in a column of water of one square meter cross section varied from 3750 to 88000, being greatest, as the plankton as a whole was richest (p. 237), off Massachusetts Bay and over the eastern basin, least in the northeast corner of the Gulf (Station 10098) and German Bank. The average of the hauls for the Gulf as a whole is 28000 per square meter of surface area. But Calanus must have actually been more numerous than this, because the calculations take no account of the failure of the net to filter the water completely.

The only species which vied with *Calanus finmarchicus* in abundance in the Gulf of Maine was *Pseudocalanus elongatus;* though it was far less important in the economy of the Gulf because of its small size. Pseudocalanus outnumbered Calanus on German Bank (Station 10095) and in the northeast corner of the Gulf (Stations 10097, 10098); and it was taken in large numbers in every haul of the quantitative net; though Calanus was usually the more abundant of the two. But the four foot and Helgoland nets failed to capture it at seven out of these thirteen stations. Probably their larger mesh allowed this minute species to pass through. The coarse nets alone being used for the subsurface work in the water south and west of Cape Cod, the apparent absence of this species there may have been partly due to the apparatus. But it can hardly have been abundant there, or it would have appeared occasionally in the catches of the four foot net, just as it did in the Gulf of Maine. And this agrees with Williams's observation (1906) that it is only in winter that Pseudocalanus appears in Narragansett Bay. In July and August it is abundant off Nova Scotia (Wright, 1907).

Eucheata norvegica was taken at practically every deep haul in the Gulf; as well as in three hauls from twenty fathoms (Stations 10090, 10091, 10101), one from fifteen fathoms (Station 10104) and one surface haul (Station 10097). It was found only once south of Cape Cod (Station 10061, 70–0 fathoms). The largest numbers were yielded by the deeper hauls, *e. g.*, 90–0 fathoms at Station 10100; 80–0 fathoms at Stations 10088 and 10097; 75–0 fathoms at Station 10090; 70–0 fathoms at Station 10061. At Stations 10092 and 10097 it was as abundant in the hauls at thirty fathoms, as in the deep hauls, and this was an interesting phenomenon for it was at these same stations that Calanus was uniformly distributed from the surface downward instead of being localized in the mid layers (p. 290). Euchaeta is never abundant in the Gulf of Maine, in the sense that Calanus, or any of the other small copepods can be so described, the richest hauls yielding a couple of hundred specimens at most. It occurred in only three of the quantitative hauls, and then only in small numbers (p. 286); but since the other nets yielded considerable numbers where the quantitative nets missed it, it is probably sufficiently active to avoid the latter, just as the Sagittae are (p. 329). *Euchaeta* was living in water colder than 50°; and at a comparatively high salinity (33‰–34‰); and its quantitative occurrence indicates the lower temperature and higher salinity for its optimum. The exceptions afforded by the one surface capture, and by its abundance at thirty fathoms at Stations 10092 and 10097, where the salinity was about 32.9–33‰ are probably due to local causes.

Metridia longa was likewise restricted to the Gulf of Maine in marked contrast to its relative *M. lucens.* Its captures are too few to allow any general statement of its range in our waters; but the fact that it occurred at all is of interest because it is the "most typically Arctic copepod of whose distribution there is any accurate knowledge"

(Farran, 1910, p. 70). It was not found in the Gulf in 1912, nor has it been recorded before from American waters.

The only other species limited to the waters north of Cape Cod was *Calanus hypoboreus*, which was taken at four stations in the Gulf, both on the surface (Station 10103) and in deep hauls. The only haul which yielded any considerable number was at 90–0 fathoms (Station 10100); where the quantitative net contained 270 *C. hypoboreus* to 5400 *C. finmarchicus;* at Station 10092 the relative numbers were 80 to 88008.

All the other copepods found regularly in the Gulf of Maine likewise occurred over the continental shelf south and west of Cape Cod. *Centropages typicus* was taken irregularly in the Gulf (eight stations) (Fig. 70), but never in large numbers. It did not appear at all in the hauls on George's Bank or on Nantucket Shoals; but it was represented at the shallow Stations south of Long Island (10062, 10063); and at most of the stations on the shelf further south and west. It was not taken at Stations 10064 or 10071; but was well represented in the deep haul at Station 10076: and it swarmed south of Nantucket (Station 10062), off Long Island (Station 10066); and on the surface off Fire Island July 13. South of New York it was much less numerous, as was the case with copepods as a whole. And it never rivalled the Calanus swarm in abundance (p. 286), for which reason and because of its small size, it must be of comparatively little economic importance in our waters in summer. Centropages was most abundant near the surface, for example, the surface haul at Station 10088 yielded ten times as many specimens as the haul from eighty fathoms, though made with a net of only $\frac{1}{6}$ the mouth area. And the discrepancy was even greater at Station 10083, where the surface haul yielded several hundred Centropages, the haul from twenty fathoms only one specimen. The swarms at Stations 10062 and 10066 were on the surface, and between fifteen fathoms and the surface. The species was living at a rather high temperature (about 54° to 76°), and rather low salinity (31.5‰, surface, Station 10066 to 33.2‰, surface, Station 10074), with an optimum, as suggested by its greatest abundance, of about 65°–69° and 31.5–33‰.

Temora longicornis was abundant only on Nantucket Shoals (Station 10060), *i. e.*, just where *Centropages typicus* was wanting, and was occasional in the surface tows on George's Bank, south of Long Island (Station 10066) and in the Gulf of Maine. But it was not taken at all outside the continental shelf or over the shelf south of New York. It was most numerous on the surface; for example, the surface haul at Station 10060 yielded thousands, while the haul from twenty fathoms only caught twenty-five specimens. And it was not taken at all in hauls from depths greater than thirty-five fathoms. Its range of temperature was from about 54° (surface, Station 10096) to about 69° (surface, Station 10066); salinity 31.5‰ (surface, Station 10066) to 33‰ (Station 10059); *i. e.*, it was living in rather

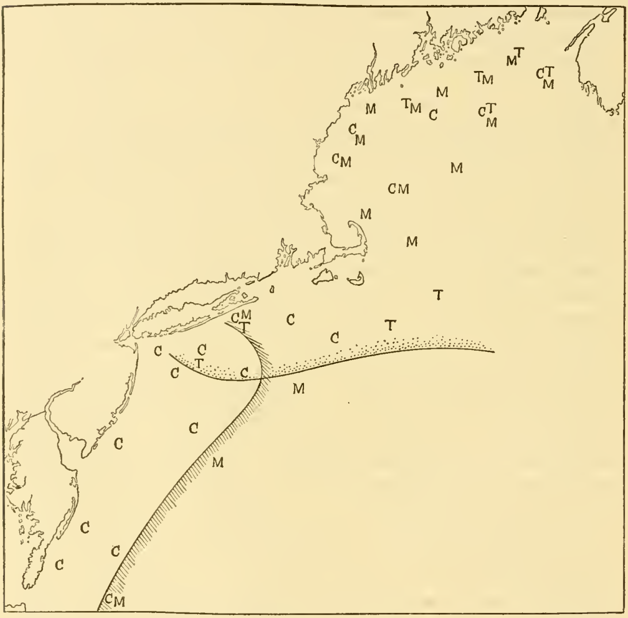

FIG. 70.— Distribution of copepods, July–August, 1913.
C, Centropages typicus; M, Metridia lucens; T, Temora longicornis; ⁞⁞⁞ Probable southern limit to Temora longicornis in July. ‖‖ Western limit to Metridia lucens in July.

colder water than *Centropages typicus*, which corresponds with its abundance as far north as the Labrador Current (Herdman, Thompson, and Scott, 1898) and with its abundance in summer off Nova Scotia

(Wright, 1907). Its absence in the Gulf Stream water and in southern waters in general, agrees with its distribution in European waters (Farran, 1910) where it seems to be of northern origin, and with Wheeler's (1901) and Williams's (1906) statements that it is most abundant in winter at Woods Hole and in Narragansett Bay.

Metridia lucens, unlike *M. longa*, was taken regularly in the Gulf of Maine (eighteen out of twenty-one stations), and it likewise occurred at all three of the Stations outside the continental shelf (10064, 10071, 10076). But it was found at only one Station on the continental shelf, south or west of Cape Cod, (10083) where the haul yielded twenty specimens. And we did not find it on George's Bank or Nantucket Shoals. *Metridia lucens* was not abundant anywhere; in fact so far as known it never swarms in the Gulf of Maine as it does in European waters. It was not taken in any surface haul, the shallowest captures being 15–0 fathoms off Cape Ann (Station 10104), and 8–0 fathoms off Long Island (Station 10083). And its invariable absence from the surface in our waters is evidence that it was not at home in the high temperatures and low salinities of the surface, because it has a well-marked habit of coming to the surface at night in other regions (Farran, 1910). The lowest salinity in which its presence can be established was about 32.4‰ (Station 10104), with a maximum of at least 35.00‰ (Station 10071). In the Gulf of Maine most of the specimens were living in water of 32.6‰ to 33.7‰. The limits to the temperature range of our captures were about 42° to about 50°. *Metridia lucens* has usually been called a northern species (Cleve, 1900). But Farran's (1910) tabulations of the data of the International Committee seem to show that it really belongs to the oceanic waters of the North Atlantic; and that it is carried to the coasts of Iceland and to the northern part of the North Sea by the Atlantic Current; an explanation which agrees fairly well with its occurrence in our waters.

Anomalocera pattersoni was taken at most of the stations in the Gulf of Maine, which supports my suggestion (1914a) that it is more universal in the Gulf than the records of 1912 would indicate; at five localities on the shelf south of New York (Stations 10070, 10077, 10080, 10081 and off Hog Island) and at one of the off shore Stations (10071); while Wheeler (1900) records it as abundant in the Gulf Stream south of Woods Hole. Most of the records are from the surface; only one from a haul as deep as forty fathoms; and of course that one specimen may have been caught at or near the surface; and this may also be true of the few specimens yielded by hauls from twenty, twenty-five, and thirty fathoms in the Gulf of Maine. Its surface habitat makes it easy to establish the hydrographic conditions in which it was living, the temperature range being 54°–76°; the salinity 32.1‰ to 35.25‰.

In European waters, likewise, *Anomalocera pattersoni* is chiefly found on the surface (Scott, 1911) though it inhabits rather salter water there, and our catches support Scott's statement that it is a creature of the open seas, to the extent that it was not found in enclosed bays or harbors. But its regular occurrence in the Gulf of Maine shows that it is not typically oceanic in the sense in which Pleuromamma or Rhincalanus may be so described.

The copepods discussed so far are more or less regular inhabitants of the Gulf of Maine; but several species were found outside the continental shelf which enter the Gulf only sporadically if at all. Such are *Rhincalanus nasutus, Euchirella rostrata,* the several species of Pleuromamma, *Euchaeta major, E. minor,* and *Candacia armata.* The first of these was taken at all three off shore stations (Fig. 69), and nowhere else, the total number of specimens detected being only forty-nine. The salinity was about 35‰–35.25‰ which agrees very well with the high salinities of 34.9‰ to over 35.6‰ from which it is recorded by Cleve (1900) and Farran (1910). The temperatures can not be established exactly, the catches all being in open nets from considerable depths: but the absence of the species on the surface and in the hauls from twenty fathoms, and its occurrence in hauls from 175 fathoms (Station 10064), 190 fathoms (Station 10071) and 120 fathoms (Station 10076) leads to the conclusion that it was living at a temperature of about 48°–55°. According to Cleve (1900, p. 139) the mean temperature for the species is 59°. But, as Farran (1911) points out, its range of temperature is very great. Its occurrence in the deeper layers at the edge of the Gulf Stream, and its absence from our coastal waters, whence it has never been recorded, agree with its oceanic habitat, for it is only in the sweep of the Atlantic current that it is recorded by the International Committee.

Pleuromamma robusta was taken in some numbers (about 400 specimens) in the deep haul (175–0 fathoms) at Station 10064; two specimens were detected in the haul from twenty fathoms at Station 10071, and a single specimen in the Gulf of Maine (Station 10100, 90–0 fathoms). Thus it, like Rhincalanus, was living in water of high salinity, from about 33.8‰ in the deeps of the Gulf to upwards of 35.2% (Station 10071). And it, too, is rarely taken near the surface anywhere (Scott, 1911), though widely distributed in the North Atlantic. *Pleuromamma xiphias* and *P. rotundum,* likewise oceanic, were each taken at one station, outside the continental shelf, in hauls from 190 and 120 fathoms respectively (p. 287).

Euchirella rostrata, a member, according to Cleve (1900), of the oceanic plankton of the temperate North Atlantic, was taken at four Stations, two at the edge of the Gulf Stream outside the continental shelf (10064 and 10076) and two in the Gulf of Maine (10096 and 10104). And it was found twice in the Gulf in 1912 (1914a, p. 116); though Wheeler (1900) does not record it from the Woods Hole region.

Candacia armata was taken at three Stations, 10074, 10076, and 10077, all south of Delaware Bay, in hauls from twenty fathoms.

The remaining copepods were taken so seldom (one or two stations and only one or two specimens each) that the captures throw little light on their distribution in our waters.

The Sagittae.

The identifications and notes on the Sagittae are due to the kindness of Dr. A. Pringle Jameson, of the University of Sheffield, England.

Eight species of Sagittae were collected by the Grampus, the numbers of individuals in the various hauls being given in the following table:—

Stations, and depths, fathoms.	10057, 15–0	30–0	10058, 40–0	10059, 20–0	10060, 0	20–0	10061, 40–0	70–0	10062, 15–0	10063, 25–0	10064, 175–0	10066, 0
Sagitta elegans	1050	223	28	997	379	1158	633	144	112	129	....	5
Sagitta serratodentata	....	....	....	....	....	....	16	6	17	7	3	1
Sagitta enflata	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta bipunctata	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta hexaptera	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta lyra	....	....	....	....	....	....	1	....	....	....	29	....
Pterosagitta draco	....	....	....	....	....	....	....	....	....	....	....	....
Eukrohnia hamata	....	....	....	....	....	....	8	29	....	....	9	....

Stations, and depths, fathoms.	10068, 10–0	10069, 10–0	10070, 0	20–0	10071, 0	20–0	190–0	10072, 15–0	10073, 0	15–0	10074, 0	20–0
Sagitta elegans	2	....	....	....	....	....	....	....	....	....	....	....
Sagitta serratodentata	....	10	453	621	3	4	1	175	2	4	3	221
Sagitta enflata	....	....	4	11	12	59	5	....	....	....	12	55
Sagitta bipunctata	....	....	....	....	....	5	....	....	....	....	3	....
Sagitta hexaptera	....	....	....	....	....	....	2	....	....	....	....	....
Sagitta lyra	....	....	....	....	....	....	2	....	....	....	....	....
Pterosagitta draco	....	....	....	....	....	1	....	....	....	....	....	....
Eukrohnia hamata	....	....	....	....	....	....	....	....	....	....	....	....

Stations, and depths, fathoms.	10076, 20–0	120–0	10077, 20–0	10079, 5–0	10080, 12–0	10081, 10–0	10082, 15–0	10085, 20–0	10086, 20–0	10087, 30–0	10088, 80–0	10089, 15–0
Sagitta elegans	....	....	....	....	....	....	45	24	53	142	14	8
Sagitta serratodentata	162	....	....	8	15	5	4	....	....	....	....	....
Sagitta enflata	10	3	33	10	....	....	....	....	....	....	....	....
Sagitta bipunctata	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta hexaptera	....	1	....	....	....	....	....	....	....	....	....	....
Sagitta lyra	....	1	....	....	....	....	....	....	....	....	....	....
Pterosagitta draco	1	....	....	....	....	....	....	....	....	....	....	....
Eukrohnia hamata	....	5	2	....	....	....	....	....	....	....	....	....

Stations, and depths, fathoms.	10090, 20–0	75–0	10091, 20–0	10092, 35–0	85–0	10093, 35–0	85–0	10095, 20–0	10096, 30–0	10097, 0	30–0	80–0
Sagitta elegans	10	22	9	37	13	24	15	14	11	14	73	16
Sagitta serratodentata	1	5	....	3	....	....	....	1	23	....	1	....
Sagitta enflata	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta bipunctata	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta hexaptera	....	....	....	....	....	....	....	....	....	....	....	....
Sagitta lyra	....	....	....	....	....	....	2	....	....	....	....	....
Pterosagitta draco	....	....	....	....	....	....	....	....	....	....	....	....
Eukrohnia hamata	....	4	....	2	35	25	63	2	2	....	10	18

Stations, and depths, fathoms.	10098, 18–0	10099, 20–0	10100, 40–0	90–0	10101, 25–0	10102, 20–0	10103, 30–0	10104, 15–0	50–0	10105, 40–0
Sagitta elegans	16	4	27	11	4	13	349	15	7	503
Sagitta serratodentata	....	....	16	....	....	2	....	....	....	....
Sagitta enflata	....	....	....	....	....	....	....	....	....	....
Sagitta bipunctata	....	....	....	....	....	....	....	....	....	....
Sagitta hexaptera	....	....	....	....	....	....	....	....	....	....
Sagitta lyra	....	....	....	....	....	....	....	....	....	....
Pterosagitta draco	....	....	....	....	....	....	....	....	....	....
Eukrohnia hamata	....	1	2	9	....	2	....	....	....	....

The most important feature of the collection, from the geographic standpoint, is the presence of a very characteristic tropical fauna, *i. e.*, *Sagitta enflata, S. hexaptera, S. bipunctata,* small *S. serratodentata,* and *Pterosagitta draco* in the coast water south of Delaware Bay and in the inner edge of the Gulf Stream. This is just what was to be expected from hydrography, and agrees with the tropical aspect of the plankton as a whole in those regions.

Elsewhere in the Grampus collecting ground the chaetognath fauna is typically boreal, characterized by the presence of *Sagitta elegans* in abundance, and of large specimens of *S. serratodentata.* Though Sagittae were taken at nearly all our Stations, it was only at eight (10057, 10059, 10060, 10061, 10070, 10103, 10105) that they were an important constituent of the plankton, quantitatively speaking.

Sagitta elegans was the prevalent Sagitta in the Gulf of Maine, where it was found at all Stations, three times in swarms (10057, 10103 10105). It likewise swarmed on George's Bank early in July (Station 10059); and was the most abundant species over the continental shelf east of Long Island. But it was rare in the coast water further west and south, and lacking outside the continental slope, as well as over the shelf south of Delaware Bay. And this agrees with its boreal habitat on the other side of the Atlantic. It was usually most abundant at about twenty fathoms depth; being numerous on the surface on one occasion only.

Sagitta serratodentata was likewise taken in the Gulf of Maine; but at eight stations only, and always in small numbers. And it was less numerous than *elegans* over the shelf south of Marthas Vineyard. But it was the prevalent Sagitta in the shallow waters south of New

York. There is a decided difference in size between northern and southern specimens, those from the Gulf of Maine being much the larger. This seems to be the general rule with this wide ranging species. And probably it is separable into distinct races, a northern and a southern.

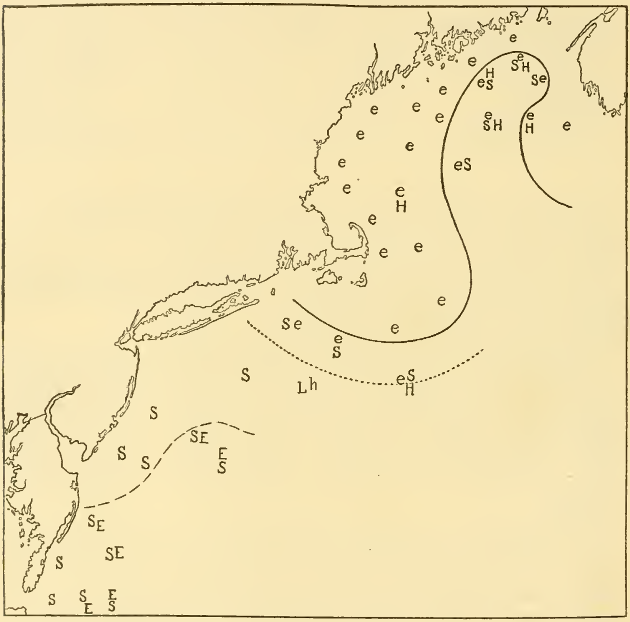

FIG. 71.— Distribution of Sagittae, July–August, 1913.
o, Sagitta elegans; E, S. enflata; H, S. hexaptera; L, S. lyra; S, S. serratodentata; H, Eukrohnia hamata.
Northern limit to S. serratodentata, - - - -, northern limit to S. enflata; . . . ., southern limit to S. elegans.

The occurrence of *Sagitta enflata, S. hexaptera,* and *Pterosagitta draco* has been noted; they were all confined to southern stations. And this was also true of *Sagitta bipunctata.* The captures of the latter deserve emphasis because it is only recently that this species has been clearly enough distinguished from allied species for its truly warm water habitat to become apparent (Ritter-Zahony, 1911). Finally, *Eukrohnia hamata* deserves brief mention. The GRAMPUS has never found it on the surface; and only rarely, and in small numbers in hauls as shallow as 20 fathoms. But it was fairly numerous in the deeps of the Gulf of Maine, (much more so than in 1912), and in the deep hauls under the inner edge of the Gulf Stream (Stations 10064, 10076). As previously noted (1914a) it was to be expected in the deeper layers, its range being from the surface in the arctic, to the mid depths in low latitudes.

TOMOPTERIS.

The specimens of Tomopteris all belong to *T. helgolandica* Graeffe. The records are from Stations 10057, 10058, 10068, 10069, 10082 10088, 10089, 10091, 10093, 10095, 10096, 10097, 10099, 10100, 10101, 10103; off Chatham, at Lat. 41° 48′, Long. 70° 5′ and at Lat. 41° 39′, Long. 69° 15′. Thus *T. helgolandica* was very generally distributed in the waters of the Gulf of Maine and off New York; but it was not found over the shelf south of New York, or in the Gulf Stream waters.

PTEROPODS AND HETEROPODS.

Identified by Mr. W. F. Clapp.

Besides the occurrences listed (p. 301) *Limacina balea* was taken by Capt. McFarland as follows:—

38° 45′ N; 73° 32′ W;	May 3, 1913	—	8–0 fath.	6 specimens
40° 45′ N; 70° W.	June 21, 1913	—	10–0 "	swarm
40° 42′ N; 69° 38′ W.	Aug. 8, 1913	—	10–0 "	13 specimens

15 miles S. E. of Chatham, Mass., Aug. 16, 1913 — 10–0 fath. 10 specimens

10–18 miles S. E. of Chatham, Mass., Aug. 21, 1913 — 20–0 fath. 5 specimens

Station	Depth	Clione limacina	Corolla calceola	Diacria trispinosa	Creseis acicula	Creseis conica	Creseis virgula	Limacina balea	Limacina inflata	Pterotrachea keraudrenii	Firoloida desmarestia	Atlanta peronii	Atlanta sp.?	Creseis sp.?
Off Gloucester	0	...	...	2	...	...	...	...	...	...	...	...	1	
10057	15–0	...	...	...	...	...	...	9						
10058	40–0	...	...	...	...	...	...	m.						
10059	20–0	...	...	...	...	...	...	5						
10060	20–0	...	...	...	...	...	...	m.						
10061	40–0	...	...	...	...	...	...	m.						
	70–0	...	...	...	...	...	...	f.						
10063	25–0	...	...	...	...	...	...	m.						
10064	175–0	...	...	...	...	...	...	4						
10065	20–0	...	...	...	...	...	...	m.						
10070	20–0	...	m.											
		...	juv.											
10071	190–0	...	...	...	...	...	...	...	27	1	1	1		
10073	30–0	...	13	...	3	1	...	...	...	...	1			
10074	30–0	...	9	...	12	5	11	...	...	...	3			
10075	8–0	...	...	...	2									
10076	150–0	...	...	...	...	...	...	...	...	...	...	...	...	2
off Hog I.	0	...	...	...	1									
10078	8–0	...	...	...	...	1								
10079	10–0	...	23	...	...	40	4	...	...	...	6			
10081	10–0	...	...	...	...	2								
10085	20–0	...	...	...	...	...	...	2						
10086	20–0	...	...	...	...	...	...	f.						
10088	80–0	...	...	...	...	...	...	7						
10090	20–0	...	...	...	...	...	...	m.						
	75–0	...	...	...	...	...	...	f.						
10091	20–0	...	...	...	...	...	...	s.						
10092	35–0	...	...	...	...	...	...	m.						
	85–0	...	...	...	...	...	...	f.						

f. = few — 25+ m. = many — 100+ s. = a swarm

Stations	Depth	Clione limacina	Corolla calceola	Diacria trispinosa	Creseis acicula	Creseis conica	Creseis virgula	Limacina balea	Limacina inflata	Pterotrachea keraudrenii	Firoloida desmarestia	Atlanta peronii	Atlanta sp.?	Creseis sp.?
10093	25–0	...	.....	...	...	...	...	m.						
	85–0	...	.....	...	...	...	...	f.						
10095	20–0	...	.....	...	...	...	...	m.						
10096	30–0	2	.....	...	...	...	...	m.						
10097	–0	...	.....	...	...	...	...	1						
	30–0	...	.....	...	...	...	...	m.						
	85–0	...	.....	...	...	...	...	f.						
10098	15–0	...	.....	...	...	...	...	f.						
10099	15–0	...	.....	...	...	...	...	f.						
10100	30–0	...	.....	...	...	...	...	m.						
	70–0	1	.....	...	...	...	...	f.						
10101	25–0	...	.....	...	...	...	...	35						
10102	20–0	...	.....	...	...	...	...	54						
	50–0	...	.....	...	...	...	...	f.						
10103	0	...	.....	...	...	...	...	31						
	30–0	...	.....	...	...	...	...	f.						
10104	15–0	...	.....	...	...	...	...	s.						
	50–0	...	.....	...	...	...	...	4						

The pteropods and heteropods of the cruise fall into two distinct groups, *Limacina balea* and *Clione limacina* in one; Corolla, *Creseis acicula, C. conica, C. virgula, Limacina inflata*, Pterotrachea, Firoloida, and *Atlanta peronii* in the other. *Limacina balea,* by far the commonest species, was universal from the neighborhood of Gloucester as far as Station 10065; and was taken again at nearly all our Gulf of Maine Stations. But it was wholly lacking in all the southern stations, and even in the cool water off New York (Stations 10066 to 10083, fig. 72). Its bathymetric range, likewise, must have been somewhat circumscribed, for, as the table shows, it was only once taken on the surface (Station 10103), although a surface haul was made at every station, usually with a net of the same mesh as the one in which Limacina was taken in the depths. On the other hand, most of the Limacinas did not come from any very great depth, because whenever two hauls were made, a deeper and a shallower, it was usually the latter which made the largest catch. This was the case both south of Cape Cod (Station 10061) and in the Gulf of Maine (Stations 10092, 10093, 10097, 10100, 10102) and the only exception (10064) yielded so few

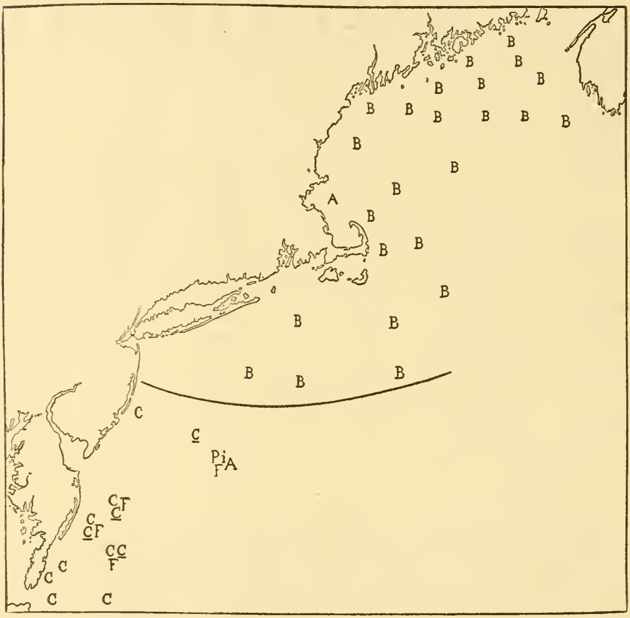

Fig. 72.— Distribution of pteropods and heteropods, July–August, 1913. A, Atlanta; B, Limacina balea; C, Criseis; C̲, Corolla; F, Firoloida; I, Limacina inflata; P, Pterotrachea.
The curve shows the probable southern limit to Limacina balea.

specimens (4) that no deductions can be drawn from it. The precise depths where Limacina was most abundant can hardly be determined by the open nets which were used, but the fact that the nets which were sent to the greater depths did not capture many specimens in their passage upward through the water, is good evidence that the large catches were made at about the depth at which the nets were working horizontally. This was fifteen fathoms at Station 10104; twenty-five fathoms at Station 10093 and 30–35 fathoms at Stations 10092, 10097 and 10100. The largest catch of all was made at twenty fathoms (Station 10091); and the depths of the rich hauls south of Cape Cod (Stations 10060, 10061, 10065) were twenty to forty fathoms. *Limacina balea* covers a considerable range both of salinity and of temperature: but was never found in the warm salt Gulf Stream water, nor is it at home anywhere in tropical seas. According to Meisenheimer (1906), it is the only pteropod endemic in the northern boreal region; and is a good index of boreal waters. All the captures were from salinities of 31.8‰ or more, and the absolute maximum may have been higher than 35‰ (Station 10064). But the few specimens from that Station were probably only stragglers from the coast waters. The maximum salinity for the rich hauls was 32.5‰–33.2‰. At the two Stations (10091 and 10104) in the Gulf where swarms were encountered, the salinities were respectively 32.5–32.6‰ and 31.9–32 5‰. Thus in summer the optimum for *Limacina balea* is neither the freshest coast water, with salinities of 32‰ or less, nor the ocean water outside the continental slope with salinity above 33‰, but the transition water.

The temperature can be precisely stated for only four captures, *i. e.*, 55° (Station 10059), 55° (Station 10097, surface), about 48° (Station 10095); and 61° at Station 10103 (surface). But the fact that no specimens were taken at the surface at any of the stations south or west of Cape Cod indicates that none of the captures were from temperatures above 60° except possibly in one or two instances; and even then (Stations 10064, 10065) the specimens may have been living in much colder water. The rarity of Limacina on the surface in the Gulf of Maine further simplifies the problem, because, to assume that the specimens came from even as small a depth as five fathoms, lowers the upper limit of temperature for most of the captures to about 58°. On the other hand, most of the Gulf specimens were certainly from water warmer than 46° (Stations 10091, 10095–10104); and we have no proof that any of them were living in water colder than this, for though the deep water temperature was 43° at several stations, there is no reason to suppose that the specimens of Limacina came from the deepest layers (p. 304). The other northern pteropod, *Clione limacina*, was restricted to the Gulf of Maine, where it was decidedly rare. And we have never found it common in the Gulf, although specimens occasionally appear there both in summer (1914a) and in winter (1914b).

The demarcation between the ranges of *Limacina balea* and of the warm water pteropods and heteropods, *i. e.*, the various species of Creseis, Corolla, *Limacina inflata*, Pterotrachea, Firoloida, and Atlanta, was remarkably sharp, for the latter were only taken at the southern and Gulf Stream stations where *Limacina balea* was lacking (Fig. 72); and not a specimen of any of them was found at any of the northern stations where *Limacina balea* occurred, except for a single Atlanta off Gloucester. They are all oceanic, as pointed out by Meisenheimer (1905). None of them occurred regularly, only one (*Creseis conica*) at as many as five of the eighteen stations south of the limits of *Limacina balea;* and the total number of specimens of this species was only forty-nine. The other warm water forms were even more sporadic in their distribution:— *Corolla calceola*, Firoloida, and *Creseis acicula* occurring at four stations each; the others at only one or two. Under these circumstances it is impossible to say much about the influence of hydrographic conditions on their distribution further than to point out that all have a southern, or oceanic origin, and that it is doubtful whether any of them would have been found in the coast water in winter. Direct evidence to the effect that they are summer visitors only is afforded by the fact that none of them were taken by Capt. McFarland off Cape May in May, 1913, although several were encountered there in July.

The occurrence of two living specimens of *Diacria trispinosa*, and of an Atlanta, in a haul off Gloucester early in July is surprising, because it is certain that neither of these genera is a regular inhabitant of the Gulf of Maine; both belong to the warmer parts of the north Atlantic, not to boreal waters (Meisenheimer, 1905). It is difficult to account for their presence, because they were taken with an otherwise typical boreal assemblage of plankton organisms, *e. g.*, Calanus, Euthemisto.

Pelagic hydroids.

BY C. MCLEAN FRASER.

During the month of July, 1913, the Grampus made a collection of floating hydroids off George's Bank, which, through the kindness of Dr. H. B. Bigelow, was sent to me for examination. Under ordinary circumstances the material would scarcely be worth a comment as none of the various species found are new to the Atlantic Coast or even rare, but when the location is taken into consideration and the effect of the conditions of such a location on at least two of the species, the collection proves to be of more than passing interest.

It is not unusual to find fragments of hydroid colonies torn from their support or from the rest of the colonies, living for a considerable time as they float on the surface. The majority of the species in this collection are represented by just such fragments, but the fact that there are so many of these species must indicate that in this region a vortex must be formed by currents whose influence reach to the shallow water some distance away. Furthermore, it would seem that some time not so very long previous to the time of collection, there must have been a rather violent storm, sufficient to make the effect of the waves felt at a greater depth than usual, as some of the species represented are not usually found at low tide or even in very shallow water. It is doubtful if any data have been obtained as to the length of time that fragments or even whole colonies of hydroids would live under such conditions. It is quite true that Sargassum torn away by storms, will carry hydroids in a perfectly fresh condition for weeks, during which time they may be carried hundreds of miles by the current, but the case is scarcely parallel as the Sargassum itself remains in good condition during this period unless it drifts ashore and dries out in the sun. In the present instance, no support was present in any case except portions of blades of eelgrass. Even here if the roots were attached, the eelgrass would remain fresh for some time, but there were no roots. There were only small fragments of leaves that may have been dead before they were carried away. In the majority of cases even this support was lacking, while one species, *Clytia cylindrica*, to which special attention is paid later, ordinarily making much use of a support, apparently regenerated and continued to grow without any support.

Doubtless if the spot where these were found is a vortex, there would be abundance of food material and the hydranths would not suffer in that regard. They might be better off even than in their own habitat. If light and specific gravity have any special directive influence on the growth of the colony, some power must have been exerted to overcome it, since the different position of the support or the lack of it places the colonies in entirely new positions. Many cases of adaptability to unusual circumstances have been cited among hydroids and this must be added to the list.

The thirteen species found make quite a varied collection, as only in two cases is a genus represented by more than one species, although but four families are included. *Clytia cylindrica* forms the great bulk of the material, although there is a good supply of *Obelia geniculata*; and *Diphasia rosacea, Sertularia cornicina,* and *Campanularia calceolifera* are represented by good specimens. The remainder of the list consists of larger or smaller fragments. In many cases gonangia are present.

List of Species.

EUDENDRIDAE

Eudendrium ramosum (Linné)

CAMPANULARIDAE

Campanularia calceolifera Hincks
Clytia cylindrica Agassiz
Obelia geniculata (Linné)

HALECIDAE

Halecium articulosum Clark
halecinum (Linné)

SERTULARIDAE

Diphasia rosacea (Linné)
Hydrallmania falcata (Linné)
Sertularella gayi (Lamoroux)
Sertularia cornicina (McCrady)
Thuiaria argentea (Linné)
cupressina (Linné)
thuja (Linné)

Clytia cylindrica Agassiz (Fig. 73, 74)

This species was first described from Massachusetts Bay by L. Agassiz,[1] and has since been collected at various points near Woods Hole. It has not been reported to the northward but the range extends far southward as I have found it in abundance at Beaufort, N. C.[2]

[1] Cont. nat. hist. U. S., 1862, **4**, p. 306.
[2] Hydroids of Beaufort, N. C. Bull. U. S. bureau fisheries, 1912, **30** p. 358.

The stolon commonly runs along its support nearly in a straight line and it never forms a very complicated network. From the stolon the individual zooids arise, the pedicel being usually rather rigidly erect. In the GRAMPUS material there are hundreds of colonies all of them entirely removed from their support. I say "removed" because one can scarcely conceive of a planula settling down to form a hydroid colony unless it had something on which to settle. As the stolons adhere quite closely to their means of support, they must have been

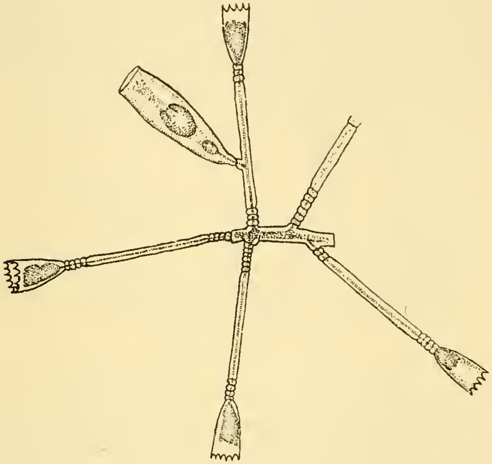

FIG. 73.— Clytia cylindrica.

torn away with some violence so that the stolons were broken in pieces as well. This separation and setting adrift produced complications, to the results of which reference must now be made.

With the first glance at a mass of this material one is immediately impressed with the fact that there are very few free stolon ends. In colonies collected under ordinary conditions, we can usually see the growing ends of the stolons. Here there seems to be nothing of the kind except in very rare instances. What has happened to them? Again one would suppose that when the colonies were torn away there would be one or two free broken ends for each piece, but one does not find it so. Occasionally a single free end may be found but scarcely ever two free ends on the one piece.

In the case of the growing end of the stolon it appears that since there is no longer any inducement to continue in the same general direction in which growth has previously taken place, on account of the lack of support, the growth is completed by producing a zooid which thus terminates the stolon and leaves no free growing end. The lack of free broken ends seems bewildering at first and it seems permissible to conclude that here is something new in hydroids, viz:— colonies developing from planulae at the surface of the high seas, for how could so many colonies, perfect ones at that, appear if they had been broken away from their regular support. Further examination

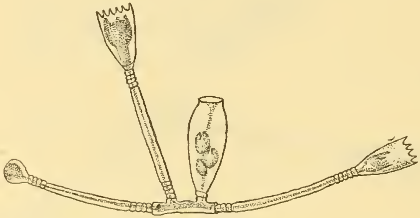

FIG. 74.— Clytia cylindrica.

brings out the fact that regeneration is responsible for the deception, but conditions must be very favorable for such regeneration since in almost every instance a zooid is growing out from the broken end and all are in good condition. In many cases the regenerated portion is so nearly equal in size to the original part, both in the perisarc and in the coenosarc, that it is difficult to detect the junction and hence the deception is complete. In other cases the regenerated part is sufficiently smaller to be readily noticed.

Besides the zooids that grow out from the broken ends, others appear to have developed in the regular way after the separation from the support, as, instead of coming off regularly in the one direction, they may come off on any side of the stolon to make the colony decidedly irregular (Fig. 73). Commonly when a straight piece of stolon regenerates, a zooid grows out from each end in line with the stolon itself, while the zooids previously attached were at right angles to this (Fig. 74). The directive influence which causes the regular erect growth must be overcome in such a case since two of them grow in a diametrically opposite direction. There seems to be no hindrance to the growth of the hydranths, as they are found in various stages of development as well as in the adult condition, and when they were preserved several of them had undigested food in the enteric cavity. The development of the gonophore is not interfered with either, as medusae of different ages are found in the gonangia and some free medusae were found just liberated in the plankton. All the gonophores were found either on the stolon or on original pedicels, none on the regenerated portions.

Regeneration is no new thing in hydroids as it has been noticed by many observers, but I know of no case where anything on such a large scale as this and in such a location has been recorded. It is quite possible that some of the experimental work that has been done on such forms as *Tubularia crocea* and *Hydractinia echinata* would have given more satisfactory results if it had been done on *Clytia cylindrica*. It may be that the election of gymnoblastic forms for such experiments might have been improved upon by taking some of the simple calyptoblastic species. I am very doubtful if under artificial conditions in any case regeneration could be successfully brought about in over 99% of the cases as it must have been here if one is to judge from the generous sample that was collected.

Obelia geniculata (Linné). (Fig. 75–78).

As this is a cosmopolitan form and as it has been described and figured in so many instances, a description of a typical specimen from a typical locality is quite unnecessary, but as many of the specimens in this material are not typical and as the location is unique, mention is especially made of the species here.

Two lots of specimens were present, both attached to eelgrass. In one case the stolon ran irregularly along throughout the whole length of the fragment of eelgrass, on both sides, making rather a dense mass. In the other case a few colonies were distributed among several colonies of *Sertularia cornicina*. I do not know that *O. geniculata* is commonly found on eelgrass, as I do not remember having found it there, or of having seen it recorded as so growing, but it does grow on certain Algae and hence the difference in the nature of the support is not sufficient to make this case remarkable. Other species, *e. g.*, *O. longissima,* are very often found on floating eelgrass, hence as long as the eelgrass fragments are of sufficient size to form a good basis of support for the stolon, it is not especially remarkable that *O. geniculata* should remain in good condition when floating. However, in hundreds of cases where *O. longissima* has been seen floating, there has been no great difference observed from the regular type (that may be because it very generally is found attached to floats, etc., where it is near the surface at all times), but in these specimens

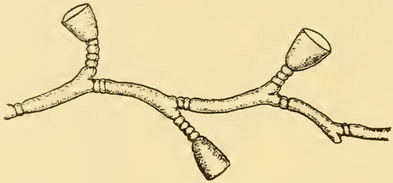

Fig. 75.— Obelia geniculata.

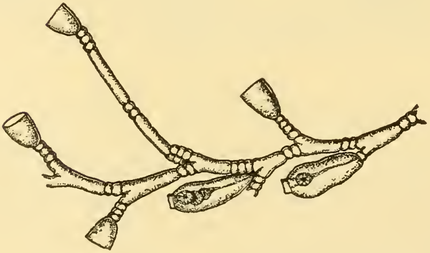

Fig. 76.— Obelia geniculata.

there are some unusual features, that may have been caused by a certain tendency towards orientation disturbed on account of a change in the position of the support. This change does not show itself in the hydranths themselves since they seem perfectly normal, possibly because the hydrotheca pedicels have sufficient adaptability to allow for sufficient change. In the stems, however, there is variation. Some of them are quite typical (Fig. 75) but a large number of them are more branched than usual, so much so, that if they were examined by themselves they would scarcely be recognized as belonging to the species. The branching sometimes is far from being regular, the position and the length of the branches vary so much. From a stem that is otherwise normal, there may be one or two hydrothecae borne on much elongated pedicels, arising either as ordinary hydrotheca pedicels, or in the axils of these. They are annulated slightly at both ends as well as towards the centre, with smooth places between (Fig. 76). The stem internodes, which typically are quite uniform in length, vary much in this respect in some specimens and the nature of the geniculation at each node also varies. The terminal internode may be much prolonged into a tendril-like process such as occurs late in the season in *Campanularia angulata, Obelia commissuralis,* and other similar species. These tendrils are noticeable chiefly on account of their breadth and the bluntness at the end (Fig. 77). Within the

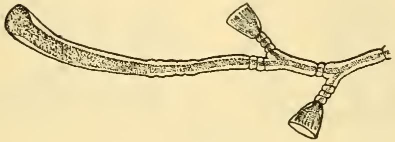

FIG. 77.— Obelia geniculata.

perisarc, at the end, the coenosarc has the appearance of a developing hydranth but no case was observed where such a hydranth had really developed.

In a previous paper[1] I referred to a specimen of this species in which the gonophores were in an unusual position. In this material a still greater variation occurs. Some gonophores are placed typically, *i. e.,* in the axils of the hydrotheca pedicels. Others appear as those in the above reference, *i. e.,* in place of hydrothecae (Fig. 76). Besides these there were several in a row growing directly from the stolon (Fig. 78). They have similar short, annulated pedicels to those in the normal position and agree very well with them in other respects, although they are slightly larger than the others usually are. The development has not been stopped at any rate, as the young medusae were in as good condition as they were in any of the others. If the

[1] Hydroids from Nova Scotia. Victoria Memorial Museum, Bull., 1913, no. 1, p. 167.

growth of the gonophores in this position is due to the change in position of the support of that particular part, the whole growth of these must have taken place after the colonies had been torn away.

Another instance is here exhibited of the ready interchange of the various parts of the colony and, here as well as in *Clytia cylindrica*, of considerable power of adaptability to varying conditions.

Medusae, siphonophores, ctenophores.

The identifications in the table (p. 316–317) require explanation.

All with broad stomach, smooth subumbrella and considerable numbers of tentacles and canals are classed here as *Ae. aequorea.*

Aequorea groenlandica Péron et Lesueur. I follow Mayer (1910, p.

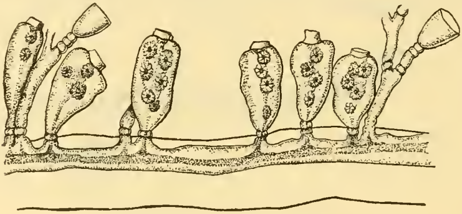

Fig. 78.— Obelia geniculata.

335) in identifying as a southern race of *Ae. groenlandica* the large aequorid, with stiff gelatinous substance, and numerous subumbral gelatinous papillae radially arranged, which is common off the coast of New Jersey in summer and autumn. The southern race has been recorded so seldom that a few counts of the radial organs are given:—

Station	Diam. mm.	Tentacles	Canals
10069	100	110	89, all with gonads
10075	75	71	96, 3 branched
"	75	68	88, 1 "
"	70	61	106, all simple
"	50	50	85, all simple

Aglantha digitale Fabricius. The status of the two forms of Aglantha, so often recorded from northern waters as "*rosea*" and "*digitale*," has been the subject of much discussion. The two have usually been separated according to the number of otocysts, specimens with eight being classed as *rosea*, those with four as *digitale*. But such a division is purely artificial, because specimens often have five, six, or seven otocysts. Mayer (1910) unites the two unequivocally. I have followed him in my discussion of Aglantha from Behring Sea (1913a) and Kramp (1914, p. 432) likewise concludes that the number of otocysts is not sufficiently constant to afford a specific character, though maintaining that *rosea* is recognizable as a variety of *digitale*. It is doubtful, however, whether even this last characterization of *rosea* will stand the test of time.

Every specimen of Aglantha in the present collection which was in good enough condition to show the otocysts at all had at least seven, and their spacing along the margin of the bell was such as to show that the number in life was eight. These specimens range from 7–11 mm. in height, with 39–94 tentacles; and are at various stages of maturity, from one with no gonads to one in which they are fully developed. The many specimens which I have studied from Labrador and Newfoundland likewise had eight otocysts (1909c, p. 312). These were recorded under the name *rosea*, following the custom usual at that time, for Aglantha with eight otocysts. And although Kramp (1913a, p. 527) has recently questioned whether these specimens were actually *rosea*, it was so simple a matter to count the otocysts that there can be no doubt that they belonged to the form with eight of these organs, no matter what may be its final nomenclatural resting place. And I may add that all the specimens of Aglantha from American waters, Atlantic or Pacific, on which I have been able to count the otocysts have more than four; usually eight.

Cyanea. The specimens from the Gulf of Maine and from George's Bank belong to the large, red northern race ("*arctica*"); but we found only the small yellowish form (*fulva* L. Agassiz) south of New York.

Stephanomia cara. The generic identity of the material is established by the fact that the few tentilla still intact have the involucre and single terminal filament. And the bracts and nectophores, which were taken in great numbers, agree perfectly with *S. cara* as described by A. Agassiz (1865) and by Fewkes (1888). But unfortunately the material was not in good enough condition to show whether or not the northern *cara* is actually separable from the southern *bijuga*.

Pleurobrachia pileus. Mayer (1912) has recently described a new Pleurobrachia, *P. brunnea*, from just the locality where Pleurobrachia was found in greatest numbers; which makes a review of the grounds on which I class our specimens as *pileus* desirable.

	10057	10058	10059	10060	10061	10063	10064, 20–0 F.	10064, 175–0 F.	10066	10067	10069	10070	10071, 20–0F.
HYDROMEDUSAE													
Steenstrupia rubra	...	...	...	...	...	...	...	...	...	...	...	...	...
Niobia dendrotentacula	...	...	...	...	...	...	...	...	...	...	...	...	...
Calycopsis typa	...	...	...	...	...	...	...	1	...	...	...	...	...
Obelia sp.?	...	...	...	m.	...	...	...	...	...	...	...	...	...
Melicertum campanula	×	...	...	...	...	...	...	...	...	...	...	...	...
[1] Staurophora mertensii	...	...	...	...	...	...	...	...	...	...	...	...	...
Laodicea cruciata	...	...	...	...	...	...	...	...	...	...	...	...	...
Tiaropsis diademata	2	...	...	...	...	...	...	...	...	...	...	...	...
Mitrocoma cruciata	×	...	...	...	...	...	...	...	...	...	...	...	...
[1] Phialidium languidum	...	...	...	...	...	...	...	...	...	...	...	...	...
Aequorea aequorea	...	...	...	...	...	...	...	...	...	...	×	...	...
" groenlandica	...	...	...	...	...	...	...	...	...	...	×	...	...
Aglaura hemistoma	...	...	...	...	...	...	...	...	...	...	...	...	1
Aglantha digitale	2	...	...	12	2	...	...	1	...	...	22	...	...
Rhopalonema velatum	...	...	...	...	...	...	...	...	...	...	1	...	...
Liriope scutigera	...	...	...	...	...	...	...	...	...	...	...	...	...
Geryonia proboscidalis	...	...	...	...	...	...	...	...	...	...	...	...	...
Cunoctantha octonaria	...	...	...	...	...	...	...	...	...	...	...	...	1
SCYPHOMEDUSAE													
Cyanea capillata	×	...	×	...	...	...	...	...	...	...	×	...	...
[2] Aurelia aurita	...	...	...	...	...	...	...	...	...	...	...	...	...
SIPHONOPHORAE													
Abylopsis eschscholtzi	...	...	...	...	...	...	...	...	...	...	...	...	1
Galeolaria quadrivalvis	...	...	...	...	...	...	...	...	...	...	...	...	×
Diphyes appendiculata	...	...	...	...	...	...	...	...	...	...	...	×	×
Agalma okeni	...	...	...	...	...	...	...	...	...	...	...	...	3
Agalma elegans	...	...	...	...	...	...	m.	...	...	...	...	...	...
Stephanomia cara	×	×	×	...	...	...	...	...	...	...	...	...	...
Physophora hydrostatica	...	...	...	...	...	...	×	...	...	...	...	...	...
Rhizophysa filiformis	...	...	...	...	...	...	1*	...	...	...	...	...	1
Physalia physalis	...	...	...	...	...	...	×*	...	...	...	...	...	...
CTENOPHORAE													
[1] Pleurobrachia pileus	...	...	...	×	...	×	...	...	×	×	×	×	...
Bolinopsis infundibulum	×	...	...	...	...	...	...	...	...	...	...	...	...
[3] Mnemiopsis leidyi	...	...	...	...	...	...	...	...	...	...	×	...	...
Beroe cucumis	×	×	...	...	...	...	...	...	...	...	...	...	...
[4] Beroe forskalii	...	...	...	...	...	...	...	...	...	...	...	...	...

[1] For the occurrences of *Phialidium languidum; Staurophora mertensii* and *Pleurobrachia pileus* in the Gulf of Maine, see table, p. 273.

[2] Noted occasionally near land in the Gulf of Maine.

* On the surface.

[3] Also seen at other localities, p. 271.

[4] Also taken in Chesapeake Bay.

10071, 190–0 F.	10072	10073	10074	10075	10076	10077	10078	10079	10080	10081	10082	10085	10086	10087	10088	10090	10095	10096	10097	10099	10100
...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	m.	...	m.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	×	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	×	×	...	...	×	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	×	×
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	×	...	...	...	...	×	...	...	...	...	...	...	...	...	...	...	...	...
...	×	...	...	×	×	×	...	×	×	×	×	...	...	...	...	...	...	...	...	...	...
...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	9	1	...	6
...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	9	...	...	m.	m.	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	×	...	×	...	×	...	...	...	×	...	×	...	...	...	...	...	...	×
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	2	...	m.	...	...	...	...	8	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	...	...	...	...
...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	×	...	×	×	...	×	...	×	×	...	×	×	×	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	×	×	...	...	...	...	...	...	×	×	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	×	...	...	×	...	...
...	...	...	...	×	...	×	×	...	...	...	...	...	...	...	...	...	...	...	...	...	...

The characters by which he (1912, p. 14) separates his *brunnea* from *pileus* are that it is more oblong and egg-shaped, by the opaque yellow-brown color of the stomodaeum, and by the presence of terminal knobs on the tentacles. But the specimens from near New York and further south were quite as globular in life as any I have collected elsewhere, though now more or less contracted by preservation. The question whether or not the tentacles end in terminal knobs is easily settled in life; and in no case did I see anything which could be interpreted thus. And the tentacles are sufficiently extended in many of the preserved specimens to show that their calibre is uniform to the tip. In many, it is true, these organs are more or less thickened near the end; but this is obviously the result of contraction. Most of the specimens, as might be expected, are so violently contracted that it is impossible to determine anything about the tentacles. As to color, the stomodaeum in many of the southern specimens was of a pale reddish hue in life; but I have also found it so in northern specimens. Furthermore, the proportional lengths of apical canal and stomodaeum, and the relative level at which the adradial canals join the meridionals in the southern specimens are well within the range of variation of typical *P. pileus*.[1] In short there is nothing to separate southern from northern specimens except that the former were, as a whole, rather smaller.

P. brunnea may still be worthy of recognition; but it is not contained in the Grampus collections, and until specimens agreeing with Mayer's account are reëxamined, its status will be dubious.

Distribution of pelagic coelenterates.

Pelagic coelenterates fall into two distinct categories according as they are, or are not bound to the coast line by a fixed stage, *i. e.*, they are either neritic or oceanic. And though some genera, for example Niobia, bridge the gap, they are not sufficiently abundant to invalidate the general classification. Among the neritic warm water species are *Steenstrupia rubra, Laodicea cruciata, Aequorea groenlandica* and the southern form of *Cyanea capillata*. Probably *Calycopsis typa* is also neritic if the term is used in its broad sense, for there is reason to believe that it passes through a hydroid stage on the continental slope (1909b). Omitting it for the moment, however, because

[1] I have been able to compare the collection with a large series from northern waters

of its deep-water habit, this southern neritic group was limited to a coastal zone south of New York, some forty-five miles broad (Fig. 79, Stations 10069, 10072, 10073, 10074, 10075, 10076, 10077, 10078, 10079, 10080, 10082). We found none of these species north of New York; but most of them appear along the southern shores of New England later in the season. The most important of the group, fau-

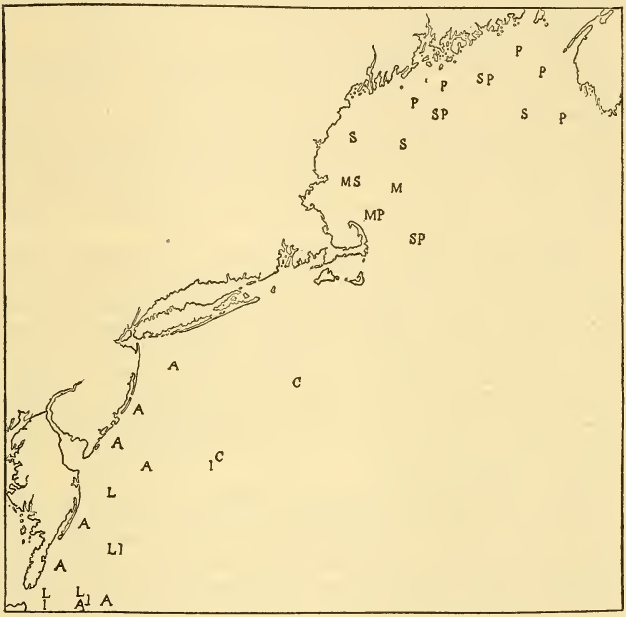

FIG. 79.— Occurrence of some neritic Medusae, July–August, 1913. A, Aequorea groenlandica, southern form . . l, Liriope scutigera; L, Laodicea cruciata; M, Melicertum campanula; P, Phialidium languidum; S, Staurophora mertensii.

nistically, *Aequorea groenlandica,* was confined to the waters over the inner half of the continental shelf south of New York; spreading seaward to the slope off Chesapeake Bay, but absent in the edge of the Gulf Stream (Station 10071) and in the tongue of ocean water off Delaware Bay (Station 10073), its range being slightly more extensive than that of *Mnemiopsis leidyi* (p. 322). Probably it was the Chesapeake current which carried it to the outer edge of the shelf off Chesapeake Bay. *Aequorea groenlandica* like Mnemiopsis was living chiefly at the surface and for a fathom or so down, the deeper hauls yielding very few even where many were seen floating past the ship. The range of salinity was from about 31.3‰ (Station 10077) to about 34‰ (Station 10076), the temperature from about 65° to about 77°.

The boreal neritic species are *Melicertum campanula, Staurophora mertensii, Mitrocoma cruciata, Tiaropsis diademata, Phialidium languidum,* and the northern form of *Cyanea capillata.* In July and August these are all confined to the waters east and north of Cape Cod, (Fig. 79) though they appear in winter in the sounds and bays, as far west as Narragansett Bay. The occurrence of Phialidium, and Staurophora has been commented on (p. 274), and I need merely add that the rarity of the others in the central part of the Gulf agrees with our experience in 1912 (1914a).

Two important species, *Mnemiopsis leidyi* and *Pleurobrachia pileus* are intermediate between neritic and oceanic, for though neither has a fixed stage, and though Pleurobrachia occasionally occurs far from land, it is distinctly a creature of coast waters rather than of the open ocean (Kramp, 1913a, p. 532), while this is even more true of Mnemiopsis. The range of Pleurobrachia extends unbroken from Labrador (1909c) at least as far south as Pamlico Sound (1913a, p. 111) and perhaps farther. And we found it more generally distributed in the coast waters than any other coelenterate, swarming locally south as well as north of Cape Cod (Fig. 80).

From the distributional standpoint, localities where a species does not occur may be fully as significant as those where it does. And this is particularly true of Pleurobrachia, for it was absent in the inner edge of the Gulf Stream (Stations 10061, 10064, 10071, 10076, in the shoreward tongue of the Gulf Stream off Delaware Bay (Station 10073), on the one hand, and in the fresh water at the mouth of Chesapeake Bay (Station 10078) on the other. Otherwise there were only two Stations over the shelf where we failed to capture it (10081, 10083), at one of which (10083) the nets yielded very little of anything (p. 272). Pleurobrachia was taken at exactly half the stations in the Gulf of Maine, a rather larger proportion of occurrences than in 1912 (1914a, p. 126). But the species was rather more restricted in its range in the Gulf than in that year, occurring only once (Station 10103) in the coastal zone between Cape Ann and Penobscot Bay; and not at all in the central part of the Gulf (Stations 10090, 10092, 10093).

Although Pleurobrachia was widely distributed, it was by no means uniformly abundant. Its chief centre was from off New York (Stations 10067, 10068) nearly to Cape May (Stations 10069, 10080), where the deep water layers were filled with it, almost to the exclusion of other plankton (p. 269), extending for some twenty-five or thirty miles

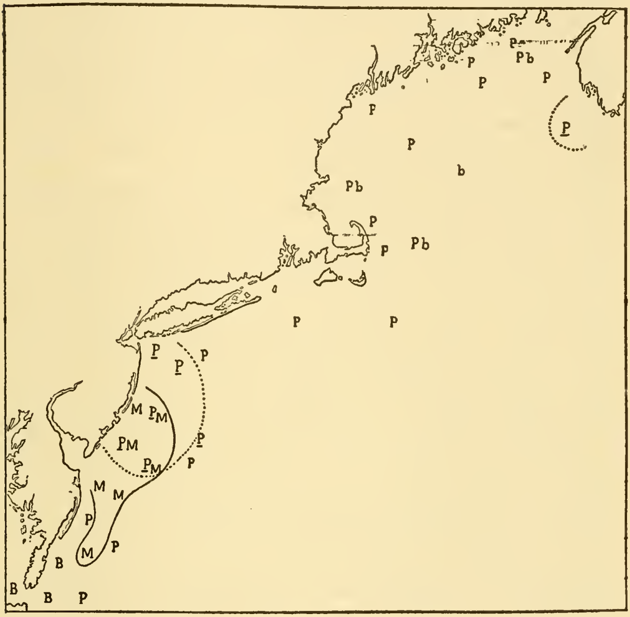

FIG. 80.— Distribution of ctenophores, July–August, 1913.
B, Beroe forskalii; *b*, B. cucumis; M, Mnemiopsis leidyi; P, Pleurobrachia pileus; P̲, P. pileus swarms. . . . . , probable limit to P. swarms. ———, probable limit to Mnemiopsis in July.

seaward (Stations 10072, 10070) beyond which their numbers rapidly decreased. It was still numerous when this region was passed again on August 1, on our way north (Station 10082). South of Cape May it was much less common, and very few were taken over the shelf east of New York (Stations 10060, 10063, 10066). The only place where Pleurobrachia was abundant in the Gulf of Maine in 1913 was German Bank (Station 10095), where small specimens swarmed. The southern swarm of Pleurobrachia only once reached the surface (off Scotland light-ship, July 12). Elsewhere it was limited to depths below about five fathoms; the water being from 15–30 fathoms deep over its area of abundance in this region. There were no Pleurobrachia in the immediate surface layers where Salpae and Mnemiopsis often swarmed (p. 269). And the absence of Pleurobrachia in the immediate surface layers and on the surface can not be credited to the effect of sunlight, because this was as true of night as of day time stations. Most of the Gulf of Maine captures were likewise in deep hauls; and there were none on the surface on German Bank, where a rich haul of Pleurobrachia was made at twenty fathoms.

The shallowness of the water in the region where Pleurobrachia was most abundant, and the general rarity of the genus on the surface, make it easy to establish the salinity and temperature in which it was living. The warmest water in which we can certainly establish its presence is 69° (Station 10066, surface), though some of the specimens from Stations 10074, 10077, and 10079, may have come from still warmer water. And south of New York in general the captures must have been in water warmer than 59°, that being the lowest temperature through which the nets fished. The swarm off New York was in temperatures of 50° (ten fathoms) to 65° (surface near Scotland light-ship). East of New York Pleurobrachia was usually living in water colder than 60°, with the minimum certainly as low as 48° (Station 10095), probably as cold as 43° (deep hauls in the Gulf). That is to say the genus covered practically the entire range of temperature encountered during the cruise, except the very warmest. It is not surprising to find Pleurobrachia at home in extremes as wide apart as this, because its range is known to be practically independent of temperature. Nevertheless, there is some evidence that specimens of Pleurobrachia grow much larger in cold than in warm water, as Esterly (1914) has pointed out for the Pleurobrachias of the west coast of the United States. And our captures strengthen this view, for although the genus swarmed in water warmer than 58° off New York and further south, the specimens taken there were all small (less than 10 mm. long). It was only in the cold water of the Gulf of Maine that we found large specimens; and work in previous years has shown that specimens upwards of 30 mm. long are common at the mouth of the Bay of Fundy, in summer, in temperatures of 50°–55°.

The extreme range of salinity for Pleurobrachia was from about 31.6‰ (surface, Station 10066) to about 35‰ (fifteen fathoms, (Station 10074). But most of the captures were from water of about 32‰–33.4‰. And there is only one Station where it is safe to assert that Pleurobrachia was living in water salter than 34‰, *i. e.*, at Station 10074, where the number taken in the horizontal haul at fifteen fathoms was so large that most of them must have been captured at about that depth, not in the short column of water through which the net fished on its way down and up (there were none on the surface). The major part of the haul at Station 10077 was likewise in water of about 34.5‰; but so few specimens were taken that they may have come from anywhere between the surface and the greatest depth reached by the net; *i. e.*, from a salinity anywhere between 31, .4‰ and 35‰. The southern swarm was living in water of about 32‰ to 33.2‰; the northern one (German Bank) in 32.8‰ to 32.9‰.

Rose (1913) has recently shown that the density of the water influences the vertical movements of Pleurobrachia; it is therefore worth while to correlate this physical constant with records for the genus. Near New York, where the captures can be located within a few fathoms because of the shallow water, they were from densities ranging from 1.022 (Station 10066, surface) to upwards of 1.0237. And the specimens taken at Stations 10082 and 10074 probably were living at a density of about 1.0252 to 1.0254. But the German Bank specimens were in much heavier water (nearly 1.026). Thus there does not seem to be any connection between the occurrence of Pleurobrachia, and density within a range of 1.022 to 1.026. But it is noteworthy that we found none in water lighter than 1.022, and seldom in densities less than 1.023, while it is doubtful whether any specimens were living in the densities of 1.027 and over, which characterize the bottom water of the deeper parts of the Gulf of Maine.

Mnemiopsis leidyi was generally distributed over the inner half of the continental shelf between Barnegat and Delaware Bay; and the mid-zone of the shelf south of the latter (Fig. 80). None were seen north of Barnegat though the species is abundant in the bays and sounds of the southern coast of New England later in the season, or off Chesapeake Bay. But the latter is not its southern limit, though it may interrupt the continuity of its range. It was most abundant near the coast, from Barnegat to Cape May, and again between Stations 10074 and 10075, swarming on the surface in myriads, and causing brilliant phosphorescence at night. And it seems to have been limited to a very shallow surface zone, the few taken in the deep hauls having probably been caught in the passage of the net down and up. The salinity in which it was living ranges from 32.1‰ (Station 10081) to 33.48‰ (Station 10073), the optimum, as shown by greatest abundance, being 32.2‰ to 33‰. The upper limit of temperature was 76° (Station 10080), its lower limit was probably about 60° (the five fathom reading at Station 10069). Thus it was living in warm water; but not in salt Gulf Stream water on the one hand, nor where the salinity is lowered below 32‰ by the influence of the Chesapeake, on the other. And this agrees with its known occurrence, for, according to Mayer (1912, p. 34) it is a creature of the pure sea water along the outer shores, its place being taken by another species, *M. gardeni,* in the brackish bays.

The swarms of Mnemiopsis and of Pleurobrachia were mutually exclusive, for though both were often taken at the same station, Mnemiopsis was invariably limited to the surface waters which it shared with the various Salpae (p. 269), Pleurobrachia to the deeper layers. Pleurobrachia and Mnemiopsis were not found side by side on the surface.

The oceanic, like the neritic coelenterates of our waters, fall into two more or less overlapping groups, according as they are at home in high or in low temperatures (Fig. 81). The most typical member of the former found in our coastal waters is *Aglantha digitale.* The captures are so scattered, and from waters of such different salinities and temperatures that they throw very little light on the conditions which are the optimum for the genus. But it is significant that although Aglantha was as abundant off Barnegat as on German Bank, only one fragmentary specimen was taken anywhere within the immediate influence of the Gulf Stream. And I may further point out that though it is a constant inhabitant of the Gulf of Maine, it never seems to attain the faunal prominence there, or anywhere further south, that it does off the coasts of Newfoundland and Labrador, or in Greenland waters. It is a creature of cold water, limited in its southern extension by the Gulf Stream.

The southern oceanic members of the list are *Niobia dendrotentacula* (put in this group by its asexual multiplication), *Aglaura hemistoma, Rhopalonema velatum,* Geryonia, *Cunoctantha octonaria* and the siphonophores Abylopsis, Diphyes, Galeolaria, *Agalma okeni,* Physophora, Rhizophysa, and Physalia. The largest catch of these species was in the edge of the Gulf Stream (Station 10071) where no less than eight of them were taken; and four were taken at Station 10074. One or other of them was likewise taken at Stations 10064, 10070, 10076.

That is to say, it was only in the waters of the Gulf Stream or over the outermost part of the continental shelf that they formed an important constituent of the pelagic fauna. The genus Liriope is also usually classed as among the typically oceanic Medusae. And this is cer-

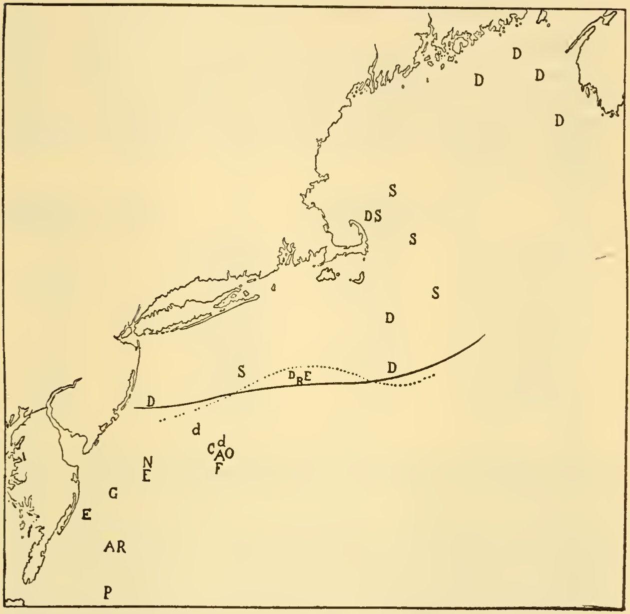

Fig. 81.— Distribution of oceanic Medusae and siphonophores, July–August. 1913.

A, Aglaura hemistoma; D, Aglantha digitale; d, Diphyes; E, Agalma elegans; F, Rhizophysa filiformis; G, Geryonia; N, Niobia dendrotentacula; O, Agalma okeni; P, Physophora; R, Rhopalonema velatum; S, Stephanomia cara.

. . . ., probable limit to tropical species in July. ———, S, probable limit to Aglantha digitale.

tainly true of *L. tetraphylla.* But the species found off Chesapeake Bay, *L. scutigera* (p. 316), is so common in southern harbors and bays, that it can hardly be considered as oceanic. *Agalma elegans,* too, though certainly not neritic, is not oceanic in the true sense, because most of its records are from the neighborhood of land, not from the high seas, in marked contrast to *A. okeni.*

Quantitative hauls in the Gulf of Maine.

Quantitative hauls were made at fourteen of the Gulf of Maine stations; and they are directly comparable with one another because the interval of time between the first and last haul was so short (six days) that they can be considered as practically simultaneous. The volumes of plankton under each square meter of sea area, calculated from them were:—

Station	cc. in a column 1 sq. meter in cross section	Station	cc. in a column 1 sq. meter in cross section
10087	180	10099	30
10089	80	10100	220
10090	120	10101	100
10092	160	10102	90
10095	60	10103	70
10096	120	10104	90
10098	70	10105	55

These volumes are not the absolute amounts actually present, because they take no account of the coefficient of filtration of the nets. This, however, would be the same for all the hauls, and with the comparatively coarse silk of which they were composed would be small. It is obvious that the volumes do not give a direct measure of the density of the plankton, because the length of the column of water through which the net fished varied from 20 to 120 fathoms, according to the depth of water at the various stations. The volume of plankton per cubic meter of water (coefficient of filtration neglected) was as follows:—

Station	cc. per. cu. m.	Station	cc. per cu. m.
10087	1.4	10099	.8
10089	.44	10100	1.3
10090	.7	10101	1.4
10092	.7	10102	.7
10095	1.7	10103	.9
10096	1.3	10104	.6
10098	1.3	10105	.5

Were the macroplankton of the Gulf uniformly distributed at all depths from surface to bottom, this table would sufficiently establish the relative richness of different regions in plankton, and hence in food for the pelagic fishes. But unfortunately such is not the case (p. 290); hence to get a fair idea of the regional density of the plankton the less exact evidence of the ordinary tow nets must be used to check the results of the quantitative hauls.

VOLUMES OF HORIZONTAL HAULS.

Station	Fathoms	cc.	Station	Fathoms	cc.
10087	15	560	10097	25	750
	40	125		85	500
10088	80	375	10098	20	30
10089	25		10099	20	130
10090	20	1500	10100	25	500
	90	250		70	100
10091	20	875	10101	25	100
10092	35	300	10102	20	125
	85	100		50	100
10093	25	500	10103	30	175
	85	200	10104	15	675
10095	20	175		50	200
10096	20	375	10105	40	150

The depth is the level at which the major part of the haul was made.

This table shows that at every station where the hauls were made at two intermediate depths, the deeper invariably yielded the smaller volume of plankton. At first sight this difference might be laid to the use of different nets, the mouth area of the Helgoland net, which was usually used for the deeper haul, being only about 50% of that of the four foot net (the same grade of silk was used in both). But at Station 10092, where the nets were reversed, the catch of the Helgoland net was three times as great as that of the four foot net. And even allowing for the different sizes of the nets, the shallow haul is still considerably the richest at six of the eight stations. Apparently the plankton was usually densest in the upper layers, and decidedly impoverished below, say, forty fathoms. On the other hand the surface water was usually barren, except at Stations 10092, 10093, 10096, 10097, 10100, and 10103, but the surface hauls are not directly comparable with the deep ones, because they were made with small nets.

Thus the volumes of plankton per cubic meter, as calculated from the quantitative hauls, would be more representative of the true conditions, if the depths below about 40–50 fathoms were left out of account, because it appears that the vertical net can have caught but little below that level. In other words, to assume that the volume of plankton taken at, say, Stations 10092 or 10093, was evenly distributed down to 100 fathoms or more, results in far too small a density per cubic meter for the upper layers of water. I have attempted to offset this error by another table in which the volume of plankton per cubic meter is calculated on the assumption that the whole catch was made in the upper fifty fathoms. But this, though a closer reflection of actual conditions, is unsatisfactory, because the plankton is not vertically uniform even above fifty fathoms. Volume is itself so rough a measure, that it has largely been abandoned by students of plankton. But no other classification so far proposed gives so satisfactory an index of the comparative density of the plankton as a whole, as distinguished from its various individual components.

Station	cc. vol. per cu. m.	Station	cc. vol. per cu. m.
10087	2.	10099	.8
10089	.8	10100	2.4
10090	1.3	10101	1.4
10092	1.6	10102	1.
10095	1.7	10103	.9
10096	1.3	10104	1.
10098	1.3	10105	.6

According to this table, the plankton was densest off Massachusetts Bay (Station 10087) and off Mt. Desert Rock (Station 10100); distinctly less so over the central parts of the Gulf and the off shore waters in general. It was scantiest near the coast off Mt. Desert, and northeast of Cape Ann (Station 10105). And the plankton was rather less dense all along the coast, north of Cape Ann, than further off shore.

The table of qualitative hauls (p. 326) might suggest a rather different distribution, with the plankton densest in the centre of the Gulf (Station 10090) and off the mouth of Penobscot Bay (Station 10091): but this is not a valid objection to accepting the results of the quantitative hauls as approximately correct, because, with the plankton stratified as it undoubtedly was (p. 290), it was a matter of chance whether a horizontal net hit or missed the richest zone.

Copepods formed the bulk of the quantitative hauls, the more active of the larger organisms, *e. g.*, Sagittae and schizopods, being so poorly represented even at localities where the qualitative nets yielded large hauls of them, that they must have avoided the slow moving quantitative net; and our experience in 1912 (1914a) was the same.

The following counts of copepods were obtained by diluting the entire catch to 150 cc.; mixing well, then taking 3 cc. in a pipette while the plankton was in suspension, and counting. Each of the catches was sampled two or three times, and the results averaged.

Station	Relative no copepods in 3 cc.	Total number of copepods in a column 1 m. in cross section
10087	101	50500
10089	62	31000
10090	87	435(0
10092	193	96500
10095	63	31500
10096	140	70000
10097	174	87000
10098	80	40000
10099	54	27000
10100	247	123500
10101	150	75000
10102	61	30500
1(103	76	38000
10104	54	27000
10105	56	28000
	Average,	53266

This table shows that the central part of the Gulf and the waters off Mt. Desert Rock were most prolific, numerically, in copepods (Stations 10092 and 10100); the Stations off Monhegan (10102) and northeast of Cape Ann (10104, 10105) the poorest. Thus there is a marked discrepancy between the numerical distribution of copepods, and the volumes of the quantitative hauls, as outlined above. This is due to the fact that besides the adult Calanus, the more prolific hauls contain hosts of a very much smaller copepod, *Pseudocalanus elongatus* (p. 291), which added very little to the volumes of the hauls. The Calanus component agrees more closely, numerically, with the plankton volumes (p. 286). The total counts of copepods are not a fair index to regional richness or poverty, as feeding grounds for pelagic fishes, because one adult Calanus is worth many Centropages or Pseudocalanus in food value, though the latter are an important food for fish fry. It is the Calanus swarms which form the chief copepod constituent of the food of mackerel, pollack, and probably of the shad which summer in the Gulf; and for Calanus as for the volume of plankton, the richest parts of the Gulf were off Massachusetts Bay and off Mt. Desert Rock (Stations 10092, 10100), with a third prolific area off Chatham detected by Captain McFarland.

Microplankton.

The microplankton of the cruise will be treated later in special reports. But it is worth while to give a brief account of the distribution of general plankton types here, because of their bearing on general oceanographic problems (Fig. 82). They fall into four general types, which may be called "Ceratium," "diatom," "mixed" (a mixture of the two), and a tropical type characterized by the presence of considerable amounts of Trichodesmium. Of course these are not actually distinct, grading into one another; but they group sufficiently well to be treated in this way. To take the rarer types first, tropical plankton (the "Desmo Plankton" of Cleve) was encountered only once, in the inner edge of the Gulf Stream (Station 10071) where the rather scanty catch consisted chiefly of *Ceratium macroceros*, and of Trichodesmium, with an occasional diatom (Rhizosolenia). Diatom plankton was encountered in three distinct regions; on George's Bank (Station 10059); off the mouth of Chesapeake Bay (Stations 10075, 10077, 10078) and in the northern part of the Gulf of Maine near Mt. Desert (Stations 10099, 10101).

The species composing these diatom swarms were quite different in these three regions. On George's Bank the mass, which was rather rich, consisted chiefly of a species Guinardia, besides such forms as *Eucampia zoodiacus*, *Rhizosolenia stolforthi*, and *R. styliformis*, practically a pure diatom haul, except for an occasional Peridinium and Ceratium. The diatom swarm off Chesapeake Bay consisted chiefly of various species of Chaetoceras (among them *C. decipiens* and *C. contortum*) with smaller numbers of Rhizosolenia, Leptocylindrus, and Thalassiothrix. And at the mouth of the Bay the haul was chiefly Rhizosolenia.

The diatom plankton found in the Gulf of Maine is difficult to place because it was chiefly debris, and evidently moribund. But fragments of Rhizosolenia and *Chaetoceras decipiens*, with other species of Chaetoceras can be distinguished. Mixed plankton (Fig. 82) partly diatom, partly peridinian, was found just north of George's Bank (no doubt the effect of the diatom swarm on the Bank); south of Nantucket Shoals (Station 10061), and at all the Stations close to land south of New York, except where the plankton was purely diatom (10069, 10072,

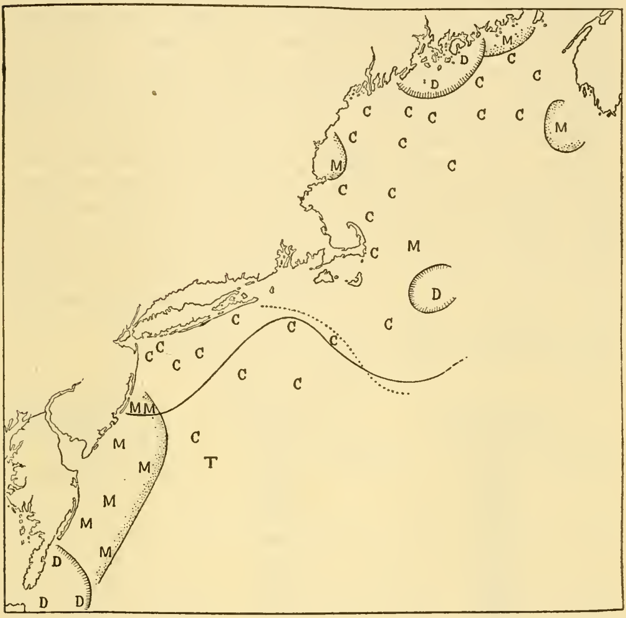

Fig. 82.— Distribution of different types of microplankton, July–August, 1913.
c, Ceratium plankton; M, mixed; D, Diatom; . . . ., northern limit to Ceratium macroceros ———; s. limit to c, longipes.

10079, 10080, 10081). The plankton along the outer part of the continental shelf, south of Delaware Bay (Stations 10073, 10074) was also of this type. In the Gulf of Maine mixed plankton was encountered on German Bank (Station 10095); near shore east of Mt. Desert Island; and again north of Cape Ann (Station 10105). There were likewise more diatoms at our other stations near land than in the centre of the Gulf; but not enough to take the hauls out of the Ceratium class. The diatom constituents of the Gulf Stations were chiefly several small species of Chaetoceras, with occasional *C. decipiens*, *Rhizosolenia semispina* and *Nitschia serriata*, etc.

Peridinian plankton, in greater or less abundance, and composed of different species at different localities, occupied the waters of the Gulf of Maine (Stations 10057, 10086–10093, 10096, 10097, 10102, 10104) except at the few limited regions just mentioned; Nantucket Shoals (Staton 10060), the continental shelf from abreast of Nantucket to New York (Stations 10062, 10063, 10067, 10082, 10083, 10070) (Fig. 82). Unfortunately we have no data on the microplankton of the Gulf Stream water at Station 10076, the bottle being broken in transit. In the Gulf of Maine the prevalent organisms, of this plankton type, were two species of Ceratium, *tripos*, and the form classed by Paulsen (1904, 1908), as var. *oceanica* of *C. longipes*. (In my Report on the cruise of 1912, these two species were treated together). *Ceratium longipes* differs so noticeably from *tripos* in its curved apical horn and serrate shell, that it is easy to count the respective numbers of the two in plankton samples. And without delaying with the exact counts, the result of the comparison was as follows:—

Longipes outnumbers *tripos*	Roughly equal numbers *Tripos* and *longipes*	*Tripos* outnumbers *longipes*
Stations 10057	Stations 10058	Stations 10088
10059	10090	10089
10087	10092	
10091	10093	
10098	10095	
10102	10096	
10103	10099	
10104	10105	

On the whole, then, *longipes* was the more abundant of the two in the Gulf, where it was taken at practically every station, though notably absent at Station 10086, where it had been abundant a month earlier (Station 10057). The table likewise suggests that the preponderance of *longipes* was greater near shore than in the centre of the Gulf, the only stations where *tripos* predominated being far from land.

C. longipes occurred in the plankton on George's Bank, on Nantucket Shoals, and over the continental shelf as a whole as far as

Barnegat (Stations 10060 to 10068); but it was absent at the more southern stations, nor was it found over the outer part of the shelf south of Long Island (Stations 10063, 10065). And *tripos* invariably outnumbered it in the hauls south and west of Cape Cod. On our coasts, at least in summer, *longipes* evidently belongs to northern water. The salinity in which it was living (on the surface, where all the hauls with the # 20 silk net were made) ranged from 31.8‰ (Station 10104) to 33.4‰ (Station 10061); the temperature from 48° (Station 10095) to 69° (Station 10069). But it was far less abundant at temperatures above 62° or 63° than in the colder water of the Gulf:— for example at Station 10061, surface temperature 68°, only two specimens were detected; Station 10062, 67°, only an occasional specimen; Station 10069, 69°, only one specimen was found.

Ceratium tripos was taken at practically all our southern stations, as well as north and east of New York and in the Gulf of Maine, and at Stations 10063, 10065 over the outer part of the shelf where *longipes* was absent. At only three Stations have I failed to find it in the plankton, viz., 10075, 10076, 10078, all of them within the influence of Chesapeake Bay water (p. 200).

A third species of Ceratium, *C. macroceros,* easily distinguished by its very long, slender horns, occurred in the hauls at the southern stations. The most northerly records are Stations 10062, 10063, and 10083. East of Barnegat it was greatly outnumbered by *tripos* (Stations 10062, 10063, 10065, 10067, 10069, 10083). South of this, where *longipes* was not found, *macroceros* was always as numerous as *tripos*, the two species being, roughly, equal at Stations 10073, 10074, 10077, 10079, 10082. At Stations 10070, 10071, 10072, *macroceros* outnumbered *tripos. Ceratium macroceros* was living at a very wide range of salinity, as much so, even, as *tripos* (31.3‰ to 35.2‰); but its temperature range was considerably less, the records all being from water warmer than 63° (63° to 77°); it was only once found in water cooler than 67°, and then only an occasional specimen (Station 10067). And at only three Stations (10062, 10067, 10069) were both *longipes* and *macroceros* taken in the same haul. If the former belongs to boreal plankton, the latter is as certainly limited to warm water along our coasts.

A fourth species of Ceratium, *C. fusus,* plays a subordinate rôle. It has been found at twenty-seven stations, including the Gulf of Maine as a whole (Stations 10057, 10058, 10086–10090, 10092, 10093, 10096, 10097, 10099, 10102–10104), and the continental shelf south and west of Cape Cod (Stations 10061–10063; 10067–10070; 10073, 10074, 10077–10081). The only regions where it was notably absent were in the Gulf Stream water (Station 10071); and in localities where diatoms swarmed (*i. e.*, George's Bank, the mouth of Chesapeake Bay, and near Mt. Desert Island). And even then its absence from the plankton samples examined may be accidental, because there are a few other stations also where I failed to find it in the tow. It was outnumbered by the other species of the genus everywhere, except at one station in the centre of the Gulf of Maine (10090) where there were about equal numbers of *tripos, longipes,* and *fusus* in a sample.

Two other genera of peridinians may be mentioned briefly. Peridinium occurs in practically every sample in which Ceratium has been noted, being absent only in the Gulf Stream hauls (Stations 10071, 10073), off Chesapeake Bay (Stations 10075, 10076, 10077, 10078, 10079), and in the diatom plankton found off Mt. Desert. One species, provisionally identified from Paulsen's account (1908) as *P. crassipes* Kofoid occurs over the whole range of stations, except as above; but always in small numbers. Two other species, *oceanicum* at Station 10062 and 10070; *pallidum* at Stations 10063, 10067 and 10090, have likewise been detected so far. And additional records for these, and other species, may be expected when the microscopic examination of the microplankton is completed.

The genus Dinophysis is represented by two species, *ovum* (noted only twice) and *norvegica;* the latter being of considerable importance from the oceanographic standpoint, because it was found only in the Gulf of Maine (Stations 10090, 10096, 10097), and because of its northern distribution in general (Paulsen, 1908).

The hauls made in 1913 were not of a type calculated to reveal the exact quantitative amount of plankton in the water; for this purpose vertical hauls with a quantitative net must be resorted to. But as I have previously pointed out (1914a), the horizontal hauls do show in a rough way whether the water is barren, rich, or intermediate between these two extremes.

Off Cape Cod, in early July (Stations 10057 and 10058) the microplankton was rich: and this was likewise true south of Nantucket (Stations 10062, 10063); on George's Bank (Station 10059); off Chesapeake Bay (Stations 10075, 10078); and near Mt. Desert Island (Stations 10099, 10101). But nowhere, in 1913, was it found as dense as it was in several places in the Gulf in 1912 (1914a). And as a rule it was notably scanty, being so classed at Stations 10061, 10069–10073; 10079–10083; 10086–10090; 10092, 10093, 10096, 10098, 10102, 10104, 10105; perhaps most barren of all at Stations 10071, 10081, 10082 and 10083. It was intermediate, quantitatively, at Stations 10060, 10065, 10067, 10074, 10077, 10091, 10095, 10097, 10103.

Gulf of Maine plankton, 1912 and 1913.

The summer plankton of the Gulf of Maine was of the same general type in 1913 as in 1912 (1914a). The lists of copepods, far the most important constituent of the macroplankton, are practically the same for the two years, the most numerous and most regularly occurring species was *Calanus finmarchicus.* But *Calanus hyperboreus,* taken only once in 1912 occurred at four stations in 1913, once in large numbers (p. 286); *Eucheata norvegica* was, likewise, taken more regularly in 1913, where it was practically universal in the deep waters of the Gulf (fourteen stations) than in 1912 (nine stations); and *Metridia longa* is recorded for the first time from our waters. Anomalocera was taken more regularly in 1913 than in 1912, but in this case the difference is probably apparent rather than real, due to different types of nets used on the surface, where Anomalocera is most abundant. *Euchirella rostrata,* singularly enough, was taken twice in each year, once on each side of the Gulf.

In the case of the hyperiids the difference between the hauls of the two years was much greater, because *Euthemisto bispinosa,* a species common in the centre of the Gulf in 1913 was not found at all during the preceding summer. Its history during the year in Massachusetts Bay is as follows: — absent there during the summer of 1912, it must have appeared in the early autumn, for it was about half as numerous as *compressa* in November (1914b). But later in the season it was proportionately rare in the hauls (six *compressa* to one *bispinosa* in April) and by August, 1913, the Euthemisto component of the plankton of Massachusetts Bay was once more exclusively *compressa.* This local series of changes suggests the possibility that there may be a parallel series for the Gulf as a whole, *bispinosa* appearing seasonally, in winter and spring, to disappear again in summer. If this be the case, the species must have persisted longer in 1913 than it did in 1912. But the appearance of *bispinosa* may have been the result of an invasion of the Gulf by this species during the autumn of 1912. In both summers *Euthemisto compressa* was very generally distributed over the Gulf. *Parathemisto oblivia,* taken at two Stations (10032 and 10036) in 1912, was not detected at all in the hauls of 1913. The rarity of this species is interesting because of its wide distribution and frequent occurrence on the other side of the Atlantic (p. 341). The remaining hyperiids, *Hyperia galba, H. medusarum* and Hyperoche were occasionally represented in both years.

The only pteropod which we have found in any great numbers in the

Gulf is *Limacina balea.* In 1912 the range of this species was limited to two circumscribed areas, *i. e.*, the northwest corner of the Gulf off Casco Bay, and German Bank. But in 1913 it was much more generally distributed over the Gulf. In 1912 it was most abundant off Cape Elizabeth (1914a), in 1913, off the mouth of Penobscot Bay. *Clione limacina,* on the other hand, was more frequently represented in our hauls in 1912 (nine stations) than in 1913 (two stations). But as the total number of specimens taken in the former year was only sixteen, it is doubtful whether the apparent difference has any special faunal significance. And this is likewise true of the one record of *Diacria trispinosa* off Gloucester in 1913. In neither year did we find any of the typical warm water pteropods in the Gulf.

Salpae are especially important because they give certain evidence of the entrance of Gulf Stream water into the Gulf. In both years Salpae were found on the eastern side of the Gulf; but while in 1912 they occurred on the surface over a considerable area (Station 10030 to Station 10031), in 1913 Salpa was taken in only one haul (Station 10096). In 1912 the species concerned was *fusiformis,* while *democratica* swarmed on the surface off Chatham in September (1914a). But in 1913 the single catch was *tilesii.*

The Sagitta fauna of the Gulf of 1913 was decidedly different from that of 1912, for while *S. elegans* was generally distributed over the whole area in both summers, *S. serratodentata* was far less numerous, and occurred at fewer localities in 1913. On the other hand *Eukrohenia hamata* was decidedly more abundant in 1913 (five stations) than 1912 (one station).

In 1912 at least one warm water siphonophore was taken in the Gulf, *Physophora hydrostatica* (one station), and probably a second, *Agalma elegans* (six stations) though the specimens of the latter were so fragmentary that identification was not so satisfactory as could be wished. In 1913 neither of these was found in the Gulf, though both were encountered south of Cape Cod, Agalma in abundance (p. 269). On the other hand *Stephanomia cara,* which appeared in numbers off Cape Ann during the winter (1914b) was occasionally represented in our tows in the Gulf in 1913 (three stations), though always in a very fragmentary condition (p. 315).

The neritic Medusa fauna of the Gulf was practically the same for the two years. But the only oceanic Medusa found there in either summer, *Aglantha digitale,* was much more generally distributed and locally more abundant in 1913 than in 1912.

These facts can be summed up as follows:—

The list is practically the same in 1913 as in 1912, hence it is evident that no great change, *i. e.*, no great ingress of water of either northern or Gulf Stream origin had taken place. In both years the plankton of the Gulf was typically boreal. But species which we can safely say are contributed to the fauna of the Gulf by the surface water of the Gulf Stream, *i. e.*, Salpae, and the warm water siphonophores, were distinctly less abundant, and less widespread in the Gulf, in 1913 than in 1912. On the other hand, several boreal and Arctic-boreal species, *i. e.*, *Limacina balea, Calanus hyperboreus, Metridia longa, Eucheata norvegica, Eukrohnia hamata*, and *Aglantha digitale*, were more prominent faunally in 1913 than in the preceding summer. And there is good reason to include *Euthemisto bispinosa* in the Arctic-boreal category, judging from its occurrence on the other side of the Atlantic and in the Arctic Ocean (Tesch, 1911). This suggests, of course, that St. Lawrence water was proportionally greater, Gulf Stream water less in amount in the summer of 1913; the plankton thus corroborating the evidence of salinity and temperature (p. 250).

The general quantitative distribution of the macroplankton was much the same for the two years; but the local differences were far greater in 1912 than in 1913; and nowhere, in the latter year, was the water as barren as the coastal zone east of Penobscot Bay in 1912. Whether or not the very rich plankton which was noted in Ipswich Bay in 1912, was reproduced there in 1913, is not known, because that exact locality was not revisited.

A question of importance is whether the Gulf as a whole was richer or poorer in macroplankton, *i.e.* in food for pelagic fish, in 1913 than in 1912, and here copepods play the chief rôle. The actual volumes, and relative number of copepods (p. 329) at corresponding stations for the two years are given in the table : —

Station 1912	Station 1913	Volume cc. 1912	Volume cc. 1913	Copepods 1912	Copepods 1913
10002	10087	25	18	239	101
10025	10089	8	8	125	62
10028	10092	3	16	25	193
10031	10096	3	12	20	140
10036	10097	3	?	50	174
10035	10099	Trace	3	10	54
10038	10101	2	10	24	150
10022	10103	3	7	97	76
10011	10104	2	9	30	54
Averages		5.5	10.3	69	111

Thus the only part of the Gulf where volume, or number of copepods, or both, was greatest in 1912 was off Massachusetts Bay, and near Cape Elizabeth and Platt's Bank; a difference which may be seasonal. Everywhere else both the volume of plankton and the number of copepods was greater in 1913 than in 1912. It is possible that locations close to shore might have proved an exception; but judging from what was found east of Mt. Desert and on German Bank, there is no reason to suppose that shore stations would have altered the case materially. On the average, the hauls for the whole Gulf were nearly twice as large in bulk, and 60% larger in number of copepods, in 1913; a difference so great that it can hardly be accidental, especially as the same net was used in both years. In short, there seems no escape from the conclusion that both the plankton as a whole, and its copepod constituent, were richer in August, 1913, than in the summer of 1912.

Very little can be said about the microplankton of the two years until the microscopic examination of the hauls is completed. But enough has been done to show that diatoms were far less numerous in August, 1913, than in the corresponding month of 1912. And the species which formed the bulk of the catch in that year, *Asterionella japonica,* has not been detected at all in the 1913 hauls. Furthermore the Ceratium plankton was nowhere so dense in 1913 as off Cape Elizabeth in 1912.

Macroplankton of the Gulf of Maine and of the northeastern Atlantic.

Our survey of the plankton of the Gulf of Maine in 1912 led to the conclusion that it was characteristically boreal, in the sense in which the term is used by Hjort (Murray and Hjort, 1912, p. 637), not Arctic, though with Arctic and Gulf Stream components (1914a, p. 106). And subsequent catches support this general thesis. The most important member of the plankton of the Gulf, *Calanus finmarchicus,* it is true, is practically eurythermal, but it is only in boreal, and in Arctic-boreal waters that it swarms (Farran, 1911) and it is not distinctive of polar water, although it is very numerous and very large in the Labrador Current (Herdman, Thompson, and Scott, 1898). On our coasts Calanus plankton apparently occupies an unbroken belt from the Labrador Current to Cape Cod. The only copepod which vies with it in abundance in the Gulf, *Pseudocalanus elongatus,* is likewise chiefly boreal, not polar, and far more plentiful in coastal than in oceanic water (Farran, 1910). And though *Temora longicornis* and *Euchaeta norvegica* are rather more northern, neither of them is distinctively polar. The only members of the copepod fauna which can be classed in that category, *Calanus hyperboreus*, and *Metridia longa*, are rare in the Gulf. The two oceanic copepods which are prominent in the Gulf belong, one, *Anomalocera pattersoni*, to the temperate Atlantic, the other, *Metridia lucens*, to rather more northern waters (Cleve, 1900); Pleuromamma and Euchirella alone are clearly of Gulf Stream origin, so far as the Gulf of Maine is concerned.

Only six species of euphausiid schizopods have yet been detected in the plankton of the Gulf (1914b, p. 410). One of these, *Meganyctiphanes norvegica*, is very widely distributed in the North Atlantic, but much more abundant in boreal water than in polar or warm waters; two, *Thysanoessa inermis*, and *raschii* are typical Arctic-boreal forms, one, *Thysanoessa longicaudata*, is rather more northern, but not polar, being found as far south as the southern part of the North Sea, and one, *Nematoscelis megalops* is oceanic, of very wide distribution in the North Atlantic. (For the general distribution of these species, see Kramp, 1913b). To one species only, *Thysanoessa gregaria* can a southern or Gulf Stream origin be assigned (Zimmer, 1909, p. 21), and this one has seldom been taken in the Gulf.

The only hyperiid amphipods which attain any faunal importance in the Gulf, *Euthemisto compressa* and *E. bispinosa*, are typical Arctic-boreal species, neither of them being found south of the English Channel in European waters. Of the two, *bispinosa* is decidedly the more northern (Tesch, 1911) which is suggestive in connection with the incursion of this species into the Gulf during the autumn of 1912 (p. 335).

The only pteropod which is common in the Gulf, *Limacina balea*, is one of the most typical of boreal organisms, at home neither in pure polar water, nor in the warmer parts of the Atlantic (Meisenheimer, 1906, Paulsen, 1910). *Clione limacina* is rather more northern, especially abundant on the Grand Banks of Newfoundland, though not an index of polar water (Murray and Hjort, 1912, p. 108).

The only chaetognath which is uniformly abundant over the Gulf as a whole, *Sagitta elegans*, has its centre of distribution in boreal coastal waters, though its extreme range includes the Mediterranean on the one hand, and the Arctic Ocean on the other (Apstein, 1911; Ritter-Zahony, 1911). The two other species which were taken in the Gulf in 1913 are of diametrically opposite origins: — *Sagitta serratodentata* is a southern species; *Eukrohnia hamata* is Arctic or from the mid depths off shore (Apstein, 1911). *Sagitta hexaptera,* taken in the Gulf in 1912 but not in 1913, is oceanic, very widely distributed.

The Salpae are, of course, all visitors from the Gulf Stream, as are such coelenterates as Physalia, *Agalma elegans,* and *Physophora hydrostatica.*

The ctenophores of the Gulf are either cosmopolitan forms (*Pleurobrachia pileus* and *Beroe cucumis*) or Arctic-boreal (*Bolinopsis infundibulum*); while a true Arctic species, *Mertensia ovum,* has been recorded rarely (A. Agassiz, 1865, Fewkes, 1888) and the only oceanic Medusa, *Aglantha digitale,* is widely distributed over the North Atlantic.

In short, the more important members of the Gulf plankton are of three types, 1, Arctic-boreal; 2, Gulf Stream; 3, Arctic; of which the first greatly outnumbers the other two in number of species and in number of individuals.

I have already pointed out (1914a, p. 107) that the summer plankton of the Gulf of Maine resembles that of the Norwegian Sea and the North Sea; a parallel which can be drawn even more closely with the collections made during the winter of 1912–1913 (1914b), and the summer of 1913.

And it is not only in its individual components that the plankton corresponds to the other side of the North Atlantic, but in their method of association; for example Dr. D. Damas informs me that the plankton assemblages found in the Gulf in 1912 (1914a) correspond almost exactly to many of the hauls taken by the MICHAEL SARS off the coast of Norway. And Dr. Otto Pettersen writes calling attention to the similarity of the GRAMPUS plankton to that of the Skagerrak. The parallel does not extend to the Norwegian Sea and North Sea as a whole, but only to the southern part of the former and northern part of the latter, where Arctic-boreal plankton, temperate neritic species, and warm water species carried around the northern end of Scotland by the sweep of the Atlantic Current, meet. There, as in the Gulf, *Calanus finmarchicus* is perhaps the most important member of the plankton being found locally in vast shoals (Farran, 1911, p. 38), and Pseudocalanus in great numbers. *Sagitta elegans* is taken in almost every haul; *Limacina balea* is locally abundant; *Anomalocera pattersoni* is taken more or less regularly on the surface, though seldom in great numbers; *Aglantha digitale* is frequently, Pleurobrachia irregularly recorded (Kramp, 1913a), *Euchaeta norvegica* is more or less regular in the deep hauls; *Eukrohnia hamata, Calanus hypoboreus,* and *Metridia longa* are both visitors from the north, as are the several northern species of Thysanoessa, and *Meganyctiphanes norvegica.* And all the hyperiid amphipods known from the Gulf of Maine are more or less regularly recorded (Tesch, 1911). In fact, all the species without exception which are listed as particularly characteristic of our Gulf (p. 273) meet one another in this region, most of them being regularly recorded in the plankton lists of the International Committee for the exploration of the sea. And the various Salpae, southern siphonophores and other warm water species make their appearance in summer (Damas, 1909, p. 107), just as they do in smaller numbers in the Gulf of Maine. But the relative importance of the various species is not quite alike, for example, *Euthemisto compressa*, one of the most constant members of the plankton of the Gulf of Maine, especially in summer, is usually rare (Tesch, 1911) in European waters. Its place is taken there by *Parathemisto oblivia*, which occurs in at least 50%, usually 75% of the hauls in the Norwegian Sea and the northern part of the North Sea; but *P. oblivia* is so rare in the Gulf that I have detected only two specimens among the thousands of Euthemisto which have passed under my notice (p. 335). *Euthemisto bispinosa*, on the other hand, is far more abundant on the western than the eastern side of the North Atlantic.

It is not yet possible to state the quantitative relationship which the plankton of the Gulf of Maine bears to that of the North and Norwegian Seas, because the quantitative nets used, speed of hauling, etc., have not been alike; and because the coefficient of filtration has not been determined for our nets. But this phase of plankton study is so important in its practical bearing on the food supply for fishes that it is worth while to compare our results briefly with Apstein's list for the North Sea (Apstein, 1906; Johnstone, 1908). The bulk of plankton below each square meter of surface of the Gulf of Maine, in the summers of 1912 (1914a) and 1913, ranged from 10 cc. to 250 cc.; in 1913 the average for the whole Gulf was about 100 cc. Much greater amounts than this were found in the northeastern part of the North Sea by Apstein, who records volumes of 96–952 cc.; below each square meter of surface in August, 1903; with an average of about 340 cc. for thirteen hauls. And even admitting all the objections which can be urged to volume as a measure of plankton (Steuer, 1910), so great a difference as this can only mean that there was a greater bulk of plankton in the North Sea in 1903 than in the Gulf of Maine in 1912 and 1913. And the discrepancy between the two regions is even greater, if the comparison be extended to the amounts of plankton per cubic meter, for the largest amounts in the Gulf (p. 326) is only about one tenth of Apstein's largest record (27.2 cc.) for the North

Sea, August, 1903. Most of the volumes per cubic meter given by Apstein are not for the whole column of water, but for parts of it only, as given by closing nets; to make them directly comparable with the GRAMPUS hauls, the entire depth at each station must be taken into account. When this is done, the average per cubic meter, for the North Sea, is about 9.1 cc.; the average for the Gulf of Maine 1 cc.–1.3 cc.

Copepods were much more numerous in the North Sea than in the Gulf, the average of fourteen hauls in the Gulf of Maine in August, 1913, being about 66000 under each square meter of surface; the average in the North Sea August, 1903, about 1,000,000 (Apstein, 1906; Johnstone, 1908). And although Calanus is present in large numbers in the Gulf, it was never found in such swarms as occur in the southern part of the Norwegian Sea, where a surface haul of five minutes duration with a meter net may yield more than a litre of Calanus (Damas, 1905, p. 15).

TABLE OF STATIONS, NETS USED, DEPTHS OF HAULS IN FATHOMS.

NETS.

A = Albatross 4 ft. net. B = 24 cm. net ※20 silk. C = 36 cm. net ※3 silk F = Young fish trawl. H = Helgoland net. S = Michael Sars 1 meter net. Q = Quantitative net. T = Otter Trawl. Italics indicate "no bottom."

Station	Lat.	Long.	Date 1913	Depth	Nets	Depth of hauls
10057	42° 6′	69° 56′	July 8	47	B. C. A. H.	0, 0, 15–0, 30–0.
10058	41° 47′	69° 10′	" 8	90	B. H.	0, 40–0.
10059	41° 06′	68° 42′	" 9	30	B. C. H.	0, 0, 25–0.
10060	40° 41′	69° 33′	" 9	27	B. C. S. Q.	0, 0, 20–0, 20–0.
10061	40°	69° 29′	" 10	80	B. C. S. H.	0, 0, 30–0, 50–0.
10062	40° 29′	70° 29′	" 10	41	B. C. A.	0, 0, 15–0.
10063	40° 45′	71° 16′	" 11	33	B. C. H.	0, 0, 25–0.
10064	39° 55′	71° 13′	" 11	370	B. C. H. A.	0, 0, 25–0, 175–0.
10065	40°	72° 06′	" 12	45	B. C. H. T.	0, 0, 20–0, 45.
10066	40° 20′	72° 55′	" 12	25	A.	0
10067	40° 29′	73° 46′	" 13	12	B. H.	0, 10–0.
10068	40° 22′	73° 50′	" 17	20	H. T.	10–0, 20.
10069	39° 35′	73° 47′	" 19	15	B. H. F.	0, 10–0, 15–0.
10070	39° 09′	72° 58′	" 19	44	B. C. H. T.	0, 0, 20–0, 44.
10071	38° 56′	72° 39′	" 20	*400*	B. C. A. F.	0, 0, 190–0, 175–0.

Station.	Lat.	Long.	Date 1913	Depth	Nets	Depth of hauls
10072	38° 50′	73° 51′	" 21	24	B. C. H. T.	0, 0, 15–0, 24.
10073	38° 26′	74° 30′	" 21	22	B. C. H. T.	0, 0, 15–0, 22.
10074	37° 41′	74° 27′	" 22	30	B. C. H. T.	0, 0, 20–0, 30.
10075	37° 29′	75° 21′	" 23	9	B. C. H. T.	0, 0, 8–0, 9.
10076	37° 03′	74° 33′	" 24	*150*	B. C. H. A.	0, 0, 20–0, 120–0.
10077	37° 03′	74° 56′	" 24	25	B. C. H. T.	0, 0, 20–0, 25.
10078	37°	75° 38′	" 29	12	B. C. H. T.	0, 0, 8–0, 12.
10079	38° 02′	74° 53′	" 30	15	B. C. H. T.	0, 0, 8–0, 15.
10080	39° 07′	74° 24′	" 31	13	B. C. H.	0, 0, 10–0.
10081	39° 45′	73° 58′	" 31	11	B. C. H.	0, 0, 8–0.
10082	40° 09′	73° 21′	Aug. 1	22	B. C. H.	0, 0, 18–0.
10083	40° 48′	72° 17′	" 1	16	B. C. H.	0, 0, 8–0.
10084	41° 10′	71° 13′	" 2	20		
10085	41° 39′	69° 42′	" 4	26	B. C. H.	0, 0, 18–0.
10086	42° 6′	70°	" 5	40	B. C. H.	0, 0, 20–0.
10087	42° 31′	70° 21′	" 9	71	B. C. A. H. Q.	0, 0, 15–0, 40–0, 70–0.
10088	42° 33′	69° 33′	" 9	149	B. C. A. H.	0, 0, 80–0, 80–0.
10089	43° 02′	69° 19′	" 10	108	B. C. H. Q.	0, 0, 30–0, 100–0.
10090	42° 51′	68° 25′	" 10	101	B. C. A. H. Q.	0, 0, 20–0, 75–0, 90–0.
10091	43° 24′	68° 49′	" 11	60	B. C. H.	0, 0, 20–0.
10092	43° 27′	67° 55′	" 11	131	B. C. H. A. Q.	0, 0, 35–0, 85–0, 120–0.
10093	43° 24′	67° 12′	" 12	120	B. C. A. H.	0, 0, 25–0, 85–0.
10094	43° 25′	66° 43′	" 12	63		
10095	43° 20′	66° 27′	" 12	31	B. C. H. Q.	0, 0, 20–0, 20–0.
10096	43° 56′	66° 50′	" 12	61	B. C. H. Q.	0, 0, 25–0, 50–0.
10097	44° 13′	67° 21′	" 13	115	B. C. A. H. Q.	0, 0, 25–0, 85–0, 100–0.
10098	44° 24′	67° 29′	" 13	37	B. C. H. Q.	0, 0, 20–0, 30–0.
10099	44° 08′	68° 10′	" 13	21	B. C. H. Q.	0, 0, 15–0, 20–0.
10100	43° 52′	67° 58′	" 13	102	B. C. A. H. Q.	0, 0, 25–0, 70–0, 90–0.
10101	43° 44′	68° 44′	" 14	54	B. C. H. Q.	0, 0, 25–0, 40–0.
10102	43° 34′	69° 13′	" 14	75	B. C. A. H. Q.	0, 0, 20–0, 50–0, 70–0.
10103	43° 32′	69° 55′	" 14	50	B. C. H. Q.	0, 0, 30–0, 40–0.
10104	43° 08′	70° 06′	" 15	87	B. C. A. H. Q.	0, 0, 15–0, 50–0, 80–0.
10105	42° 48′	70° 27′	" 15	63	B. C. H. Q.	0, 0, 40–0, 60–0.
10106	42° 29′	70° 37′	" 20	38		
10112	40° 17′	70° 57′	" 22	60	T.	60.

TABLE OF TEMPERATURES, SALINITIES, AND DENSITIES.

Temperatures are Fahrenheit; Salinity = grams of salts per kilogram of water. Density is at the temperature *in situ*, and = specific gravity at T°, compared to distilled water at 4°C. × 1000.

The density readings for depths greater than fifty fathoms are corrected for pressure by Ekman's (1910) tables IV and V. Readings at 50 fathoms or less, are corrected for pressure by table IV (Ekman, 1910) alone.

Station	Depth Fathoms	Temp.	Salinity	Density
10057	0	61.°	31.9	23.43
	10	50.6°	31.97	24.69
	20	42.6°	32.48	25.75
	30		32.7	
	40	41.2°	32.68	26.19
10058	0	63.°	32.4	25.53
	30	41.1°	33.1	26.44
	60	40.6°	33.35	26.91
	90	41.3°	33.36	27.17
10059	0	56.°	33.06	24.93
	15	54.7°	33.07	25.20
	30	54.7°	33.13	26.38
10060	0	61.°	32.63	23.94
	10	57.4°	32.68	24.42
	25	50.3°	33.04	25.67
10061	0	68.°	33.41	23.55
	25	47.9°	33.51	26.18
	50	47.3°	33.62	26.55
		51.°		
	75	51.5°	34.30	26.86
10062	0	67.°	32.86	23.42
	20	46.2°	33.04	25.93
	40	43.6°	33.44	26.57
10063	0	67.°	32.11	22.71
	15	53.2°	33.22	25.54
	30	44.3°	33.22	26.30
10064	0	70.°	33.16	23.15
	50	54.°	35.18	27.54
	150	48.5°	35.05	28.38

Station	Depth Fathoms	Temp.	Salinity	Density
10064	250	41.6°	34.96	29.80
10065	0	69.°	32.68	23.03
	15	54.9°		
	20		33.04	25.62
	30	44.6°		
	40	46.2°	33.89	26.75
	45	51.°		
10066	0	69.°	31.55	22.17
	15	51.5°	33.26	25.56
	25	45.8°	33.22	26.10
10067	0	63.°	31.22	22.64
	12	49.2°	32.82	25.57
10068	0	67.°	31.53	22.41
	20	47.3°	33.16	25.99
10069	0	69.°	32.27	22.76
	7	60.°	33.2	23.58
	15	48.°?	33.25	24.97?
10070	0	74.°	32.23	21.85
	10	70.4°		
	20	50.°	33.68	26.16
	40	48.4°	34.02	26.96
10071	0	76.°	35.25	23.87
	50	58.8°	35.55	27.46
	150	49.1°	35.25	28.52
	250	43.6°	35.03	29.65
10072	0	73.°	32.22	22.12
	10	66.2°	33.29	23.81
	24	47.8°	33.56	26.40
10073	0	75.°	33.48	22.50
	10	70.5°	34.04	23.89
	22	51.4°	33.93	26.16
10074	0	75.°	33.24	22.31
	15	64.6°	35.06	25.48
	30	50.8°	34.32	26.72
10075	0	75.°	31.88	21.27
	9	59.°	33.48	24.9
10076	0	76.°	33.57	22.57
	25	59.5°		
	50	54.5°	35.37	27.64
	100	51.3°	35.36	27.92

Station	Depth Fathoms	Temp.	Salinity	Density
10076	150	49.3°	35.15	28.37
10077	0	77.°	31.32	20.59
	10	68.5°	34.96	24.74
	25	51.5°	34.33	26.36
10078	0	80.°	29.25	18.46
	5	75.7°	31.91	21.34
	12	57.6°	33.5	25.13
10079	0	76.°	32.41	21.70
	5	74.5°	32.76	22.22
	10		33.86	
	15	52.5°	33.86	26.05
10080	0	76.°	32.23	21.56
	5	53.6°		
		52.6°		
	13	52.6°	33.14	25.47
10081	0	75.°	32.11	21.45
	5	74.2°	32.14	21.51
	7	53.°		
	11	52.6°	32.65	25.02
10082	0	74.°	31.85	21.61
	10	54.7°	33.01	25.09
	22	47.°	33.09	25.92
10083	0	68.°	31.29	21.97
	8	64.8°	31.49	22.72
	16	50.6°	32.75	25.34
10084	0	71.°	32.29	22.32
	10	62.3°	32.33	23.58
	20	50.1°	32.65	25.30
10085	0	63.5°	32.05	23.15
	10	43.6°	32.47	25.68
	26	42.5°	32.56	25.87
10086	0	62.8°	32.09	23.30
	10	53.1°	32.23	24.56
	20	43.8°	32.52	25.71
	30	43.3°	32.52	25.89
	40	43.2°	32.52	25.93
10087	0	62.°	32.09	23.41
	10	51.4°		
	20		32.68	
	25	42.9°		

Station	Depth Fathoms	Temp.	Salinity	Density
10087	50	41.3°	32.77	26.37
	70	41.3°	32.75	26.40
10088	0	66.5°	32.21	22.91
	25	45.9°		
	50	41.3°	33.17	26.68
	100	43.3°	33.87	27.47
	150	43.4°	34.27	28.21
10089	0	61.5°	32.52	23.88
	10	53.7°		
	25	44.°	32.95	26.11
	50	44.°?	33.26	
	100	41.2°	33.46	27.29
10090	0	61.°	32.56	23.91
	10	52.1°		
	25	44.2°	32.92	26.08
	50	43.5°	33.21	26.59
	100	43.9°	33.84	27.41
10091	0	61.°	32.47	23.84
	10	58.1°	32.57	24.34
	25	47.5°		
	50	44.1°		
	60		33.40	26.69
10092	0	62.°	32.59	24.05
	10	52.6°		
		48.6°		
	25	43.2°	33.1	26.22
	40–45	42.°		
	50	42.5°	33.28	26.66
	100	43.°	33.91	27.53
	130	42.9°	34.14	28.01
10093	0	60.5°	32.61	23.95
	10	58.1°		
	20	51.2°		
	30		32.95	25.87
	50	42.°		26.81?
	60		33.58	
	75	42.6°		
	120	42.6°	34.10	27.89
10094	0	48.°	32.75	25.46
	10	47.°		

Station	Depth Fathoms	Temp.	Salinity	Density
10094	20		33.01	25.86
	25	47.°		
	40		33.24	26.22
	50	46.7°		
	60		33.62	26.84
	62	44.9°		
10095	0	48.°	32.79	25.43
	5	47.8°		
	10	47.6°	32.92	25.69
	30	47.4°	32.94	25.88
10096	0	54.°	32.75	24.89
	10	51.7°		
	25	49.4°		
	30		33.42	26.14
	50	47.2°		
	60		33.39	
	65	43.°		26.86
10097	0	55.°	32.75	24.80
	10	53.°		
	25			
	30		32.77	
	50	46.4°		
	60			
	110	42.8°	34.09	27.74
10098	0	50.5°	32.47	25.01
	10	49.2°		
	15		32.59	25.33
	37	48.3°	32.70	25.62
10099	0	55.°	32.38	24.39
	20	48.8°	32.61	25.39
10100	0	55.°	32.72	24.67
	10	50.2°		
	20		32.95	
	25	47.3°		25.86
	50	46.°	33.28	26.46
	100	43.2°	33.87	27.49
10101	0	53.5°	32.68	24.83
	10	50.2°		
	20		32.92	
	25	48.7°		25.79?

Station	Depth Fathoms	Temp.	Salinity	Density
10101	50	47.3°	33.26	26.27
10102	0	61.°	32.23	23.65
	10	49.2°		
	20		32.66	
	25	47.7°		25.63?
	50	45.4°		26.20?
	70		33.17	26.76
	75	42.6°		
10103	0	61.°	31.83	23.35
	10	52.5°?		
	20		32.63	
	25	46.5°		25.66
	50	44.1°	32.83	26.23
10104	0	63.°	31.85	23.14
	10	49.3°		
	20		32.57	
	25	45.2°		25.76?
	50	41.9°	33.06	26.54
	80		33.1	26.94
	85	39.8°		
10105	0	64.°	32.09	23.18
	10	49.7°		
	25	44.4°		25.78?
	30		32.66	
	50	41.6°		26.28
	60	40.3°	32.74	26.45
10106	0	61.°	32.16	23.59
	15	48.5°	32.41	25.26
	38	44.10	32.57	25.90
10112	0	69.5°	34.	
	20	63.°		
	35	60.2°	34.83	
	60	59.8°	35.17	

TABLE OF SURFACE TEMPERATURES, TAKEN BY W. W. WELSH, BETWEEN CAPE COD AND CAPE MAY.

August 21–September 1, 1913.

Stations	Latitude	Longitude	Date	Surface Temperature
10107	40° 36′	69° 38′	Aug. 21	67.5°
10108	40° 21′	69° 39′	"	69.5°
10109	40° 07′	69° 46′	"	69.°
10110	40° 16′	70° 07′	"	68.°
10111	40° 23′	70° 38′	Aug. 22	67.°
10112	40° 17′	70° 57′	"	69.5°
10113	40° 22′	71° 15′	"	69.°
10114	40° 26′	71° 30′	"	70.5°
10115	40° 31′	71° 45′	"	71.25°
10116	40° 37′	72°	"	70.°
10117	41° 01′	71° 43′	Aug. 25	66.°
10118	40° 51′	71° 58′	"	69.5°
10119	40° 22′	71° 55′	"	71.5°
10120	40° 10′	71° 50′	"	72.°
10121	40° 04′	71° 54′	Aug. 26	72.°
10122	39° 58′	71° 52′	"	70.5°
10123	40° 08′	72° 03′	"	72.°
10124	40° 03′	72° 03′	"	72.°
10125	40° 03′	72° 22′	"	72.°
10126	40° 09′	72° 37′	"	71.5°
10127	40° 16′	72° 56′	"	71.°
10128	40° 27′	73° 38′	Aug. 27	71.°
10129	40° 22′	73° 28′	"	71.°
10130	40° 17′	73° 34′	Aug. 28	72.25°
10131	40° 10′	73° 21′	"	72.°
10132	40° 05′	73° 11′	"	71.5°
10133	40°	73° 27′	"	71.5°
10134	39° 53′	73° 17′	Aug. 29	71.°
10135	39° 47′	73° 09′	"	72.°
10136	39° 39′	73°	"	73.°
10137	39° 39′	73° 16′	"	73.°
10138	39° 41′	73° 19′	"	72.°
10139	39° 46′	73° 30′	"	72.°
10140	39° 48′	73° 42,	"	72.°
10141	39° 50′	73° 53′	"	72.°

Stations	Latitude	Longitude	Date	Surface temperature
10142	39° 39′	73° 49′	Aug. 30	72.°
10143	39° 43′	74°	"	71.°
10144	39° 34′	73° 53′	"	72.°
10145	39° 29′	73° 44′	"	72.5°
10146	39° 23′	73° 34′	"	73.°
10147	39° 16′	73° 26′	Aug. 31	74.°
10148	39° 09′	73° 23′	"	74.°
10149	39° 02′	73° 19′	"	75.°
10150	39° 02′	73° 34′	"	76.°
10151	39° 02′	73° 46′	"	75.5°
10152	38° 54′	73° 53′	"	75.°
10153	38° 45′	74° 01′	"	74.5°
10154	38° 40′	74° 09′	Sept. 1	72.5°
10155	38° 42′	74° 15′	"	74.5°
10156	38° 46′	74° 25′	"	74.5°

SALINITIES OF WATER SAMPLES COLLECTED BY CAPTAIN McFARLAND.

May–Aug., 1913.

Lat.	Long.	Date	Depth Fath.	Sal. ‰
38° 45′ N.	73° 52′ W.	May 3	0	34.18
38° 49′	73° 38′	" 9	"	34.18
"	"	" "	25	34.18
40° 46′	70° 32′	June 5	0	32.94
40° 48′	70° 05′	" 6	"	32.65
"	"	" "	15	32.75
40° 45′	70°	" 21	0	32.68
40° 42′	69° 38′	Aug. 8	20	32.77

Locality	Date	Depth Fath.	Sal. ‰
off Chatham, Mass.	Aug. 1	0	32.07
15 miles SE. of Chatham	Aug. 16	0	32.38
SE. of Chatham	Aug. 21	20	32.34

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PLATE 1.

Chart of the route, showing the Stations, and the 20, 50, and 100 fathom curves.

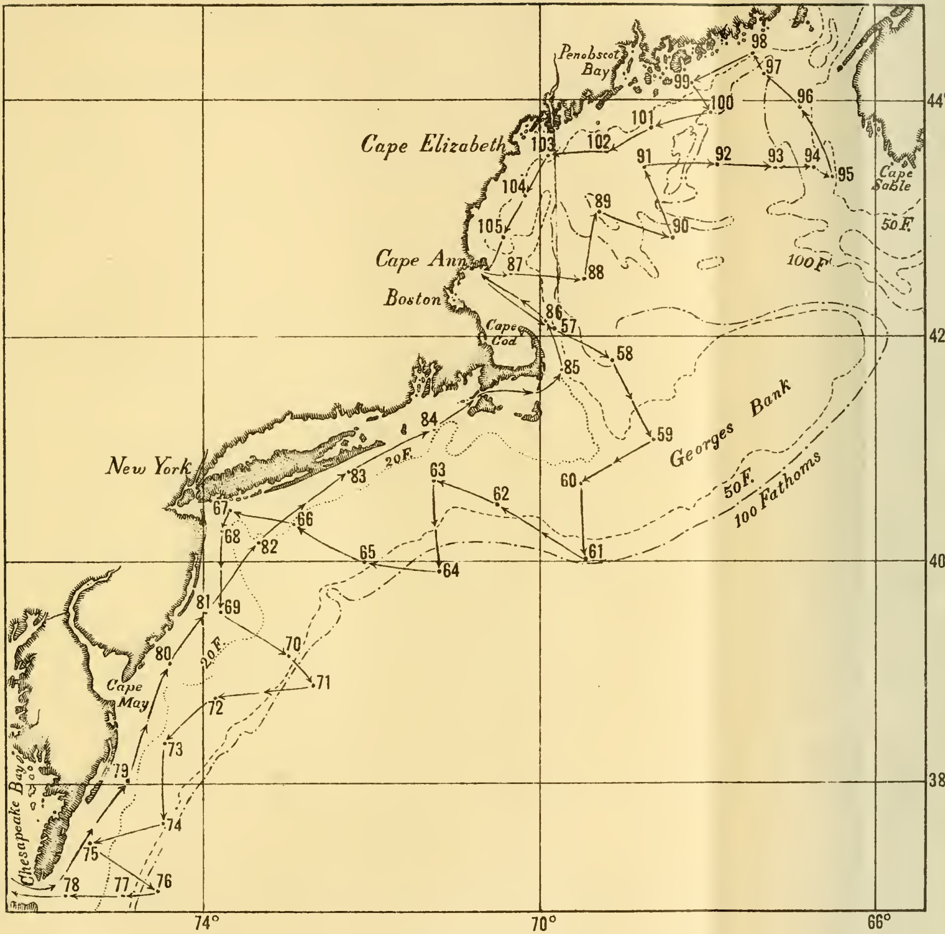
Penobscot Bay
Cape Elizabeth
Cape Ann
Boston
Cape Cod
Cape Sable
New York
Cape May
Chesapeake Bay
Georges Bank
50 F.
100 F.
20 F.
100 Fathoms
44°
42°
40°
38°
74°
70°
66°
57
58
59
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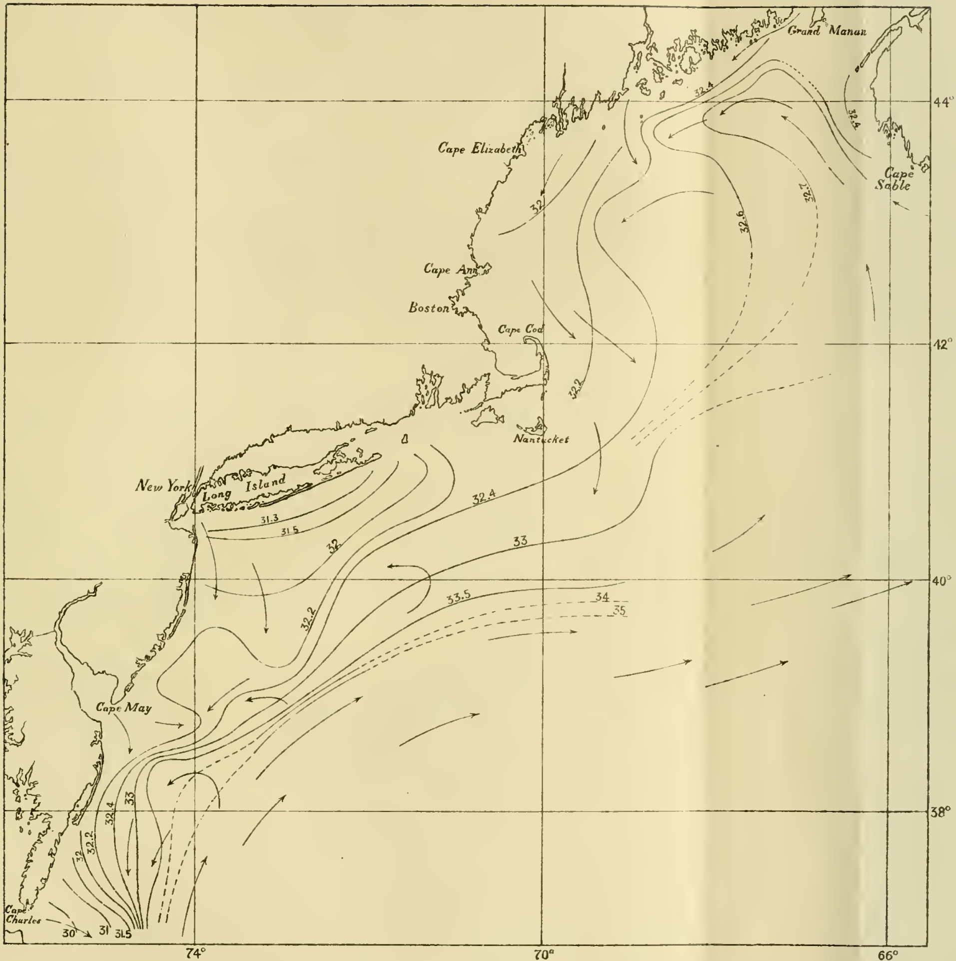
PLATE 2.

Chart of surface salinities and surface currents for the Gulf of Maine in August, and for the waters south and west of Cape Cod in July.


Grand Manan
Cape Elizabeth
Cape Sable
Cape Ann
Boston
Cape Cod
Nantucket
New York
Long Island
Cape May
Cape Charles
44°
42°
40°
38°
74°
70°
66°
32.4
32.6
32.7
32
32.2
31.3
31.5
33
33.5
34
35
30
31
31.5

The following Publications of the Museum of Comparative Zoölogy are in preparation:—

LOUIS CABOT. Immature State of the Odonata, Part IV.
E. L. MARK. Studies on Lepidosteus, continued.
E. L. MARK. On Arachnactis.
H. L. CLARK. The "Albatross" Hawaiian Echini.

Reports on the Results of Dredging Operations in 1877, 1878, 1879, and 1880, in charge of ALEXANDER AGASSIZ, by the U. S. Coast Survey Steamer "Blake," as follows:—

A. MILNE EDWARDS and E. L. BOUVIER. The Crustacea of the "Blake."
A. E. VERRILL. The Alcyonaria of the "Blake."

Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieutenant Commander Z. L. TANNER, U. S. N., Commanding, in charge of ALEXANDER AGASSIZ, as follows:—

K. BRANDT. The Sagittae.
K. BRANDT. The Thalassicolae.
O. CARLGREN. The Actinarians.
R. V. CHAMBERLIN. The Annelids.
W. R. COE. The Nemerteans.
REINHARD DOHRN. The Eyes of Deep-Sea Crustacea.
H. J. HANSEN. The Cirripeds.
H. J. HANSEN. The Schizopods.
HAROLD HEATH. Solenogaster.
W. A. HERDMAN. The Ascidians.
S. J. HICKSON. The Antipathids.
E. L. MARK. Branchiocerianthus.
JOHN MURRAY. The Bottom Specimens.
P. SCHIEMENZ. The Pteropods and Heteropods.
THEO. STUDER. The Alcyonarians.
—— The Salpidae and Doliolidae.
H. B. WARD. The Sipunculids.

Reports on the Scientific Results of the Expedition to the Tropical Pacific, in charge of ALEXANDER AGASSIZ, on the U. S. Fish Commission Steamer "Albatross," from August, 1899, to March, 1900, Commander Jefferson F. Moser, U. S. N., Commanding, as follows:—

R. V. CHAMBERLIN. The Annelids.
H. L. CLARK. The Holothurians.
H. L. CLARK. The Ophiurans.
—— The Volcanic Rocks.
—— The Coralliferous Limestones.
S. HENSHAW. The Insects.
G. W. MÜLLER. The Ostracods.
MARY J. RATHBUN. The Crustacea Decapoda.
G. O. SARS. The Copepods.
L. STEJNEGER. The Reptiles.
C. H. TOWNSEND. The Mammals, Birds, and Fishes.
T. W. VAUGHAN. The Corals, Recent and Fossil.