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AT HARVARD COLLEGE.

Vol. LVIII. No. 10.

OCEANOGRAPHY AND PLANKTON OF MASSACHUSETTS BAY AND ADJACENT WATERS, NOVEMBER, 1912–MAY, 1913.

By Henry B. Bigelow.

With One Plate.

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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.
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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.
[7] Bull. M. C. Z., Vol. L., No. 4, November, 1906, 26 pp., 4 pls.
[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.
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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.
[19] Bull. M. C. Z., Vol. LII., No. 11, August, 1909, 10 pp., 3 pls
[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.

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No. 10.—*Oceanography and Plankton of Massachusetts Bay and adjacent waters, November, 1912–May, 1913.*

By Henry B. Bigelow.

CONTENTS.

Introduction.

During the winter and early spring of 1912–1913 the Bureau of Fisheries Steamer Blue Wing carried on oceanographic investigations in Massachusetts Bay, under my supervision, continuing the work of the Grampus during the summer of 1912 (Bull. M. C. Z., 1914, **58**, p. 29–148). It was planned to make a trip every two weeks to a locality some eight miles south of Gloucester, in 35–40 fathoms; and also a few visits to Ipswich Bay, and to the waters off Cape Ann; but the frequent gales which made the season an exceptionally rough one interfered more or less with the program. This work was supplemented by Mr. W. W. Welsh, of the Bureau of Fisheries, who took temperatures, water samples, and tows at 32 stations, chiefly north of Cape Ann, during March, April, and May, while investigating the spawning habits of the coast schools of haddock. And a few temperatures, water samples, and tows were also taken on George's Bank, by Mr. W. F. Clapp, of the Museum of Comparative Zoölogy, and by Mr. Douthart, of the Bureau of Fisheries.

The subsurface temperatures were all taken with the Negretti and Zambra reversing thermometers; the water samples with the stop-cock water bottle previously described (Bull. M. C. Z., 1914, **58**, p. 37, fig. 1). The purpose of our plankton work being chiefly qualitative, we depended on horizontal tows, at different depths, with the 4 ft. net used on the GRAMPUS (Loc. cit., p. 39) beside various small nets. The salinities listed below were all obtained by titration. Each sample was tested twice, by Mr. Welsh, or myself, standard water being supplied by the International Committee for the exploration of the sea.

TEMPERATURE AND SALINITY, SOUTH OF CAPE ANN.

When we ceased work on the GRAMPUS at the end of August, 1912, the surface temperature was about 60° over the northern half of Massachusetts Bay, a noticeable cooling having already taken place from the summer maximum of 64° to 66°; and though there was a very rapid temperature decline from the surface downward to about 44.5° at 30 fathoms and 43° at 40 fathoms, the bottom temperatures in general at 30–40 fathoms were several degrees warmer than they had been at the beginning of July; the exact readings varying from place to place, consequent on tidal currents (*Loc. cit.*, p. 48). The salinity at the end of August was about 31.6 on the surface, 32.55‰ at 30 fathoms over the northern half of the Bay; 31.9‰ at the surface, 32.6‰ at 30 fathoms, 32.9‰ at 40 fathoms over its central portion, showing practically no change from the early part of July; and the water of the Bay was in stable equilibrium, the density (at the temperature *in situ*) being about 23.2 at the surface, about 25.5 at 30 fathoms.

On resuming work on November 20 (fig. 1, 3) it was found that the surface temperature had dropped to 48.5°, but the reverse change had taken place on the bottom, for while the 30 fathom temperature was 44.7° on August 31, on November 20, at nearly the same locality, it was 48° both at that level and at 25 fathoms. Thus the mean temperature for the whole column of water had fallen less than one degree, being about 49° on August 31, and 48.2° on November 20. The salinity (fig. 2), like the temperature, was nearly uniform with depth on November 20, being 32.57‰ at the surface, 32.57‰ at 25 fathoms; 32.6‰ at 30 fathoms, a degree of saltness about the same as the bottom salinity in this region at the end of August, and considerably higher than the mean salinity of the entire column of water at that time (August 31, Station 10,046, mean salinity 32.2‰). Density, for November 20, at the temperature *in situ*, disregarding pressure, was 25.24 at the surface, 25.27 at the bottom; *i. e.*, the vertical stability of the water was so slight that all that would be necessary to

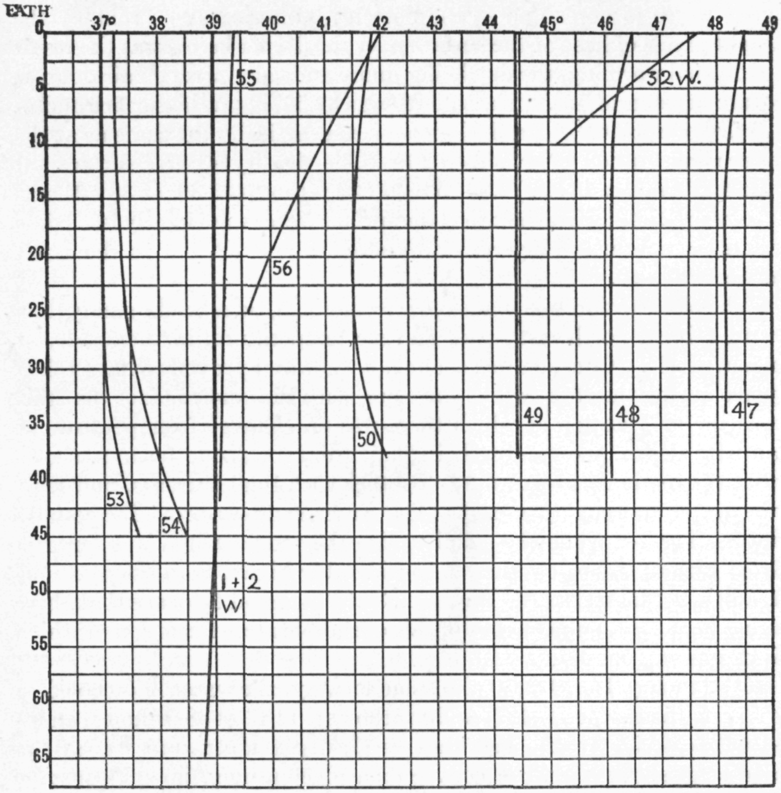


Fig. 1.—Temperature sections off Cape Ann, November 20 (Station 10,047); December 4 (Station 10,048); December 23 (Station 10,049); January 16 (Station 10,050); February 13 (Station 10,053); March 4 (Station 10,054); March 19 (Stations 1 and 2, W. W. Welsh); April 3 (Station 10,055); and off Gloucester Harbor, April 14 (Station 10,056) and May 17 (Station 32 W. W. Welsh).

cause a reversal of density, with consequent vertical circulation, would be a cooling at the surface of about 1°. Evidently then, dynamic overturning of the water might be expected to be active from this time onward as the surface became colder and colder with the advance of winter. And the data show that such was the case, for on the next visit, December 4, we found that the water was not only appreciably colder at all depths, but very nearly uniform from surface to bottom, the surface temperature having fallen to 6.6°, with 46.1° at 20 fathoms and at the bottom (30 fathoms). Probably the slight excess of heat at the surface over the deeper layers was the result of diurnal warming, the day being sunny and calm, with an air temperature at noon of 46°. The salinity was 32.56‰ on the surface and at 25 fathoms, 32.61‰ on the botton, *i. e.*, practically the same as at the preceding station (November 20). The density at the surface (at the temperature *in situ*) was 25.38, at 25 fathoms 25.39, at 38 fathoms (bottom) 25.42. The fact that the surface water was slightly less saline than the subsurface layers is no doubt to be explained as the result of recent rains.

The next station was made on December 23, on a bright sunny day, with a brisk northwest wind, and air temperature, in the shade, at noon, of 36°. Considerable cooling of the water proved to have taken place during the three weeks since our last visit, and the fact that this was the first station at which there was no change of temperature at all with depth, the reading being 4.5° from surface to bottom, shows that convectional overturning, together with tidal currents, now kept the water thoroughly mixed. The water samples proved especially interesting, for while the salinity, like the temperature, was uniform from surface to bottom, it was considerably higher than any previous reading in Massachusetts Bay, *i. e.*, 32.74‰, good evidence that there must have been an accession of salt offshore water, the origin of which is discussed (p. 400).

On January 16, 1913, at the same locality, the water had cooled to 41.7° at the surface; 41.5° at 25 fathoms; 42.1° at 38 fathoms, an instructive series for the fact that the lowest temperature was at the mid-level shows that the convectional overturning, now a constant phenomenon only interrupted by diurnal warming of the surface, was most active in the upper 25 fathoms, foreshadowing the time when cooling would be so rapid at the surface that the latter would be constantly cooler than the bottom. The slight excess of warmth (.2°) of the surface over the 25 fathom reading, was no doubt the result of diurnal warming during the preceding two or three days, which were unseasonably warm. The salinity was 32.81‰ at the surface; 32.86‰ at 25 fathoms; 32.94‰ at 38 fathoms (bottom); a considerable rise since the previous stations. The difference in salinity between surface and bottom was probably in part evidence of an inshore flow of salt bottom water from the deep basin (p. 400); but it was probably in part the result of heavy rains which fell during the preceding week.

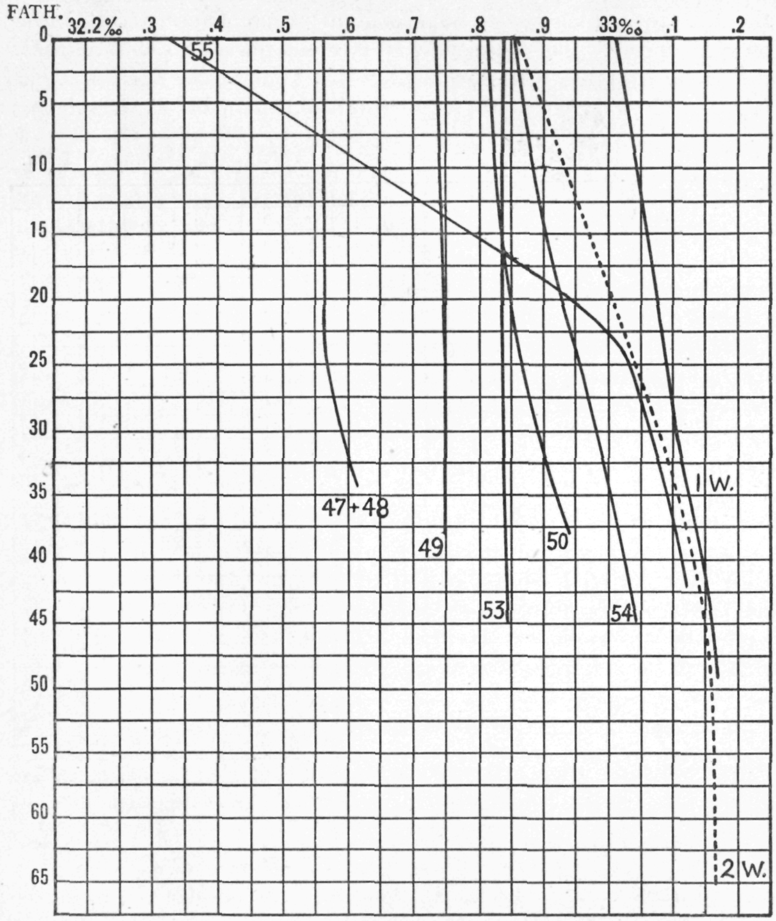


FIG. 2.— Salinity sections off Cape Ann, November 20 (Station 10,047); December 4 (Station 10,048); December 23 (Station 10,049); January 16 (Station 10,050); February 13 (Station 10,053), March 4 (Station 10,054); and March 19 (Stations 1 and 2 W. W. Welsh).

On January 30, a strong southwest wind and heavy sea made the occupation of our usual locality out of the question, though a station was occupied in 20 fathoms of water some three miles off Gloucester. The surface temperature had now dropped to 40.5° and at 19 fathoms to 41.7°, *i. e.*, we found the reversal of temperature foreshadowed on the last visit, which was to be a constant phenomenon from this time on until spring. The salinity at 19 fathoms proved to be practically the same as at the last station (32.8‰); but at the surface it had fallen to 32.56‰, no doubt as the result of a snow-fall of three inches

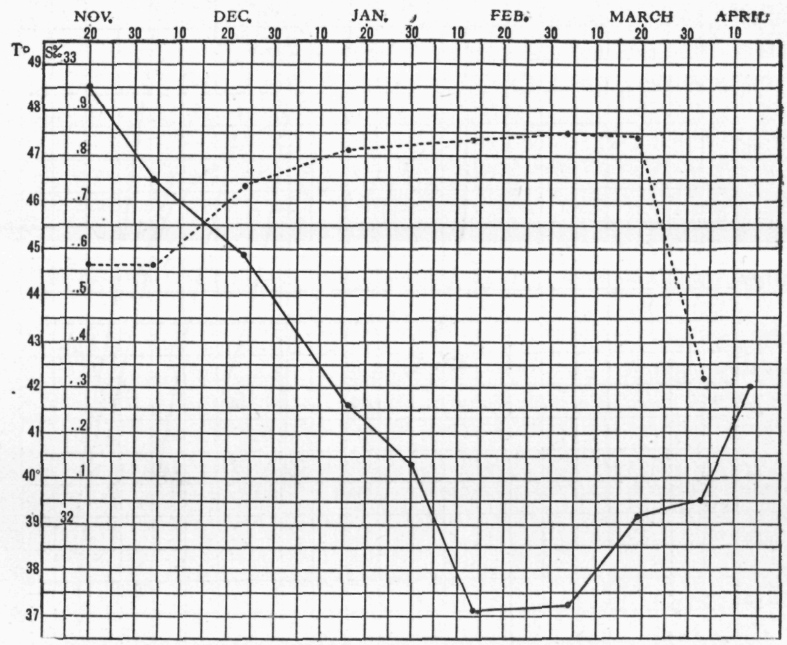


Fig. 3.— Surface Temperature ———, off Cape Ann and Gloucester, November 20 to April 13; and surface salinity . . . ., off Cape Ann, November 20 to April 3.

on the previous day. Owing to the comparatively fresh surface, the water was now temporarily in stable equilibrium, in spite of the fact that it was coldest at the surface, the density being 25.77 at the surface, 25.98 at 19 fathoms. After completing the station we ran through Squam River to Ipswich Bay, where, sheltered from the wind, we made a station for the sake of comparison with the waters on the south side of Cape Ann. The surface water proved to be considerably colder here, 40.3°, with 40.7° at 8 fathoms. But at 18 fathoms the temperature was 41.7°, practically the same as it was at the same depth on the Massachusetts Bay side of Cape Ann. The surface salinity, likewise, was much lower on the surface in Ipswich Bay, 32.20‰; but at 19 fathoms it was slightly higher, 32.9‰ as against 32.82‰. Of course it is impossible to be certain of the reasons for these differences, without any data on conditions in Ipswich Bay during the preceding three months, but the simplest, and probably the correct explanation for its low surface temperature is that the snow-fall in the recent storm was heavier there than over Massachusetts Bay, for melting snow ranks second only to melting ice as a cooling agent for surface waters; while the low surface salinity is no doubt an indication of the fresh water from the Ipswich and Merrimac rivers which empty near by.

The minimum temperatures for the winter were reached about the middle of February. Thus on February 13, at a station some five miles southeast of Cape Ann, the surface temperature was only 37.1°, with 37° at 25 fathoms, and 37.6° on the bottom in 45 fathoms: thus reflecting the wintry weather which had at last set in after an unusually mild season. At this station the air temperature was 20°, with a high northwest wind, and during the preceding night the thermometer had fallen to −2°. Salinity differed little from what was found at the last station but one in Massachusetts Bay, being 32.83‰ on the surface and at 25 fathoms, 32.84‰ on the bottom. And the fact that the difference between surface and bottom salinity was so slight is as good evidence as are the inverted temperatures, of active vertical circulation, for there had been two falls of snow since the last visit. And as a matter of fact, the water was in unstable equilibrium, the density being 26.19 at the surface, 26.18 on the bottom (pressure disregarded).

By March 4, when we made the next station some five miles east of the usual location, choosing this point because of the slightly greater depth (45 fathoms), both the weather and the water showed signs of spring warming, the surface temperature having risen by .1°, to 37.2°: at 25 fathoms by .5° to 37.5°, and at 45 fathoms by .9° to 38.5°, the air temperature being 32° with light snow falling. At the same time the water samples showed a decided rise in salinity, the surface being 32.85‰, with 32.96‰ at 25 fathoms, and 33.04‰ at the bottom, the latter a much higher salinity than any which we had previously obtained in Massachusetts Bay. In summer, water as salt as this was first found on the bottom some 35 miles east of the mouth of the Bay. The water was now once more in stable equilibrium (density at surface 26.18, at 45 fathoms, disregarding pressure, 26.30); and its stability might be expected to increase as warming of the surface progresses. Thus the process of winter cooling on the surface, with its consequent inversion of density, had come to an end by the beginning of March at the mouth of Massachusetts Bay.

It was a month before the BLUE WING resumed work; but in the meantime Mr. Welsh had commenced his haddock investigation at Gloucester, and on March 19, he occupied two hydrographic stations at very nearly the same locality as our last station, nine miles southeast from Cape Ann, in 45 and 65 fathoms of water. Mr. Welsh's temperature records show a decided rise on the surface, which had warmed to 39°, with the same temperature at 48 fathoms, the latter being unchanged from the last BLUE WING station. At 65 fathoms the temperature was 38.8°, 1.5° colder than I found it at that depth, and, indeed, generally over the bottom of the western half of the deep basin, in summer. The salinity proved to be 33.17‰ at the bottom, at both stations, a decided rise from two weeks previous; and interesting further because the deeper sample (65 fathoms) came from a circumscribed basin, the shallower one from its rim, thus repeating our experience in this same basin in July (Bull. M. C. Z., 1912, **58**, p. 65), when the bottom salinity was found to be the same as the salinity on the bottom over the enclosing shoal. At the surface, over the deep basin, the salinity was 32.84‰, precisely the same as it was when the BLUE WING last visited this region: but over the rim it was decidedly salter (33.01‰): probably an evidence of vertical stirring by tidal currents.

On April 3, the BLUE WING occupied a station some five miles southeast of Gloucester. By this time the surface temperature had risen to 39.3°, being practically uniform down to 30 fathoms, and slightly colder, 39.1° at the bottom, in 42 fathoms, the latter reading showing a rise of only .1° from Mr. Welsh's records two weeks before. And the fact that the temperature of the entire column of water had risen slightly is good proof that tidal currents still caused active vertical circulation, in spite of the increasing vertical stability of the water, the conductivity of sea water being too slight for us to suppose that the warmth of the surface had thus been propagated downward. But though the temperature had followed the expected course, the salinity had undergone a very striking change, for while the bottom and intermediate waters continued to show the progressive increase in saltness which had been taking place during the winter, with the very high readings of 33.12‰ on the bottom and 33.03‰ at 25 fathoms, (fig. 2) the surface salinity had fallen from 32.8‰ to 32.3‰ (fig. 3), which is, of course, good evidence that the influx of river water was beginning to flood the surface. And from the standpoint of dynamics this phenomenon is important, because it suddenly lowers the surface density to a marked degree, with consequent increase in vertical stability. Unfortunately only two more stations were occupied in Massachusetts Bay during the spring; but though both were so close to land that they are not strictly comparable with the data acquired further offshore, they show the advance of the general vernal hydrographic change. Thus on April 14, two miles off the mouth of Gloucester Harbor, the surface temperature had risen to 42°, the 25 fathom reading (bottom) being about the same as at the last station (39.4°). And on May 17, the surface water off Magnolia had warmed up to 47.3°, with 45.1° at 9 fathoms. Salinity meantime had fallen to 31.11‰ on the surface, 32.79‰ at 25 fathoms, on April 14: and it continued to fall, reaching 30.95‰ on the surface, 31.25‰ at 10 fathoms on May 17.

Temperature and salinity north of Cape Ann, March and April.

Mr. Welsh's oceanographic data for these months were taken chiefly in three general regions, *i. e.*, the neighborhood of the Isles of Shoals, near Boon Island, and a few miles off the coast between Cape Porpoise and Wood Island (Plate); and though his stations were chosen primarily for their fisheries interest, they proved to be well located for oceanographic purposes. The first two grounds together cover an area of some fifteen miles from northeast to southwest; but there is no important separation between the two, so far as temperatures are concerned. The salinity of the area, however, is less uniform, because subject to the immediate influence of the Piscataqua River. The Cape Porpoise ground, though nearer in actual distance to the Boon Island stations than the latter are to the Isles of Shoals, was very distinct hydrographically.

The Boon Island ground was visited on March 29, April 4, April 5, and May 14, while from April 22 to May 16 frequent observations were taken close to the Isles of Shoals and between them and the coast. On the first date the water was coldest at the surface, the readings being 38.3° at the surface, 38.7° at 17 fathoms, and 38.9° at 35 fathoms; *i. e.*, winter conditions still prevailed (fig. 4), although the surface had begun to grow warmer in Massachusetts Bay by this date (p. 391). At Boon Island, however, it was not until April 5 that the first sign of spring warming was evidenced by the equalization of temperature (39°) from surface to bottom. From this time onward, near the Isles of Shoals, there was a steady rise of temperature, which made itself felt first and most strongly at the surface, and later, to a much smaller degree, at the bottom (fig. 4). But the surface warming was very irregular, and often interrupted, and even temporarily reversed, by climatic conditions. During the winter

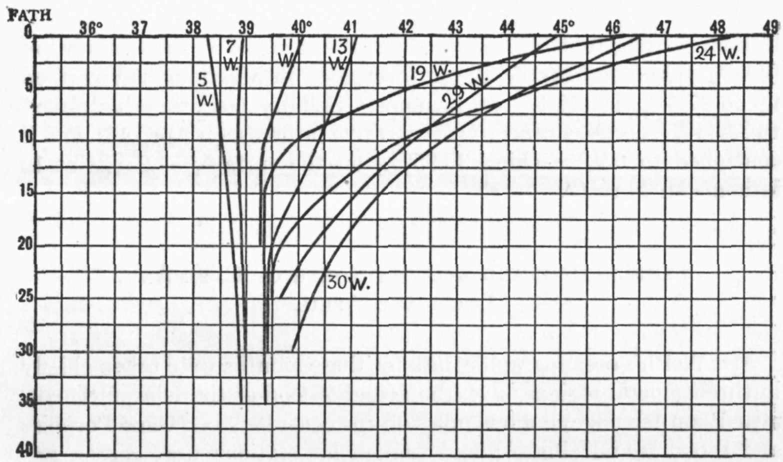


Fig. 4.— Temperature sections off Boon Island, March 29 (Station 5 W. W. Welsh); April 4 (Station 7 W. W. Welsh); and near the Isles of Shoals, April 13 (Station 11 W. W. Welsh); April 16 (Station 13 W. W. Welsh); April 26 (Station 19 W. W. Welsh); May 5 (Station 24 W. W. Welsh), May 13 (Station 29 W. W. Welsh) and May 14 (Station 30 W. W. Welsh).

when the column of water is of nearly uniform temperature from the surface downward, offshore winds have little effect on surface temperature, because although the surface water moves offshore, yet the waters which well up from below to take its place are of nearly the same temperature as those which they displace. But as soon as the surface is appreciably warmer than the underlying waters, any upwelling, or vertical mixing, is at once evidenced by a decided drop in surface temperature. Along the coast, upwelling is usually the result of northwest winds; but any gale causes more or less vertical mixing of the upper few fathoms by wave action. How active these disturbing factors were off the Isles of Shoals during the spring of 1913 is illustrated by the diagram of surface temperature (fig. 7). After a steady rise from 38.3° to 41°, a northwesterly gale cooled the surface to 40.3° by upwelling. It then warmed once more, under the influence of unseasonably warm weather, to 46.3° on April 26, when a northeasterly gale and rain, followed by high northwest wind, once more lowered the surface temperature to 44°. This was followed by another rise to 49° when a third northwesterly gale blew for several days, with the result that the surface was cooled to about 45°. When the wind changed to the south, the surface once more grew warmer, its temperature being 46.6° on May 14, when the latest observation was made. These surface irregularities are traceable down to about 5 fathoms (fig. 4) below which depth the progressive warming was comparatively regular. Until April 19 warming was limited to the upper 15 fathoms, below which depth the temperature was about 39.3° to the bottom (the deepest observations were at 30 fathoms); but by May 5 this temperature was found only below 20 fathoms, and from that time onward there was a slight rise in the bottom temperature to 39.9° on the 14th (latest station). This is about 2° colder than it was at this depth (30 fathoms) in this same region in the summer of 1912, but only about 1° lower than the water in the deeper parts of the basin between Jeffrey's Ledge and the mainland at that time.

The Boon Island stations (fig. 5) show that salinity reaches its maximum here in early spring just as it does southeast of Cape Ann. Unfortunately the observations do not show exactly what the maximum was for there is a gap in the data at the critical time from April 5 to April 13: but the fact that the salinity was 32.45‰ on the surface, 32.99‰ at 40 fathoms, March 29, with a mean of about 32.76‰ for the entire column of water, rising to 32.74‰ on the surface, 33.04‰ at 32 fathoms, on April 5, suggests that the maximum was about the same here as it is on the other side of Cape Ann. But whether or not this is the case, it is certain that in 1913 the maximum salinity was not reached off Boon Island until at least a week after surface freshening had begun to show itself in Massachusetts Bay. The numerous observations near the Isles of Shoals show a marked decline in salinity in that region from the middle of April till the middle of May, *i. e.*, from 31.43‰ to 29.54‰ followed by an irregular rise which was still in progress when the work came to an end. And a glance at the salinity curve for the surface (fig. 7) shows that it agrees closely with the temperature curve, periods of temporary cooling corresponding to a temporarily heightened salinity, surface salinity being raised as surface temperature is lowered by the upwelling of cold saline waters consequent on the several northwest gales already mentioned, or by the mixing of the upper few fathoms by wave action. An excellent example of the effect of the latter is afforded by two successive stations, April 26 and 29, a few miles outside the Isles of Shoals. On the former day the surface salinity was 30.03‰, when a northeast gale and heavy sea mixed the water sufficiently to raise the surface to 31.5‰, and to lower the 15 fathom salinity from 32.45‰ to 32.3‰, the bottom salinity remaining the same (fig. 5), the fact that the average salinity of the entire column of water had

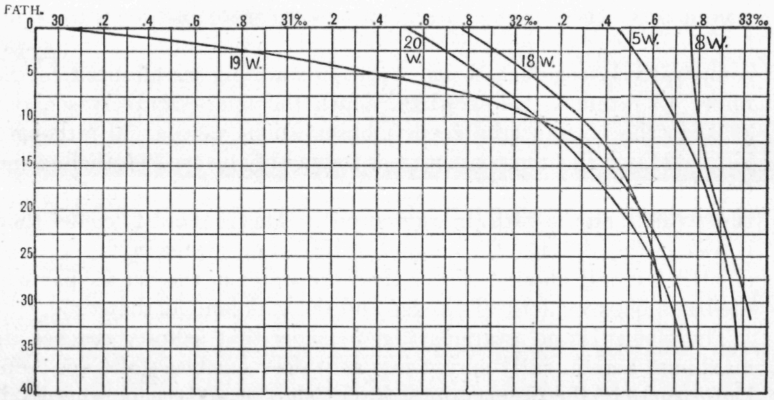


Fig. 5.— Salinity sections near Boon Island March 29 (Station 5 W. W. Welsh); April 5 (Station 8 W. W. Welsh); and April 25 (Station 18 W. W. Welsh); and east of the Isles of Shoals, April 26 (Station 19 W. W. Welsh) and April 29 (Station 20 W. W. Welsh).

risen only from 32‰ on the 26th to 32.15‰ on the 29th showing that there had been very little influx of salt water from off shore.

The effect of a northwest wind, with consequent upwelling of bottom water, is illustrated by the sections for April 16 and 22 (Stations 13 and 16 Welsh, fig. 6), which show how the salinity of the entire column of water was raised by this process (mean salinity, Station 13 Welsh, 31.7‰: Station 16 Welsh, 32.0‰), though most markedly near the surface. And the fact that the rise is evident at the bottom (25 fathoms) shows that the influence of the wind causes an inshore movement of bottom water from greater depths further to the east, while the next salinity section (Station 17 Welsh, fig. 6) shows that this movement continued at least a day after the surface freshening once more reestablished itself. The minimum surface salinity was reached about May 5, near the Isles of Shoals, from which time on a rise is to be expected to the summer condition.

There was no separation between the waters just outside the Isles of Shoals, and the channel between them and the mainland so far as surface salinity is concerned. But the salinity sections (fig. 5, 6) show that the progressive freshening was much more strictly a surface phenomenon outside the islands than it was nearer the mainland, as might be expected from the fact that the inshore stations lie near the mouth of the Piscataqua River. After about May 5, when the water was freshest, there followed not only a rise in surface salinity, but a progressive though slight increase in mean salinity of the whole

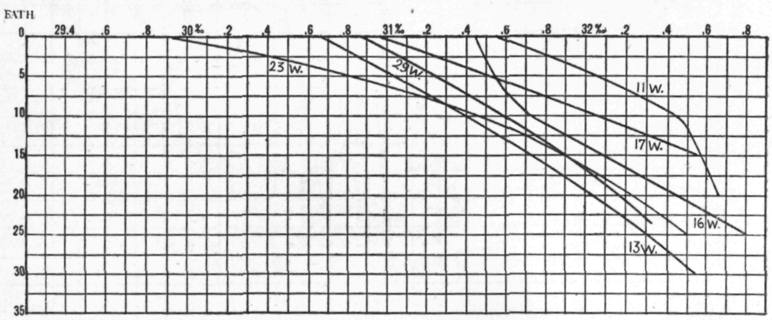


FIG. 6.— Salinity sections between the Isles of Shoals and the mainland, April 13 (Station 11 W. W. Welsh); April 16 (Station 13 W. W. Welsh); April 22 (Station 16 W. W. Welsh); April 23 (Station 17 W. W. Welsh); May 3 (Station 23 W. W. Welsh) and May 13 (Station 29 W. W. Welsh).

column (Station 25 Welsh, mean 31.1‰; Station 26 Welsh, mean about 31.2‰; Station 27 Welsh, mean about 31.4‰, Station 28 Welsh, mean about 31.4‰; Station 29 Welsh, mean 31.5‰; Station 31 Welsh, mean 32.7‰, the depths varying from 20–26 fathoms). And though the rise on the surface was once interrupted by heavy rain (Station 30 Welsh, May 16) the mean of 29 fathoms, 31.6‰, was practically unchanged from the last station. The weather was stormy during the period May 5–15, with a northwest gale on the 10th and 11th and 12th (*i. e.*, Stations 27 and 28 Welsh), which may partly explain the rising salinity. But the fact that it continued to grow salter after this, except as just noted, shows that the spring influx of river water had passed its maximum, and was gradually being absorbed by the general circulation of the Gulf.

The one station (18) made off Boon Island near the end of April (April 25, fig. 5) is especially interesting because the water proved to be considerably salter (surface 31.76‰, 15 fathoms, 32.46‰; 30 fathoms, 32.65‰) at the surface, and down to about 15 fathoms than the Isles of Shoals stations the day before or the day after, though below 15 fathoms its curve agrees almost exactly with the latter.

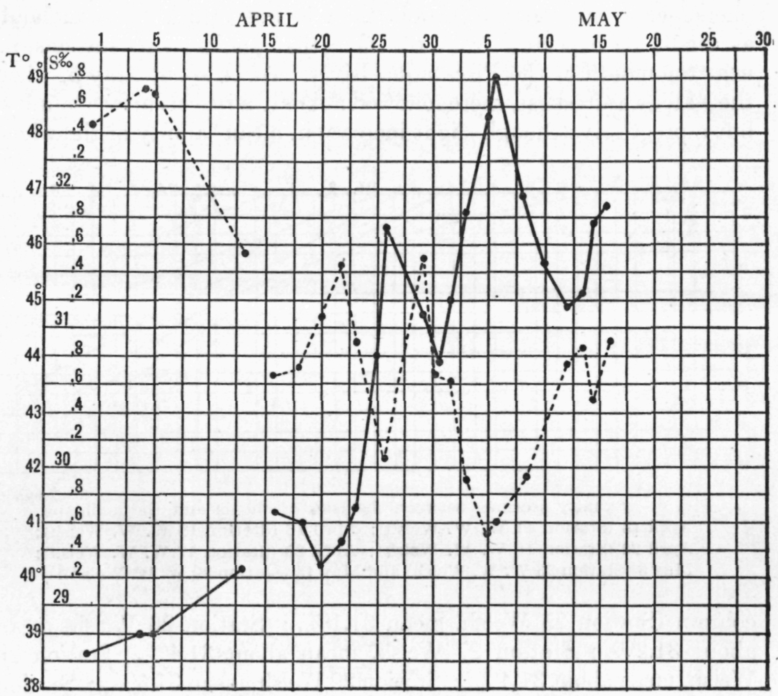


FIG. 7.— Surface temperature ——— and surface salinity, - - - - - - - -, near Boon Island, April 1–14, and near the Isles of Shoals, April 16–May 16

And inasmuch as there is no reason to assume any upwelling, the weather having been calm for the two preceding days, it is safe to conclude that the surface water was normally salter a few miles north of Boon Island than it was near the Isles of Shoals.

The Wood Island ground was visited April 9, 10, and 14. On the 9th, the temperature was practically equalized at 39° from surface to bottom, just as it had been off Boon Island four days earlier; and by the 14th, the surface had warmed up to 40.2°, though the bottom reading was still 39°. But although the water here agreed with the Boon Island region so closely in temperature, it differed widely in salinity, for on the 9th it was only 29.51‰ on the surface, with 30.79‰ at 9 fathoms, and 31.‰ at 18 fathoms: and the next day, a few miles closer to shore, the surface salinity was only 26.74‰, though the deeper readings were rather higher than before, *i. e.*, 31.8‰ at 11 fathoms and 32.52‰ at 29 fathoms. On the 14th, on the contrary, some five miles further south, off Cape Porpoise, the surface salinity was 29.13‰, with 31.92‰ at 10 fathoms, and 32.47‰ at 21 fathoms, these differences between stations so close together being probably the result of the tidal currents which were encountered in this region in the summer of 1912 (Bull. M. C. Z., 1914, **58**, p. 87).

Temperature and salinity on Georges Bank.

The data obtained from Georges Bank during the past season, is more important than its scantiness would suggest, because our knowledge of oceanographic conditions in that interesting region is extremely fragmentary. Mr. Clapp's water samples showed that in February the surface salinity was 33.04‰ on the southeastern side of the Bank (41° 10′ N, 66° 30′ W) which proves that it was not washed by the Gulf Stream, at least at that time. In the middle of April (Mr. Douthart's records, p. 419), the surface temperature, on the northern side of the Bank, was 44°; temperature at 25 fathoms (bottom), 43°; with 41.5° at 70 fathoms on its northern slope. The surface salinities varied from 33.21‰ to 33.38‰ at stations within a few miles of one another, the differences probably being due to more or less active vertical mixing which must result from the very violent tidal currents. No water samples were taken below the surface. The second set of records, April 26 to 27, is more instructive, because a series of water samples was taken from Boston Light ship to the northwestern edge of the Bank, as well as a bottom sample, and surface and bottom temperatures, on the latter. These showed an increase in salinity passing offshore, from 31.5‰ near Boston Light ship 32.29‰ off Cape Cod, and 33.13‰ half way from the latter to Georges Bank, to a maximum of 33.25‰ at Lat. 41° 34′ N, Long. 68° 45′ W, over the northwest slope of the Bank. But on its northwest part, the surface salinity was only 33.16‰, with 33.21‰ on the bottom in 35 fathoms. The surface temperature on the Bank was 46°, 2°

higher than on the last visit, the 35 fathom reading being 44°. The general increase in surface salinity from west to east, of course, was to have been expected from the previous records on the Bank, as well as from its geographic location, and from the fact that the shore water was at this time at its freshest (p. 393). But that the salinity was higher just northwest of the Bank than on the Bank itself is less easily explained. A bottom sample from the former would have shown whether the higher surface salinity was the result of the vertical mixing of a column of water nearly twice as deep, and consequently with a higher mean salinity, than the water over the Bank; and inasmuch as the tidal currents in this region are proverbially violent, it is likely that this is the explanation. But it is also possible that there was an indraught of salt water from the south, via the broad channel between Georges Bank and Nantucket shoals. Without more extensive data, it is impossible to settle the question.

General discussion.

The temperature and salinity records presented in the preceding pages, when added to the 1912 summer records, allow us to reconstruct the seasonal changes which the waters of the western side of the Gulf underwent from the summer of 1912 to the early spring of 1913. Summer conditions were marked by high surface temperature, with a rapid decline, and considerable increase in salinity, with depth. But even as early as the end of August the surface had cooled appreciably, while the bottom temperature, in 30–40 fathoms, had risen. And this process of equalization of temperature and salinity, progressed until, by the end of November, both these factors were nearly uniform from surface to bottom. Meanwhile the mean temperature of the whole column of water had fallen about 1°, while its mean salinity had risen appreciably. During the winter and early spring there was an irregular rise in salinity at all depths: the bottom water being usually saltest, in spite of the active vertical circulation. And the fact that the bottom salinity continued to rise after the surface salinity commenced to diminish, is good evidence that the rise is in general the result of an inward movement of the salt bottom water. It is evident that the thorough mixing of the water which had taken place by November must be caused by vertical circulation, which is no doubt the result of the rather strong tidal currents, growing more and more active as it is less and less strongly opposed by the vertical stability of the water. For the latter is diminished by surface cooling as the season advances, while it is, of course, progressively lessened as the column of water becomes more and more uniform in temperature and salinity, until, by the end of November, it no longer opposes any barrier to vertical currents.

After the water is practically uniform from top to bottom, a new cause for vertical currents is introduced, namely, the reversal of density consequent on further cooling at the surface. And after the beginning of December surface chilling was rapid, owing to the low temperature of the air, and to occasional falls of snow. As the winter progressed the surface temperature fell so fast that it was constantly coldest at that level, so that the water was in unstable equilibrium, aiding active vertical circulation which kept it thoroughly mixed until early March, when the first sign of spring was evidenced by a rise in surface temperature. The minimum temperature for the year was reached about the middle of February (surface 37.1°, 45 fathoms 37.6°), and though data from north of Cape Ann is lacking for this month, it is probable that it was about equally cold over the whole region studied. By the middle of March the surface was once more as warm as the bottom in Massachusetts Bay, and vertical stability thus reestablished, for the surface was rather less salt than the deeper layers. But north of Cape Ann, *i. e.*, near Boon Island and Cape Porpoise, surface warming was not apparent until about two weeks later. Up to this time dynamic overturning, together with the strong tidal currents, wave action, and the frequent upwelling of bottom water near shore, must all be active factors in reducing the inequalities of temperature and salinity over the Gulf as a whole; while there is very little influx of shore water to hinder the process. But the sudden flooding of the surface with river water acts as an effective check to vertical circulation by lowering the surface density to such a degree that the water shortly assumes a state of pronounced vertical stability, constantly increased by the progressive warming at the surface, a condition which characterizes it throughout the summer. The immediate result of this change is that surface warming goes forward more and more rapidly, while the bottom temperature, in 30–40 fathoms, rises so slowly that the difference between April and July at that level is only about 1°. And vertical movements are so much retarded that the surface freshening persists near the coast as late as August, although the river floods which cause it are at their maximum in April and May.

The fact that the spring freshening was felt first near Cape Ann and near Cape Porpoise is important as showing that there is a southwesterly long-shore movement of the river water at this season, its chief sources on this part of the coast being the Merrimac, the Kennebec, and possibly the Penobscot. And this agrees with our summer data (*Loc. cit.*, p. 91), as well as with the common report of a "spring current" flowing across the mouth of Casco Bay from northeast to southwest. The Merrimac water evidently flows around Cape Ann; but that it hardly enters Massachusetts Bay, is shown by the comparatively high salinities encountered by Mr. Douthart (p. 419), while summer salinities suggest that it must swing eastward off Cape Ann.

It is not known of course, how closely the changes outlined above are reproduced in other years; but to judge from the climate of the neighboring land mass, there is every reason to assume that they represent the normal cycle, though no doubt there are slight differences in salinity and temperature from year to year.

The Georges Bank records show that the water was considerably warmer there in April than it was close to the western coast of the Gulf at the same season; and salter than the latter is at any season. Furthermore the Bank water showed no sign of the spring freshening so evident near shore.

Our winter records do not afford any evidence that the low temperatures of winter are caused by an influx of northern water into our Gulf. On the contrary, the cooling is no more rapid, nor extreme, than can be accounted for by the winter climate of the neighboring land mass. And the data show clearly that the surface chilling depends closely on air temperature, a conclusion which is equally pertinent to the waters of Georges Bank in spring. But this does not prove that St. Lawrence water never affects the Gulf, for this source of supply may be expected to exert its greatest influence in autumn, as shown by Dickson's charts of salinities off Nova Scotia.

The salinities on Georges Bank in April are so low as to forbid the idea that the water there is chiefly Atlantic bottom water, though of course there may be some upward movement over the continental slope: and this is even more true of the Gulf itself, for nowhere does the water of the latter, at any depth, or at any season, approach the high salinity (34.9) of the abyssal water of the North Atlantic, so far as we know. The Gulf Stream certainly exerts little influence on the Gulf of Maine in winter; but plankton records show that there are irregular penetrations of its surface layers in summer.

Plankton notes.

The following general notes on the plankton may be of value, pending the appearance of the special reports on the more important groups of pelagic organisms collected during the winter.

The plankton which occupied the waters of Massachusetts Bay and the coast region between Cape Ann and Cape Elizabeth in August, 1912, consisted chiefly of copepods (*Loc. cit.*, p. 98), the most abundant species at the offshore stations being *Calanus finmarchicus,* with smaller numbers of *Pseudocalanus elongatus, Centropages typicus,* and *Metridia lucens; Anomalocera patersoni,* so conspicuous by its brilliant blue color, was often common on the surface, while the large boreal copepod *Euchaeta norvegica* occurred sparingly, though more or less regularly, in the hauls from intermediate depths. In addition to these copepods, the amphipod *Euthemisto compressa,* the schizopod *Meganyctiphanes norvegica,* the chaetognath *Sagitta elegans,* and the coelenterates *Staurophora mertensii,* Aurelia, Cyanea, *Pleurobrachia pileus, Bolinopsis infundibulum,* and Beroe, were regularly represented in the hauls. Other characteristic forms, less often taken, were the pteropods *Clione limacina* and *Limacina balea; Tomopteris helgolandica,* and *Sagitta serratodentata.* Quantitatively the macroplankton was very rich, the microplankton, on the other hand, was decidedly scanty, consisting chiefly of the peridinian, *Ceratium tripos,* with copepod eggs and nauplii, and very few diatoms.

When we resumed work at the end of November, the macroplankton was very much the same qualitatively as it had been in summer, *Calanus finmarchicus* being much the most numerous organism, with a few other copepods, *e. g., Metridia lucens, Centropages typicus,* and *Pseudocalanus elongatus,* and notably *Euchaeta norvegica* (10–0 fathoms.) But Anomalocera, so numerous off Cape Ann in August, was noticeably absent, nor did we meet it at any time during the winter or early spring. Next in numerical importance were the chaetognaths, represented chiefly by *Sagitta elegans,* with a few *S. serratodentata,* the relative quantity in the haul with the 4 ft. net being copepods, 75 cc., Sagittae 15 cc. Considerable numbers of the amphipod *Euthemisto compressa,* a few pteropods, *Limacina balea,* many *Pleurobrachia pileus,* and fragments of Beroe, with a few crab and other decapod larvae were likewise found in the tow. The haul with the no. 20 silk net at the surface revealed a very scanty microplankton of much the same type as in summer, chiefly *Ceratium tripos,* with an occasional diatom (Rhizosolenia), and a good many copepod eggs and nauplii. Schools of pollack (*Pollachius virens*) were spawning near by, and consequently it is rather surprising that our hauls contained very few of their eggs and only two pollack fry. And throughout the spawning period, which lasted until January, the eggs were only very sparsely represented in the plankton catches; but with the haddock in spring the case was quite the contrary.

We found much the same type of plankton in early December, and though the catch, taken at its face value, would suggest a quantitative increase; the hauls are not comparable with one another though of the same length, because all were horizontal, while the speed of the vessel varied more or less. Furthermore, one might, another might not, pass through the zone of maximum richness; so that all they can be expected to yield in the way of quantitative results is whether the plankton was scanty, notably rich, or intermediate. The greater mass of the haul still consisted of *Calanus finmarchicus*, with a few *Euchaeta norvegica*. Sagittae were about one half as plenty in bulk as the copepods, chiefly *S. elegans*, with a few *S. serratodentata;* and as usual, Euthemisto was a conspicuous member of the plankton; the only coelenterates were a few *Pleurobrachia pileus*. The microplankton had not changed appreciably since November, being still very scanty, chiefly *Ceratium tripos*, with an occasional *C. fusus* and Peridinium, and very few diatoms, chiefly Chaetoceras.

As the winter advanced, and the water grew colder and colder, there was little noticeable change in the general type of the plankton. Thus on January 16th (St. 10,050) the bulk of the haul consisted of *Calanus finmarchicus* as usual, and of Sagittae, chiefly *S. elegans*. But though no Euchaeta were taken, the net yielded four specimens of the large northern copepod *Calanus hyperboreus*, a species not previously taken in the Bay, though we obtained it in other parts of the Gulf in summer (*Loc. cit.*, p. 102). The haul also contained a few *Sagitta serratodentata*, appendicularians (Oikopleura) *Tomopteris helgolandica*, and *Clione limacina,* all of which occurred more or less frequently in summer. Euthemisto, too, was plentiful. Two species of fish eggs were numerous, but no fish fry. The microplankton was still very scanty; but diatoms, chiefly Chaetoceras, with a few Coscinodiscus and *Thalassiothrix nitzschioides* now formed about one half its mass.

At the end of January, the tow in Massachusetts Bay was quantitatively about the same, with the addition of a few specimens of the large copepod Euchaeta; but Sagittae formed fully half its bulk. In Ipswich Bay, however, on the same day (St. 10,052) there were only twenty specimens of Sagitta in the haul, while we encountered a swarm of copepods, almost pure *Calanus finmarchicus,* with one *C. hyperboreus* and one *Euchaeta norvegica,* no less than 225 cc. being taken in the net. And this tow was decidedly richer, quantitatively, than any we had made since summer. Qualitatively it was extremely monotonous, the only large organisms, besides copepods and Sagittae, being a few Euthemisto, four *Tomopteris helgolandica,* unrecognizable fragments of an agalmid siphonophore, a few fish eggs, and a pycnogonid, the latter, of course, an accidental visitor from the bottom. The microplankton, likewise, was decidedly richer in bulk in Ipswich Bay than on the Massachusetts Bay side of Cape Ann, with fully as many diatoms (Chaetoceras) as Ceratium.

At our coldest Station (10,053, February 13th) Sagittae had usurped the chief importance from the copepods, there being 125 cc. of the former, and only about 50 cc. of the latter. The most abundant species was *S. elegans*; while the copepod swarm consisted chiefly of *Calanus finmarchicus,* as usual, with an occasional *Euchaeta norvegica.* The tow likewise yielded a considerable number of the boreal pteropod *Limacina balea,* besides appendicularians (*Oikopleura dioica*), *Tomopteris helgolandica,* and fragments of Beroe.

Up to this time the plankton had been decidedly uniform, the most important change being an irregular but unmistakable increase in the relative number of Sagittae. But when the water began to grow warmer, the zoöplankton decreased noticeably in quantity. Thus on March 4th, there were only 15 cc. of copepods (chiefly *Calanus finmarchicus*) in the haul, and only twelve specimens of Sagittae (*S. elegans*), nine Tomopteris, a few Euthemisto, and very little else except a considerable number of haddock eggs. On the other hand, the no. 20 net haul showed that there had been an appreciable increase of diatoms, chiefly Chaetoceras, with a few Coscinodiscus, and Thalassiothrix, these forms combined far outnumbering the few Ceratium (*C. tripos* and *C. fusus*). Later stations showed that this haul foreshadowed the vernal diatom swarm, a phenomenon now well known for the North Sea and for other parts of the eastern side of the north Atlantic. Thus on April 3d (Station 10,055) the water was visibly cloudy, and the nets were soon clogged with a slimy brown mass of diatoms. However, it was not a Chaetoceras plankton, as might have been expected from our earlier work; but was almost exclusively composed of two species of Thalassiosira, *T. gravida,* and *T. nordenskioldi,* with occasional specimens of *Chaetoceras decipiens, C. densum, C. atlanticum, C. contortum, Biddulphia aurita,* *Coscinosira polychorda, Thalassiothrix nitzschioides,* and *Rhizosolenia semispina.*

It is interesting to note that the diatom swarm was not uniformly distributed. On the contrary, while the net was towing near the surface, we could see it pass through clear bands, as well as through bands of diatoms, which gave it a brown color. This observation shows, too, how erroneous an idea of the quantitative richness of diatoms in the waters of Massachusetts Bay would have been afforded by a single vertical haul with a quantitative net.

At this same station the zoöplankton was as poor as the diatom plankton was rich, the only large organisms yielded by the nets being a few dozen copepods, one Euthemisto, two *Clione limacina* and a few unrecognizable bells of some agalmid siphonophore, besides a few barnacle (Balanus) nauplii, and, to my surprise, a considerable number of tests of Foraminifera. This was the first haul in which there were no Sagittae.

The diatom swarm continued at its height during the first half of April, hauls on the 14th (St. 10,056) yielding the same rich Thalassiosira plankton just described, and the zoöplankton still proved to be very scanty, the catch being only a few Calanus, one Tomopteris, one *Sagitta elegans*, one fragmentary Beroe, and one young Staurophora. But there were considerably more Balanus nauplii than before.

No plankton hauls were made north of Cape Ann, except the one station in Ipswich Bay noted above, previous to March 29th. But from that date onward, Mr. Welsh's stations show that the Thalassiosira swarm filled the coast water very generally from Cape Ann to Cape Porpoise during the whole of April, often being so dense as to discolor the water. Thus on May 2, he writes "the water yesterday and today full of green slime," and on the 3d, "the water is full of the greenish brown algae." Microscopic examination of his catches showed that the plankton was extremely uniform qualitatively, consisting almost altogether of Thalassiosira, with an occasional specimen of the other species noted for Stations 10,055 and 10,056 (p. 405). The catches were very clean up to about the first of May, but about that date, they began to contain noticeable amounts of diatom debris, and as the season progressed the relative amounts of dead specimens, and variously fragmented remnants, grew progressively greater until by the 25th of the month there were very few living diatoms, contrasted with large amounts of debris, among which the various genera which formed the swarm (particularly Chaetoceras and Thalassiosira) could be distinguished. In the latest hauls there were hardly any living specimens, though the nets yielded masses of fragments in various stages of decay.

During all this time the microplankton was extremely uniform qualitatively over all the area studied; but instead of being evenly distributed, it was streaky; and occasionally the hauls missed these streaks, and yielded hardly anything.

Mr. Welsh's hauls could not be expected to give as satisfactory an idea of the macro- as of the microplankton, because all of them were made on the surface in the day time, and previous experience has shown that it is only occasionally that daylight hauls at that level yield a representative sample. But they show that the larger organisms were usually scanty in April and May, just as they were in Massachusetts Bay early in April, and consisted of the same components, except that Euthemisto was lacking. However, off Wood Island, April 10th, he made a rich haul of Calanus, with many haddock and sand-dab eggs, Clione, Euthemisto, and Sagittae. And again, off the Isles of Shoals, on April 26th, the haul contained hardly any diatoms, but instead, great numbers of copepods, *Calanus finmarchicus* and Eurytemora in roughly equal proportions, though in each of these instances a haul the next day at almost the same locality yielded swarms of diatoms, chiefly Thalassiosira, with almost no macroplankton except fish eggs, and larval Balanus. And on May 14–16, when diatoms were diminishing, there was a decided increase in small copepods (chiefly Calanus) which probably foreshadows the time when the latter once more form the bulk of the plankton. This apparently takes place by the middle of May in Massachusetts Bay, for on the 3rd, Mr. Welsh found the water in Gloucester Harbor "reddened for areas of about a square yard several yards apart" with what proved to be swarms of copepod nauplii and young copepods. And on the 17th, hauls off Magnolia, Mass., yielded great numbers of small copepods, chiefly *Calanus finmarchicus*, with a few Eurytemora, besides many crab zoaeae, but no large organisms, and almost no diatoms.

The haul in Gloucester Harbor, just mentioned, was also notable for the number of Medusae which it contained, the list including swarms of *Sarsia tubulosa*, a few *Bougainvillea superciliaris*, *Rhathkea blumenbachi*, in both budding and sexual phases, half-grown *Tiaropsis diademata*, many very young stages of *Staurophora mertensii*, Obelia, young Aequorea, a very young Cyanea, and an agalmid bell. The fact that the Tiaropsis, Staurophora, Aequorea, and Cyanea were all very young, suggests that they must have passed through the fixed stage in the near neighborhood, as the Sarsia and Bougainvillea undoubtedly did. And in the case of the Staurophora this is especially important, because this Medusa has often been classed as an Arctic form. As a matter of fact, however, the available data show that it is a constant inhabitant of the Gulf of Maine. On May 17th, several specimens about two inches in diameter were taken; and I have seen it adult in Massachusetts Bay at the beginning of June.

Other animals, the young of which occurred in notable numbers were crabs (Cancer) as noted above, and especially the common barnacle (Balanus). In the case of the latter, the whole reproductive period was covered by the hauls near Boon Island and the Isles of Shoals, for its eggs were taken in large numbers on March 29th and April 4th off Boon Island, the nauplii at the same locality April 5th. By the 9th, the nets yielded large numbers of the "Cypris" stage with a few nauplii, and by the 19th, Cyprids only were taken. These reached their maximum abundance April 25th to 30th, when they formed the bulk of the macroplankton, from which time onward they diminished, though they were constantly present in small numbers until the middle of May, when they had practically disappeared.

The most interesting feature of the spring macroplankton, from the fisheries standpoint, was the sudden appearance of great swarms of the schizopod *Thysanoessa raschii.* A few specimens were taken in the nets on April 22, and on the 23d, when none chanced to be caught Mr. Welsh noted the "pollack schools feeding on shrimps which were also in dense schools," near the Isles of Shoals. On the 25th many were taken off Boon Island, and Mr. Welsh noted "the feed (shrimps) breaking water trying to get away from the pollack which are after them. The feed occurs in dense swarms, apparently 6 inches to a foot below the surface." Evidently they were an important food for surface-schooling fish. Early in May they were no longer in schools though from this time on occasional specimens were taken; and they again appeared in considerable numbers in the hauls near the Isles of Shoals on the 12th and 13th.

Mr. Welsh's work covered the spawning period of the haddock, and several of the hauls yielded great numbers of eggs, notably on April 23 (Station 17), May 6 (Station 25).

List of copepods. By *C. O. Esterly.*

The numbers indicate proportional, not absolute, numbers of the various species in each haul, except those in italics, which are the actual numbers of individuals. The symbol 00 indicates that the copepod component of the haul was composed almost exclusively of the species in question. The list includes the material taken at the Blue Wing stations and on Georges Banks.

Stations	Calanus finmarchicus	Calanus hyperboreus	Pseudocalanus elongatus	Euchaeta norvegica	Metridia lucens	Temora longicornis	Centropages typicus	Tortanus discaudatus
10,047	50		1		1		10	
10,048	20						2	1
10,049	40			*3*	10			
10,050	00	*6*						
10,051	00	*1*		*1*				
10,052	200	*2*	4	*2*				
10,053	200		1		4			1
10,054	80		6					
10,055	15		2					
41°, 37′ N. 67° 18′ W.	125					5		

List of hyperiid amphipods.

The numbers denote the relative abundance of the various species in the Plankton hauls, November, 1912–May, 1913, except those in italics, which give the absolute numbers of individuals in the hauls in question.

Stations	Euthemisto compressa	Euthemisto bispinosa	Hyperoche abyssorum	Hyperia medusarum
10,047	20	12	*1*	
10,048	15	25	*1*	
10,049	15	12		*1*
10,050	30	2	*1*	
10,051	*4*			
10,052	25	3	*1*	
10,053	30	5	*1*	
10,054	20		*2*	
10,055				*1*

No hyperiids were taken in any of the hauls made by Mr. Welsh.

List of euphausiids, identified by *H. J. Hansen.*

The Euphausiacea collected in the Gulf of Maine, during the summer of 1912 and winter of 1912–1913, have been identified by Dr. H. J. Hansen. They belong to six species:— *Meganyctiphanes norvegica* Sars, *Thysanoessa inermis* Kröyer, *Thysanoessa raschii* Sars, *Thysanoessa longicaudata* Kröyer, *Thysanoessa gregaria* G. O. Sars, and *Nematoscelis megalops* G. O. Sars, all so well known that only the geographic aspect of their occurrence need be touched on here. But this is considerable, because, so far as I can learn, only two euphausiids *Thysanoessa inermis,* and *Meganyctiphanes norvegica,* had been recorded from the Gulf previous to the cruise of the GRAMPUS in 1912.[1]

Thysanoessa raschii was not taken during the summer. The occurrence of the other species, for July and August, is shown on the accompanying table.

Stations	Meganyctiphanes norvegica	Thysanoessa inermis	Thysanoessa longicaudata	Thysanoessa gregaria	Nematoscelis megalops
10,002		×			
10,003	×				
10,007	×	×			
10,011		×			
10,019	×	×	×	×	
10,022		×			
10,023		×		×	
10,025	×				
10,026a	×				
10,027	×	×	×	×	
10,028			×		
10,029	×				
10,030		×			
10,031		×			
10,032	×	×	×	×	×
10,035	×	×			
10,036		×	×		
10,038		×			
10,041	×				
10,043	×	×	×	×	
10,049				×	
Eastport	×	×			

Thysanoessa inermis was very generally distributed over the Gulf, both in its central portion (Station 10,027) and near shore both east

[1] M. J. Rathbun. Fauna of New England. 5. List of the Crustacea. Occasional papers, Boston soc. nat. hist., 1905, 7, p. 26.

and west, from Cape Cod to German Bank; the stations of capture being so located that it can not be said to have been absent from any considerable part of the Gulf. And it was even found in water as barren of plankton as the Grand Manan Channel (Station 10,035) and Eastport Harbor (*Loc. cit.*, p. 104). Few animals, except the copepod Calanus, were more consistent in their occurrence than *T. inermis*. It was most abundant north of Cape Ann in early July (Station 10,011), and on German Bank in August (Station 10,030); with minor centres of abundance off Penobscot Bay in August (Station 10,038) and in the northeast corner of the gulf (Station 10,036).

Meganyctiphanes norvegica was taken at nearly as many localities as *T. inermis* (12, as against 14); and its distribution over the Gulf was practically the same, except that we did not find it so regularly. However, its occurrences are too uniformly distributed to suggest any important local restriction further than that it, like *T. inermis*, was apparently not living in Massachusetts Bay. Meganyctiphanes was most abundant on German Bank (Station 10,029) and in Eastport Harbor, where it swarmed on the surface (*Loc. cit.*, p. 104). Elsewhere it was represented by a few specimens.

Thysanoessa longicaudata was taken less often than either of the preceding species, *i. e.*, at six stations (10,019, 10,027, 10,028, 10,032, 10,036, 10,043), thus being widely distributed over the shore parts of the Gulf, from Cape Cod to German Bank. But it was absent, so far as our hauls show, from the water close to the coast, in striking contrast to the abundance of Meganyctiphanes and *Thysanoessa inermis* near land. The only place where we found it in numbers was in the centre of the Gulf (Station 10,027), far from land. Elsewhere it was represented by occasional specimens only.

Thysanoessa gregaria was taken at the same number of stations (10,019, 10,023, 10,027, 10,032, 10,043, 10,049), and usually in the haul with *T. longicaudata*, the only station where the former was found and not the latter being on Platt's Bank (Station 10,023). But it was most numerous near Mt. Desert Rock (Station 10,032) instead of further off shore. In the other hauls there were only a few specimens.

Nematoscelis megalops occurred in only one haul, off Mt. Desert rock (Station 10,032 surface, a single specimen).

When work was resumed in autumn, off Cape Ann, schizopods were wholly absent, though the plankton was decidedly rich otherwise (p. 403). And the only euphausiid taken all winter was a single specimen of *Thysanoessa longicaudata* off Cape Ann, December 23. But, as pointed out above (p. 408) swarms of euphausiids appeared on the surface between Cape Ann and Boon Island, during the last half of April and continued more or less abundant until the middle of May. To my surprise the great majority of specimens in these hauls proved to be a species, *Thysanoessa raschii,* not taken in the Gulf in the summer. A few *T. inermis* were also taken on April 22, May 12, and May 13. But there were no *T. longicaudata, T. gregaria,* or Meganyctiphanes in the hauls.

The captures of *T. raschii* being from the surface, it is easy to establish salinity and temperature: — the former ranges from 30.6‰ to 31.7‰, the latter from 40.7° to 46.7°. Thus the species was living in extremely uniform water, with a combination of physical characters, low temperature coupled with low salinity, not paralleled anywhere in the Gulf, at any depth, in summer.

There is nothing surprising in the occurrence of any of these euphausiids in our Gulf, considering their distribution elsewhere.[1] In fact all might have been expected there. Thus Meganyctiphanes is widely distributed in Boreal waters near land. *Thysanoessa inermis, raschii,* and *longicaudata,* though cold water species, all extend as far south as the northern part of the North Sea [2]; *inermis* to Vineyard Sound (Rathbun, *Loc. cit.*). *Nematoscelis megalops* is a wide ranging oceanic species. *Thysanoessa gregaria,* according to Zimmer, (*Loc. cit.*, p. 21) is a southern form of very wide distribution in the warmer parts of the Atlantic. Its appearance in the Gulf of Maine is caused by the Gulf Stream water, which is its oceanic constituent. But the details of the occurrence of these various species in the Gulf are less easily understood. For example, it was surprising to find *Thysanoessa longicaudata* and *T. gregaria,* a cold water and warm water species, side by side, instead of finding the latter side by side with other warm water organisms, *e. g.* Salpa and Physophora (Bull. M. C. Z., 1914, **58**, p. 103). Equally hard to explain is the fact that the occurrence of *T. raschii,* absent in summer, abundant in early spring, is exactly the opposite of that of *T. inermis* (abundant in summer, absent in winter and early spring), although both are northern species, finding their southern limit near Cape Cod. Possibly the seasonal influence of the St. Lawrence water may give the clue, *T. raschii* being rather the more northern of the two species; but this seems hardly likely, inasmuch as both are widely distributed in the Arctic Ocean. Other possible factors are salinity and food supply.

[1] Zimmer, C. Schizopoden. Nordisches Plankton, 1909, **6**.

[2] Kramp, P. L. Cons. Int. Expl. de la Mer. Bull. Trimestr. 1913, **3**, p. 539, Schizopoda.

Finally, a phenomenon of some interest is the apparent absence of *Meganyctiphanes norvegica* from Massachusetts Bay at all seasons. There seems to be nothing in temperature or salinity to bar it from the waters of the Bay, for in summer, at some depth, the Bay closely reproduces the combination of temperature and salinity in which we found it swarming in Eastport Bay in August (salinity about 32.4‰ to 32.6‰, temperature 52°); and in winter the Bay is very little colder than the northern part of the North Sea, where Meganyctiphanes is common at that season. Its absence or rarity in the Bay is perhaps analogous to its absence in the southern part of the North Sea, where, as Kramp points out, both salinity and temperature would allow its existence. His explanation is that it is prevented from spreading southward in the North Sea by the shallow water, Meganyctiphanes being, according to his view, chiefly an inhabitant of the deeper water layers. But it can hardly be shallow water which bars it from Massachusetts Bay because many of our records for the species were from hauls no deeper than the deeper parts of the Bay, and because it was found in swarms on the surface at Eastport, in water of almost precisely the same temperature and salinity as the surface water off Cape Ann in November. Food supply, not hydrographic conditions, may be the factor which determines the local occurrence of Meganyctiphanes in the Gulf.

Plankton from Georges Bank.

The data for the season is limited to the few hauls made by Mr. Douthart during two trips, April 14th and 26th–27th, which, being taken at the surface with a small net, cannot be expected to give so complete a survey of the plankton as the work carried on in Massachusetts Bay. There must have been a fairly abundant macroplankton on his first visit, for the samples contained a considerable number of copepods, chiefly *Calanus finmarchicus* and *Temora longicornis* in the proportion of about 5–2; *Sagitta elegans*, and many specimens of the small Anthomedusa *Hybocodon prolifer*, with a few young *Staurophora mertensii*. The list also includes occasional specimens of *Oikopleura dioica* and *Tomopteris helgolandica*, besides many Arachnactis larvae; but the most interesting find is a large number of small colonies of two species of campanularian hydroids which were evidently living under pelagic conditions at the time, because the stems present no broken ends, but are growing actively in all directions. No doubt the strong tides and currents which flow over the Bank keep them afloat. They were submitted to Prof. S. F. Clarke for identification, and will be described more fully elsewhere. Large numbers of haddock eggs, nearly ready to hatch, were likewise found in the haul. The microplankton was decidely more abundant than the larger organisms, so much so, that, according to Mr. Douthart's accounts, the nets were soon clogged, although of large mesh. And he further noted that it was in streaks, not uniformly distributed. On microscopic examination, the mass proved to consist of diatoms; but qualitatively it was far more complex than the diatom swarm near shore, while the chief role was played by various species of Chaetoceras, especially *C. densum*, *C. atlanticum*, and *C. decipiens*, instead of by Thalassiosira, although *T. nordenskioldi* and *T. gravida* were both abundant. Other conspicuous species are *Ditylum brightwellii*, *Rhizosolenia obtusa*, *R. styliformis*, *R. semispina*, *Thalassiothrix nitzschioides*, Coscinodiscus, Coscinosira *Asterionella japonica*, with large numbers of Pleurosigma.

A little more than a week later, Mr. Douthart made a second series of tows on the western side of the Bank (p. 419), which showed that the macroplankton was apparently less abundant; and though it was of the same general type as before, Temora was about as abundant as Calanus. But the fact that the hauls were restricted to the surface makes it doubtful whether apparent variations in the relative numbers of different organisms have any real meaning. Other characteristic members of the plankton were *Sagitta elegans*, Oikopleura, the campanularian hydroids noted above, Actinian larvae, Hybocodon, *Pleurobrachia pileus*, and many haddock eggs. The microplankton was quantitatively as rich as on the last visit; but it had undergone a decided change qualitatively, its most important component, numerically, now being *Rhizosolenia styliformis*. In the last haul, this form was represented by occasional examples only; now it formed the greater part of the mass; and many of the specimens were so large (1.1 mm.) as to be easily visible with the naked eye.

Temperatures and salinities at Blue Wing Stations.

The numbers are consecutive with the Grampus stations of 1912. (Bull. M. C. Z., 1914, **58**, p. 135).

No.	Date	Position Lat.	Position Long.	Depth	Temp.	Sal. ‰
10,047	Nov. 20	42° 27′	70° 40′	0	48.5°	32.57
				25	48.2	32.57
				34	48.2	32.66
10,048	Dec. 4	42° 26′	70° 40′	0	46.6°	32.56
				25	46.1	32.56
				38	46.1	32.61
10,049	Dec. 23	42° 26′	70° 40′	0	44.5°	32.74
				23	44.5	32.75
				38	44.5	32.75
10,050	Jan. 16	42° 26′	70° 40′	0	41.7°	32.81
				25	41.5	32.86
				38	42.1	32.94
10,051	Jan. 30	42° 33′	70° 41′	0	40.5°	32.56
				10	40.7	
				19	41.7	32.82
10,052	Jan. 30	42° 43′	70° 39′	0	40.3°	32.20
				8	40.7	
				18	41.6	32.90
10,053	Feb. 13	42° 37′	70° 30′	0	37.1°	32.83
				25	37	32.83
				45	37.6	32.84
10,054	Mar. 4	42° 33′ 30″	70° 30′	0	37.2°	32.85
				25	37.5	32.96
				45	38.5	33.04
10,055	April 3	42° 33′	70° 30′	0	39.3°	32.32
				10	39.3°	
				20	39.3	
				25		33.03
				30	39.2°	
				42	39.1°	33.12
10,056	April 14	42° 33′	70° 39′ 30″	0	42°	31.11
				25	39.4	32.79

Temperatures and Salinities at Stations Occupied by W. W. Welsh.

The deepest record depth at each station is at the bottom.

No.	Date		Position Lat.	Long.	Depth	Temp.	Sal. ‰
1	March	19	42° 31′	70° 29′	0	39°	33.01
					48	39	33.17
2	"	19	42° 35′	70° 28′	0	39.1°	32.84
					65	38.8	33.17
4	"	27	42° 51′	70° 20′	0	39.2°	32.61
5	"	29	43° 12′	70° 25′	0	38.3°	32.45
					17	38.7°	32.83
					35	38.9	32.99
7	April	4	43° 13′	70° 24′	0	39°	32.77
8	"	5	43° 10′	70° 28′	0	39°	32.74
					14	38.8	32.81
					28	39	
					32		33.04
9	"	9	43° 24′	70° 20′	0	38.9°	29.51
					9	39.1	30.79
					18	39.3	31.00
10	"	10	43° 23′	70° 21′	0	38.2°	26.74
					10	39.3	31.80
					21	39.2	32.52
11	"	13	42° 57′	70° 39′	0	40.1°	31.56
					10	39.4	32.43
					20	39.3	32.66
12	"	14	43° 18′	70° 26′	0	40.2°	29.13
					10	39.5	31.92
					20	39	32.47
13	"	16	42° 55′	70° 41′	0	41.1°	30.66
					11	40.4	31.47
					30	39.3	32.52

No.	Date		Position Lat.	Long.	Depth	Temp.	Sal. ‰
14	April	18	42° 56′	70° 41′	0	41°	30.79
					10	40.5	30.97
					24	39.3	32.47
15	"	20	42° 55′	70° 45′	0	40.4	31.11
16	"	22	42° 55′	70° 37′	0	40.7	31.43
					10	40	31.71
					25	39.3	32.80
17	"	23	42° 59′	70° 39′	0	41.2°	30.93
					6	40.4	31.53
					15	39.3	32.56
18	"	25	43° 12′	70° 27′	0	44°	31.76
					15	39.3	32.46
					30	39.2	32.65
19		26	43°	70° 35′	0	46.3°	30.03
					15	39.2	32.45
					35	39.2	32.74
20	"	29	43° 02′	70° 35′	0	44.8°	31.51
					15	39.3°	32.33
					35	39.2	32.72
21	May	1	42° 57′	70° 38′	0	43.8°	30.66
					26	39.3	32.48
22	"	2	42° 57′	70° 40′	0	45°	30.64
23	"	3	42° 54′	70° 42′	0	46.6°	29.92
					11	42.8	31.56
					25	39.3	32.49
24	"	5	42° 54′	70° 42′	0	48.3°	29.54
					12	41.3	31.95
					26	39.4	32.50
25	"	6	42° 56′	70° 41′	0	49.6°	29.60
					25	39.4	32.52
26	"	8	42° 56′	70° 41′	0	46.8°	29.93
					5	45.2	
					10	41.8	
					24	39.5	32.30

No.	Date	Position Lat.	Long.	Depth	Temp.	Sal. ‰
27	May 10	42° 56′	70° 44′	0	45.6°	30.44
				11	42	
				22	39.4	32.46
28	" 12	42° 56′	70° 45′	0	44.9°	30.73
				10	42.2	
				20		32.18
29	" 13	42° 56′	70° 44′	0	45.1°	30.88
				12	41.6	
				24	39.6	32.33
30	" 14	42° 58′	70° 35′	0	46.6°	30.50
				15	41.5	
				29	39.9	32.62
31	" 16	42° 56′	70° 42′	0	46.7°	30.94
				26	42.8?	32.39
32	" 17	42° 32′	70° 44′	0	47.3°	30.95
				9	45.1	31.25

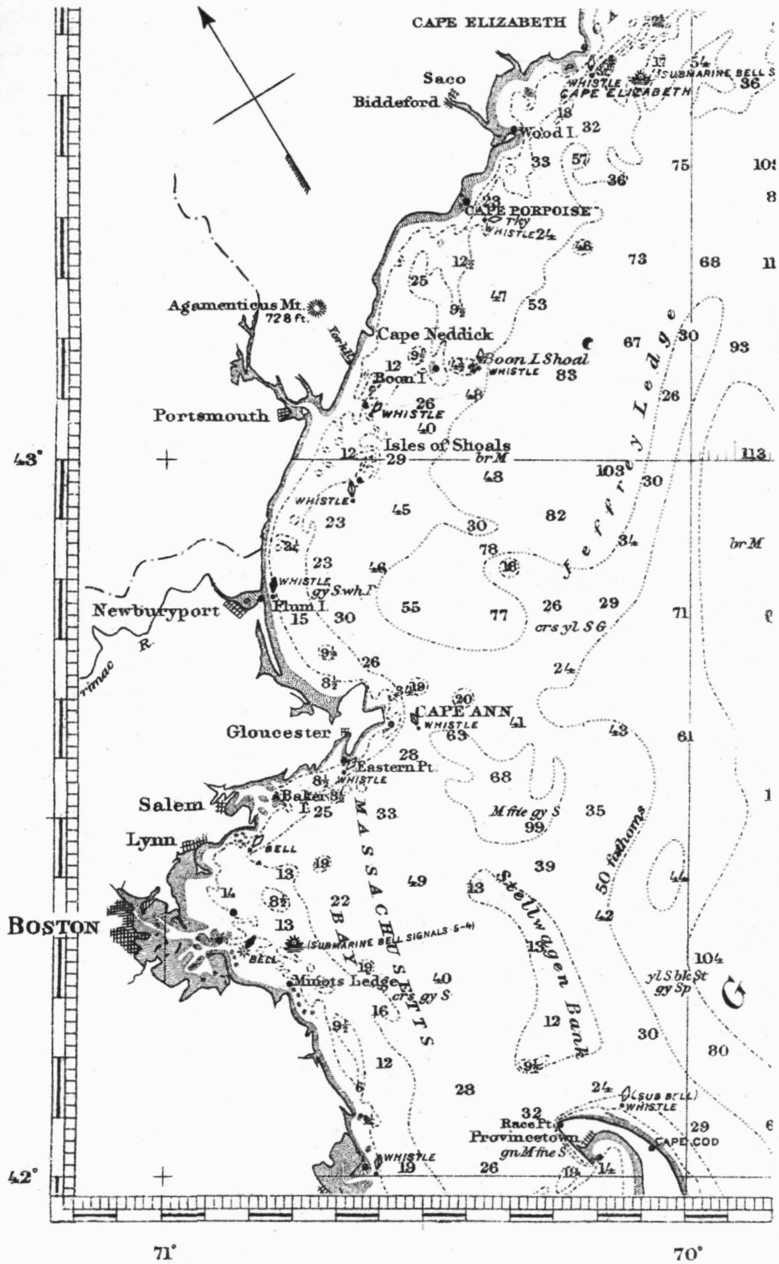
TEMPERATURES AND SALINITIES, MASSACHUSETTS BAY TO GEORGES BANK.

Location	Date	Surface temp.	Bottom temp.	Depth Fath.	Surface salinity	Bottom salinity
41°47′N 67°18′W	April 11				33.22	
41°37′N 67°18′W	" 14	44°	43°	25	33.21	
41°52′N 66°45′W	" 15				33.33	
42° 3′N 67° 1′W	" 15				33.22	
42° 8′N 67°12′W	" 15				33.38	
42°14′N 67°28′W	" 15	44°	41.5	70		
42°20′N 70°45′W	" 26				31.51	
42° 8′N 70°10′W	" 26				32.29	
41°48′N 69°21′W	" 27				33.13	
41°34′N 68°45′W	" 27				33.25	
41°27′N 68°20′W	" 27	46°	44°	35	33.16	33.21

EXPLANATION OF PLATE.

EXPLANATION OF PLATE.

Chart of the Coast, from Cape Elizabeth to Cape Cod. Reduced from the U. S. Coast Pilot.


CAPE ELIZABETH
Saco
Biddeford
Wood I.
CAPE PORPOISE
Agamenticus Mt.
728 ft.
Cape Neddick
Boon I.
Boon I. Shoal
Portsmouth
Isles of Shoals
Jeffrey Ledge
Newburyport
Plum I.
CAPE ANN
Gloucester
Eastern Pt.
Salem
Lynn
BOSTON
Minots Ledge
MASSACHUSETTS BAY
Stellwagen Bank
50 fathoms
Race Pt.
Provincetown
CAPE COD
43°
42°
71°
70°

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.
A. AGASSIZ and C. O. WHITMAN. Pelagic Fishes. Part II., with 14 Plates.
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.
R. VON LENDENFELD. The Siliceous Sponges.
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.

PUBLICATIONS

OF THE

MUSEUM OF COMPARATIVE ZOÖLOGY

AT HARVARD COLLEGE.

There have been published of the Bulletin Vols. I. to LIV.; of the Memoirs, Vols. I. to XXIV., and also Vols. XXVI. to XXIX., XXXI. to XXXIV., XXXVI. to XXXVIII., XLI., and XLIV.

Vols. LV. to LVIII. of the Bulletin, and Vols. XXV., XXX., XXXV., XXXIX., XL., XLII., XLIII., XLV. to XLVIII. of the Memoirs, are now in course of publication.

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The following publications are in preparation:—

Reports on the Results of Dredging Operations from 1877 to 1880, in charge of Alexander Agassiz, by the U. S. Coast Survey Steamer "Blake," Lieut. Commander C. D. Sigsbee, U. S. N., and Commander J. R. Bartlett, U. S. N., Commanding.

Reports on the Results of the Expedition of 1891 of the U. S. Fish Commission Steamer "Albatross," Lieut. Commander Z. L. Tanner, U. S. N., Commanding, in charge of Alexander Agassiz.

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.

Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, on the U. S. Fish Commission Steamer "Albatross," from October, 1904, to April, 1905, Lieut. Commander L. M. Garrett, U. S. N., Commanding.

Contributions from the Zoölogical Laboratory, Professor E. L. Mark, Director.

Contributions from the Geological Laboratory, Professor R. A. Daly, in charge.

These publications are issued in numbers at irregular intervals. Each number of the Bulletin and of the Memoirs is sold separately. A price list of the publications of the Museum will be sent on application to the Director of the Museum of Comparative Zoölogy, Cambridge, Mass.