UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

CLIMATIC TRENDS AND THE DISTRIBUTION OF MARINE ANIMALS IN NEW ENGLAND

By CLYDE C. TAYLOR, HENRY B. BIGELOW
and HERBERT W. GRAHAM

FISHERY BULLETIN 115

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 57

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON : 1957

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 40 cents

ABSTRACT

The possible influence of temperature changes on the distribution and abundance of marine species is examined. Mackerel catches show a relation to air temperature fluctuations in data extending over a period of 130 years, the catches having declined to about one-third their former level since 1900 and also having decreased in the amplitude of their fluctuations. Decreased landings of both lobsters and whiting (*Merluccius bilinearis*) south of Cape Cod may be due to a warming of inshore waters, while north of Cape Cod the warming has produced optimal conditions resulting in greatly increased catches of both species since 1940 and also in late fall and winter catches of whiting. Menhaden, which had not been fished in Maine waters since the end of the 19th century, reappeared there in 1945 and have become commercially exploited.

The abundance of the yellowtail flounder (*Limanda ferruginea*) has declined on the southern New England fishing grounds while showing an increase on Georges Bank. The decline in the yellowtail flounder and the growth of a thriving fishery for "trash" species on the grounds where the yellowtail was formerly abundant suggests a major ecological change. New northern records of southern species have been published with increasing frequency since about 1930 with no corresponding increase in records of extensions of the southern ranges of northern species, thus indicating these increases are real and not the result merely of an increased number of observers.

The changes in distribution and abundance of marine animals produced by the upswing in temperature fall in several categories and these are discussed. These changes do not appear to have produced any obvious alteration of the general faunal characteristics of the Gulf of Maine region.

CONTENTS

	Page
Introduction	293
Trends in air temperatures	294
Sea surface temperatures	298
Relation between air and sea temperatures	301
Temperature trends in offshore waters of Gulf of Maine	302
Gulf of Maine temperatures, 1912–26	302
Trend in water temperatures between 1912–26 and 1953–54	306
Comparison of temperatures for 1953–54 and 1912–26	307
Changes in abundance and distribution of marine animals	323
Fluctuations in mackerel	324
Fluctuations in lobsters	325
Fluctuations in whiting	329
Fluctuations in menhaden	333
Fluctuations in yellowtail flounder	334
Northward extension of southern species	335
Role of temperature in faunistic changes	338
Summary	340
References cited	340
Appendix:	
Monthly mean water temperatures, Boothbay Harbor, Maine, 1949 to 1905	344
Monthly mean water temperatures, Woods Hole, Mass., 1952 to 1881	345

CLIMATIC TRENDS AND THE DISTRIBUTION OF MARINE ANIMALS IN NEW ENGLAND

By CLYDE C. TAYLOR, *Fishery Research Biologist*, HENRY B. BIGELOW, *Oceanographer*, and HERBERT W. GRAHAM, *Fishery Research Biologist*

For many years Americans have commented on an apparent warming of their climate; older people have referred to the "old-fashioned winters" they once knew. Climatologists long shrugged off the idea as unfounded, but a melioration in climate is no longer confined to the popular mind: a decided trend toward warmer winters during the past 50 years is now well-documented. Air temperatures in winter, particularly since 1910, are definitely higher in higher latitudes of the Northern Hemisphere and probably throughout the world generally. Glaciers have been receding and in far northern latitudes, plants and land animals following the retreating ice have extended their ranges northward and to higher altitudes. For a bibliography dealing with responses of plants and animals to climatic changes, the reader is referred to Rapports et Procès-Verbaux des Reunions, vol. 125, pp. 42–52, Conseil Permanent International l'Exploration de la Mer, Part 1, 1949.

Warming of the oceans during periods of higher air temperatures is difficult to demonstrate because of the paucity of observations of sea-water temperatures. Evidence shows, however, as Smed (1949, 1953b) points out, that the Arctic Ocean has warmed appreciably since 1921. This author also presents evidence of increased water temperatures beginning in the 1920's in the North Sea and in the North Atlantic from the British Isles to the west coast of Greenland.

The warming of northern waters has been accompanied by the northward extension of many marine vertebrates to the region of Iceland (Fridriksson 1949) and by profound changes in the fish populations around Greenland (Tåning 1949). The development of the cod fishery on the west coast of Greenland has been spectacular. As the waters warmed in this area, an offshoot from the Icelandic stock of cod became established and now supports a substantial fishery (Jensen and Hansen, 1931). In the years 1911 to 1921, the West Greenland cod fishery produced less than 500 tons a year. In 1925, the catch doubled and thereafter continued to increase. In 1952, some 252,758 metric tons of cod were landed from the West Greenland area (International Commission for the Northwest Atlantic Fisheries, 1954, table 2, p. 28). The fishery now reaches 300 nautical miles farther north than formerly. The Eskimos in some areas who had never seen a cod in 1924 are now busily occupied in the cod fishery, whereas they formerly were seal hunters.

Although temperature is only one factor in the ecological complex determining the presence or abundance of a species, in high latitudes temperature may in some instances be the sole limiting factor and have a direct effect on distribution. Thus, cod show a definite response to low temperatures and their northward extension is probably determined by temperature alone. The abundance of cod in the Greenland area may be related to temperature in a somewhat less-direct manner. Hermann (1953) has shown that the strength of cod year-classes in Greenland waters has a very high correlation with bottom temperatures in June. Thus, temperature in some way affects survival of whole populations of young fish, perhaps through affecting their food supply or rate of growth and, consequently, their resistance to adverse environmental conditions.

The warming of arctic areas and the accompanying ecological changes have been so marked and so well-documented that it seems reasonable to suppose that similar changes have taken place, although perhaps on a smaller scale, in more southern latitudes. It is the purpose of this paper to examine temperature fluctuations in recent years, and to explore the relations which may

NOTE.—Clyde C. Taylor and Herbert W. Graham, United States Fish and Wildlife Service, Woods Hole, Mass.; Henry B. Bigelow, Museum of Comparative Zoology, Harvard University.

Approved for publication, November 1, 1956.

exist between these fluctuations and the abundance and distribution of marine animals along the eastern coast of the United States and in the New England area, in particular.

In the following pages we present some of the available data on trends in air and sea temperatures and trends in the distribution of certain species of marine fish and invertebrates. We are aware that, in some instances, we may be misinterpreting the causes of observed changes, or even may be misled in believing that some of the changes have occurred. It is hoped that the presentation of these relationships will stimulate others, especially specialists in particular fields, to examine more critically the data they may have at hand. A great deal of the theory of fishery science is based on the premise that the environment is unchanging and that the fluctuations which do occur take place within certain limits on either side of a stable norm. We find, therefore, that changes in abundance of fishes are frequently attributed to the effects of overexploitation. If the premise of a stable environment is not valid, it will be necessary, at least, to reexamine the overfishing explanation of such fluctuations.

The observations on which this paper is based end with the winter of 1953–54. The authors emphasize that their purpose is to document the events of a period of warming of air and sea temperatures. No prediction of future temperature trends is offered.

TRENDS IN AIR TEMPERATURES

Extensive evidence of an upward trend in air temperatures over the United States and Canada was presented by Kincer as early as 1933. In addition to a general upward trend in annual means, Kincer's (1933) analysis showed that winters, springs, and falls were becoming milder, while summer temperatures were remaining about the same. Similarities in trends as well as in the patterns of fluctuations are evident in Kincer's diagrams at representative stations throughout the United States and Canada. Kincer also showed similar trends for other stations throughout the Northern Hemisphere and for a few in the Southern Hemisphere. His data encourage one to believe that air-temperature records at any one point on the eastern seaboard will reflect the general trend of air temperatures for latitudes north and south, although, of course, not in level or in magnitude of fluctuations.

It is now generally conceded that a significant warming has occurred throughout the Northern Hemisphere. As Mitchell (1953, p. 244) states—

> It apparently has taken the relatively severe temperature changes of more recent years, coupled with many kinds of climatological, glaciological, oceanographical and biological evidence, to establish the unmistakable reality of important climatic trends in secular time.

The pattern of these changes is examined in the following section to establish a background to which changes in the abundance and distribution of marine species may be related.

The longest series of air temperature records for North America was taken at New Haven, Conn., beginning in June 1778 (Loomis and Newton, 1866). Monthly means of these temperatures are available (Clayton, 1927, 1934; Clayton and Clayton, 1947; U. S. Weather Bureau, 1941 to 1953). Many years ago, Loomis and Newton made a comprehensive study of the New Haven series. These authors not only provide an account of the early observers and circumstances of observation, but also reduce the observations to a standard series corrected for the time of day the observations were made. After comparing the temperatures for the first and second halves of the period of study, the authors state (p. 246), "We conclude therefore, finally, that during the past 86 years there has been no permanent change at New Haven either in the mean temperature of the year, or in that of any of the separate months; * * *." This conclusion is the more striking because of the subsequent upward trend in New Haven temperatures.

Annual deviations from the mean computed for the period 1780–1950 (49.3° F.) are presented in figure 1 and a curve of 5-year moving averages has been drawn through them to indicate the trends. The data have several interesting aspects. Considering deviations from the grand mean by 20-year periods beginning with 1781, the minimum deviations occurred over the periods 1821–40 and 1841–60. Since 1900, 44 of the 51 annual means show positive deviations, and over half of the positive deviations are greater than 1° F. Equally warm periods occurred prior to 1900. The outstanding feature revealed by figure 1 is that equally cold periods have not occurred. The trend in minima has been upward since about the first third of the 19th century.

Annual means may not indicate all of the significant changes that may be occurring in an area. Mild winters and cool summers may, for example, result in the same annual means as severe winters and very warm summers—the climate in the two situations being quite different.

In figures 2 and 3, curves for January and July deviations from their respective means are shown for New Haven for the period 1780–1953. The curves are smoothed by 15-year moving averages. The January temperature deviations show a pronounced trend from a low in the 1810's. The mean for the period 1780–1900 is 26.72° F., while that for the period 1901–53 is 29.66°, a difference of nearly 3°. The mean since 1930 is 30.57°, an increase of 3.85°, even though the trend was generally downward over the latter part of this period. It will be observed, on the other hand, that aside

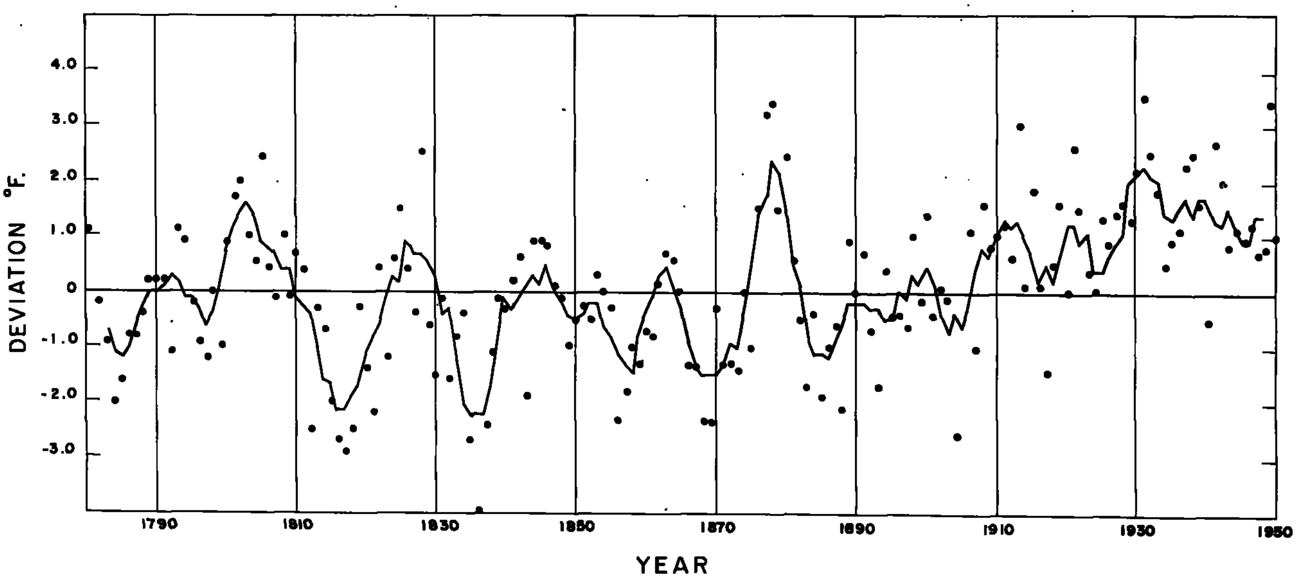

FIGURE 1.—Annual deviations from the mean air temperature, 1781 to 1950, at New Haven, Conn. The solid line is a 5-year moving average.

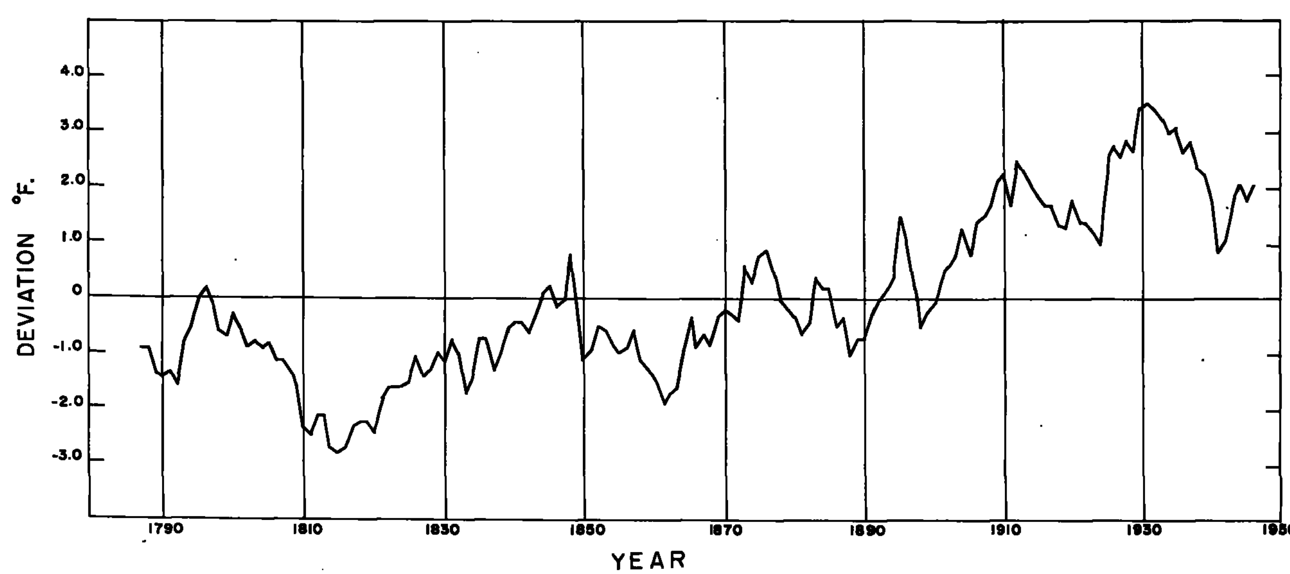

FIGURE 2.—January air temperature deviations from the mean, 1780 to 1953, at New Haven, Conn. (Curve smoothed by 15-year moving average.)

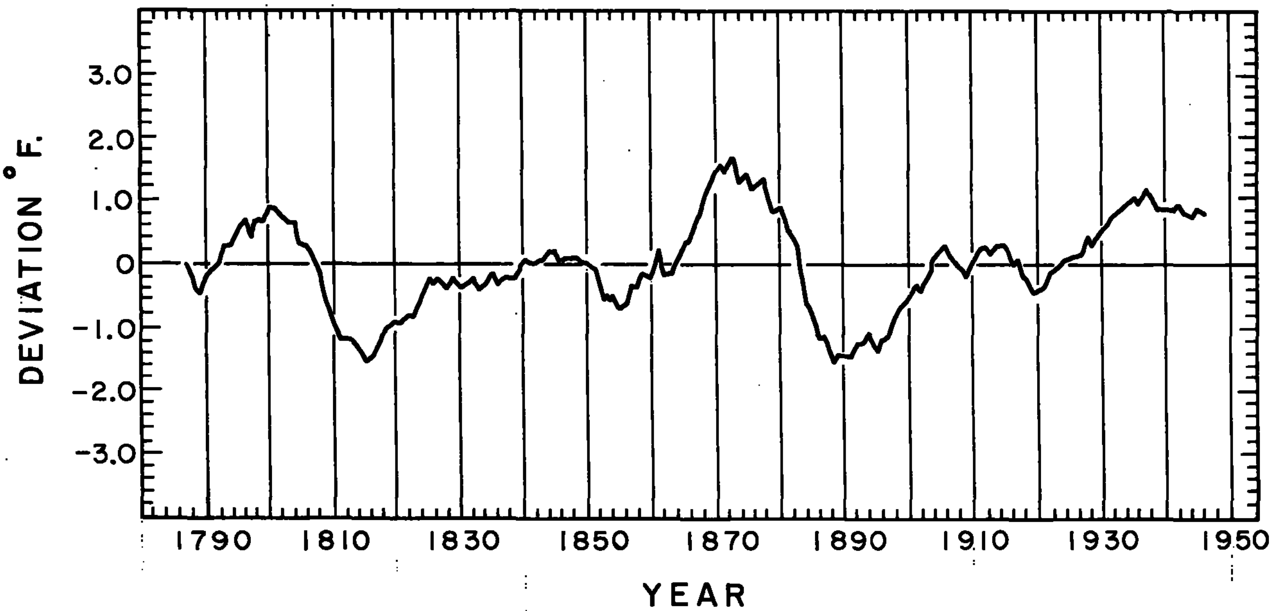

FIGURE 3.—July air temperature deviations from the mean, 1780 to 1953, at New Haven, Conn. (Curve smoothed by 15-year moving average.)

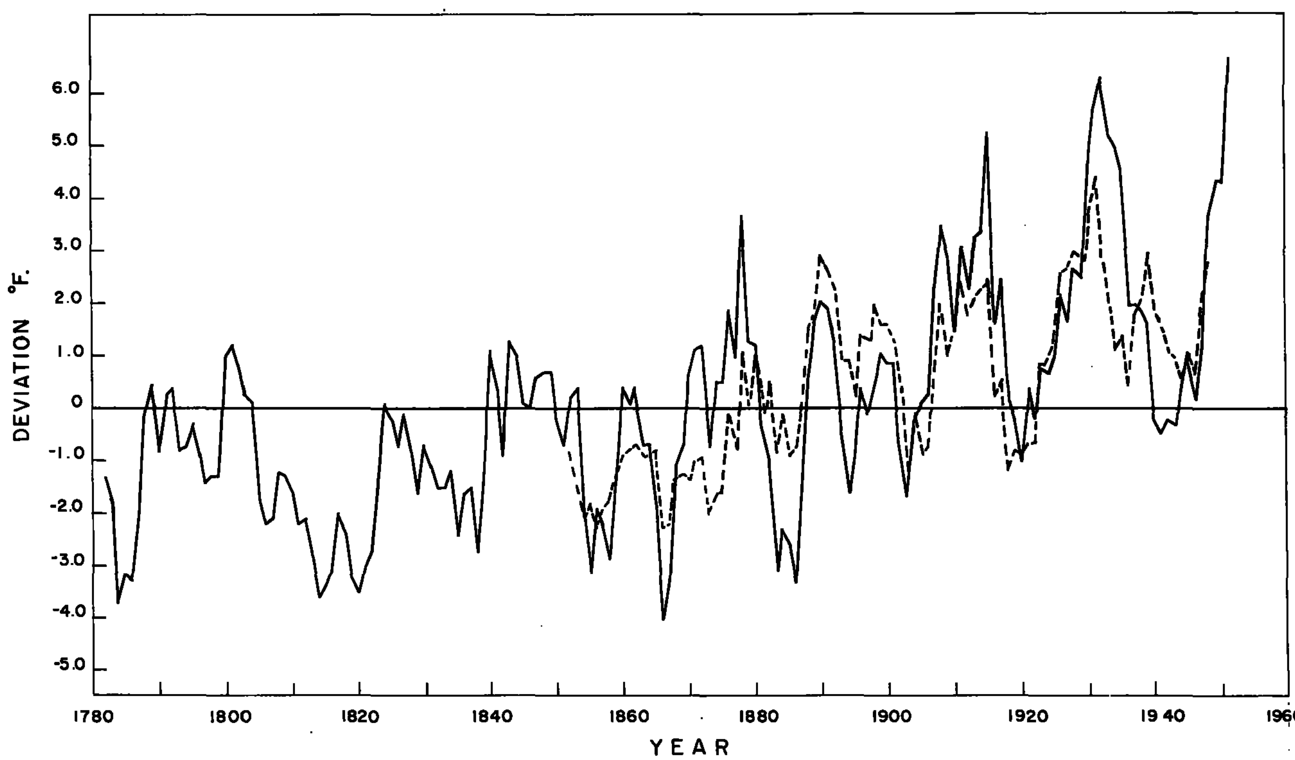

FIGURE 4.—January air temperature deviations at New Haven, Conn., 1780 to 1953 (solid line), compared with those for the winter months of December, January, and February, 1849–1950 (broken line), at the Bluehill Meteorological Observatory. (Curves smoothed by 5-year moving averages.)

from showing roughly the same periodic fluctuations, the July temperatures have remained very nearly the same over the entire period.

The imperfections of the New Haven temperature record have been pointed out by Mitchell (1953). He considers the most serious of these to be the effect of urban development which may have contributed as much as 1° F. to the average temperature during the winter months. He cites the temperature records at the Bluehill Meteorological Observatory of Harvard University, located 10 miles south of Boston, as being quite free from urban effects. Conover (1951) has published mean winter temperatures (December, January, and February) for the Bluehill Observatory covering the period 1849–50 to 1949–50. In figure 4, we have compared the January deviations at New Haven with those at Bluehill for the winter months.

The difference between the January means at New Haven for the periods 1780–1900 and 1901–53 is 2.94° F. The standard error of this difference is 0.6873. The difference is then highly significant (t=4.28, 172 d. f.). If the difference were only 1.8°, it would still be highly significant, and if only 1.35°, it would be significant. The reality of the increase can hardly be denied even if one allows a maximum value for the effect of urban development. With regard to temperatures at the Bluehill Observatory over the period 1849–1950, Conover (1951, p. 9) states, "The amount of warming up in general winter temperature over the last 100-year period has been about 3½° Fahrenheit."

To analyze further the pattern of temperature changes, mean temperatures for each month have been averaged for the 20-year period 1780–1800 and by 25-year periods thereafter to 1950 for New Haven, Conn., and for comparison, from 1876 to 1950 for Eastport, Maine (fig. 5). The New Haven temperatures were adjusted to the level of Eastport temperatures by subtracting from them the mean difference between temperatures at New Haven and at Eastport by months for the period 1874–1923. The means for this period for Eastport and New Haven are given by Clayton (1927).

Upward trends in temperature are noted fo

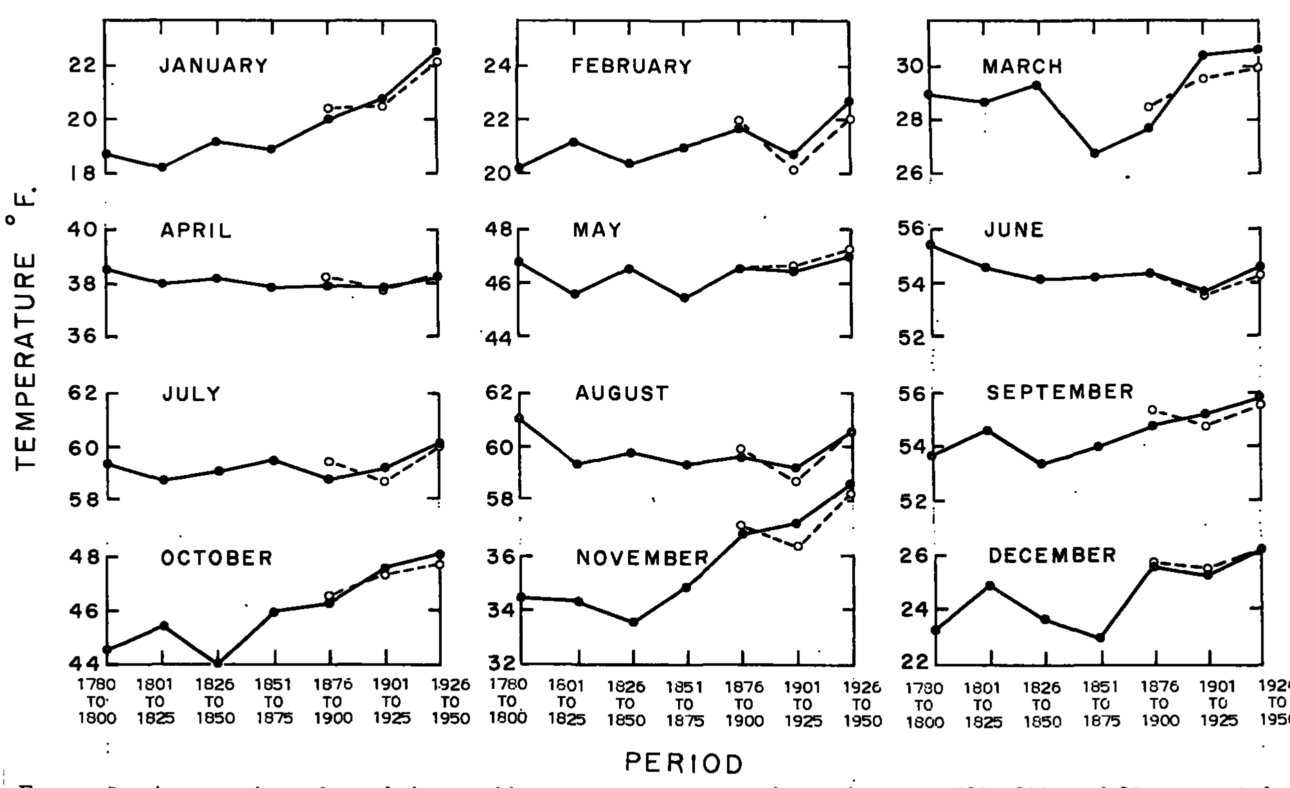

FIGURE 5.—A comparison of trends in monthly temperatures averaged over 21-year (1780–1800) and 25-year periods; New Haven, Conn., 1780–1950 (solid line), Eastport, Maine, 1876–1950 (broken line).

the months of January, February, October, November, and December. March and September also show rather pronounced upward trends for the latter part of the period. It will be noted that temperatures at New Haven were, in general, relatively cooler than at Eastport for the period 1875–1900 and relatively warmer for the periods 1901–25 and 1926–50. These differences in the later years may reflect urban development at New Haven. Figure 5 shows clearly that the important changes in temperature occurred during the fall and winter months.

SEA SURFACE TEMPERATURES

Trends in sea temperatures in the North Atlantic north of latitude 55° have been reported by Smed (1949, 1953b). Some records covering periods of time sufficient to indicate significant trends are available for the Atlantic coast. Hachey and McLellan (1948) have published data for St. Andrews, New Brunswick, for the period 1921–47. Annual means, with 12-month moving averages of temperatures, are shown by Lauzier (1952) for St. Andrews and for Sambro Lightship, Nova Scotia, for the period 1936–51.

Daily readings of surface temperature were made at Boothbay Harbor, Maine, for the period 1905–49. These readings were made at 8 a. m., 12 noon, and 4 p. m., in conjunction with the operations of the fish hatchery there during that period. The monthly means are presented in appendix table 1, p. 344. Examination of the original records indicates that these temperatures (recorded to the nearest degree) were carefully taken for the most part; however, some temperatures below the freezing point of sea water were recorded. The trends and fluctuations in these temperatures are in good agreement with those appearing in the St. Andrews data (cf. figs. 6 and 7).

Annual deviations from the 43-year mean at Boothbay Harbor (1906–48) are shown in figure 6. There is only a slight increase in the annual means over the period. For the 25 years, 1906–30, the annual means average 45.9° F.; for the 18 years, 1931–48, the average is 46.4°.

A striking melioration of winter conditions in recent years is shown when the January–July difference in water temperature at Boothbay Harbor is plotted as a deviation from the mean difference for the period of record (fig. 8). The average January and July temperatures for various periods are as follows:

Period	January	July
1906-20	33.3	61.1
1921-30	33.0	61.6
1931-40	34.6	60.7
1941-49	35.2	60.5

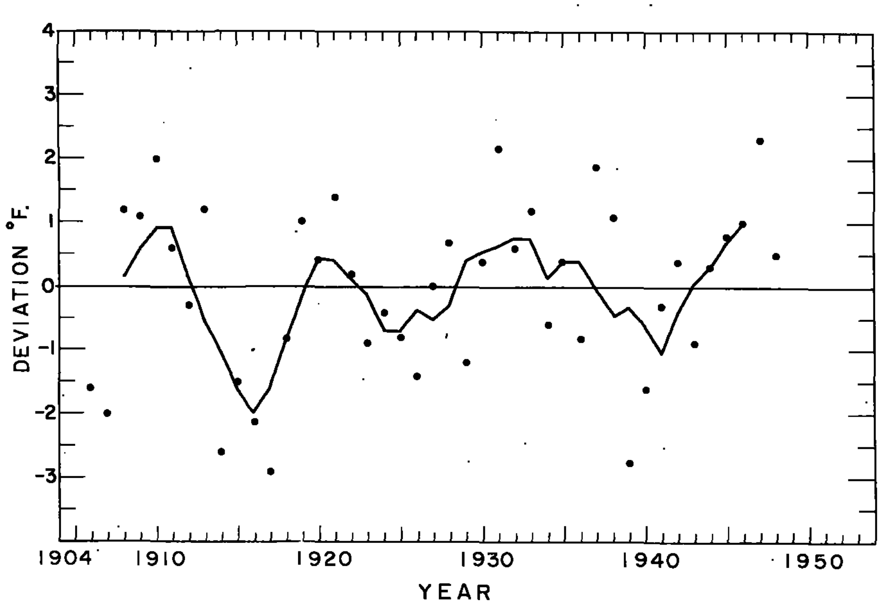

FIGURE 6.—Annual deviations from the mean surface temperatures, 1906 to 1948, at Boothbay Harbor, Maine. (The solid line is a 5-year moving average.)

Since 1930, January temperatures have increased about 2° while July temperatures have decreased about 1°. These opposite trends account, of course, for the magnitude of the phenomenon to be observed in figure 8.

Records of surface water temperatures, smoothed by 5-year moving averages, for each month over the period 1905–49 (fig. 9) show significant upward trends for the months of January, February, November, and December. To establish the degree and significance of these trends, we have divided the records into two approximately equal periods of 22 and 23 years, calculated the mean for each month for each period, the standard error of the difference between these means, and Student's t (table 1). January, February, and December show highly significant increases in mean temperature, while a statistically significant increase has occurred for the November period. March, July, August, and September show slight downward trends, but these trends are not statistically significant.

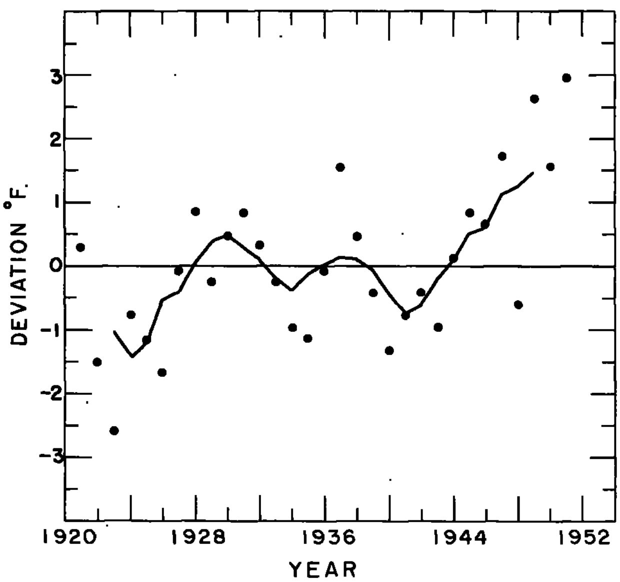

FIGURE 7.—Annual deviations from the mean surface water temperatures, 1921 to 1951, at St. Andrews, New Brunswick. (The solid line is a 5-year moving average.)

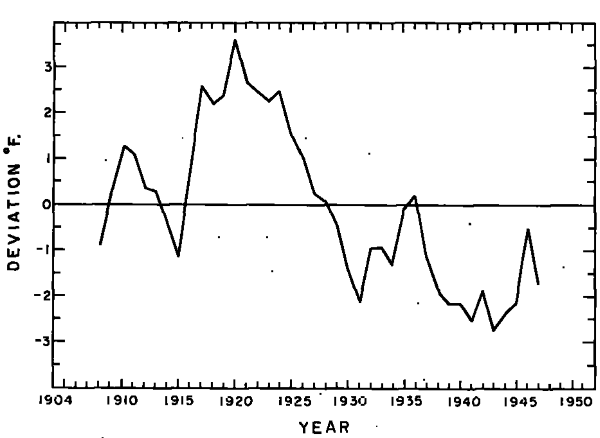

FIGURE 8.—January–July differences in surface water temperatures as deviations from the mean difference, 1906 to 1949, at Boothbay Harbor, Maine. (The curve is a 5-year moving average.)

TABLE 1.—*Comparison of mean monthly surface temperatures at Boothbay Harbor, Maine, for the first and second halves of the period 1905–49*

[Temperatures in °F.]

Month	Mean		Difference	t
	Period A [1]	Period B [1]		
January	33.00	34.89	+1.89	9.27**
February	31.26	33.33	+2.07	3.58**
March	35.40	34.95	−0.45	0.70
April	39.50	39.98	+0.48	0.93
May	47.04	47.44	+0.40	0.49
June	54.83	55.01	+0.18	0.27
July	61.21	60.54	−0.67	1.12
August	61.25	60.95	−0.30	0.61
September	56.98	56.90	−0.08	0.16
October	50.10	50.73	+0.63	1.02
November	43.38	44.70	+1.32	2.14*
December	37.00	38.15	+1.15	5.08**

[1] Periods A and B for January and February are 1906 to 1927 and 1928 to 1949; for March to July, 1905 to 1927 and 1928 to 1949; for August to December, 1905 to 1926 and 1927 to 1948, respectively. See also appendix table 1, p. 344.
*5-percent level of significance.
**1-percent level of significance.

Water-temperature records for Woods Hole, Mass., for the period 1881–1914, 1932–42, and 1945–52 are given in appendix table 2. The means for various periods are as follows:

Period	January	July	Annual mean
1885–94	34.2	69.2	50.9
1896–1904	32.9	68.3	50.7
1905–14	33.8	69.6	51.1
1933–41	34.0	67.6	50.3
1945–51	35.2	70.3	52.3

The trend in surface water temperatures for January at Woods Hole is similar to that for Boothbay Harbor for comparable periods. Except for the period 1933–41, however, there does not appear to be any trend at Woods Hole toward declining July temperatures comparable to that for Boothbay Harbor. The annual mean for the period since 1945 is considerably higher than the annual means for the earlier periods. This increase is statistically significant. The data show

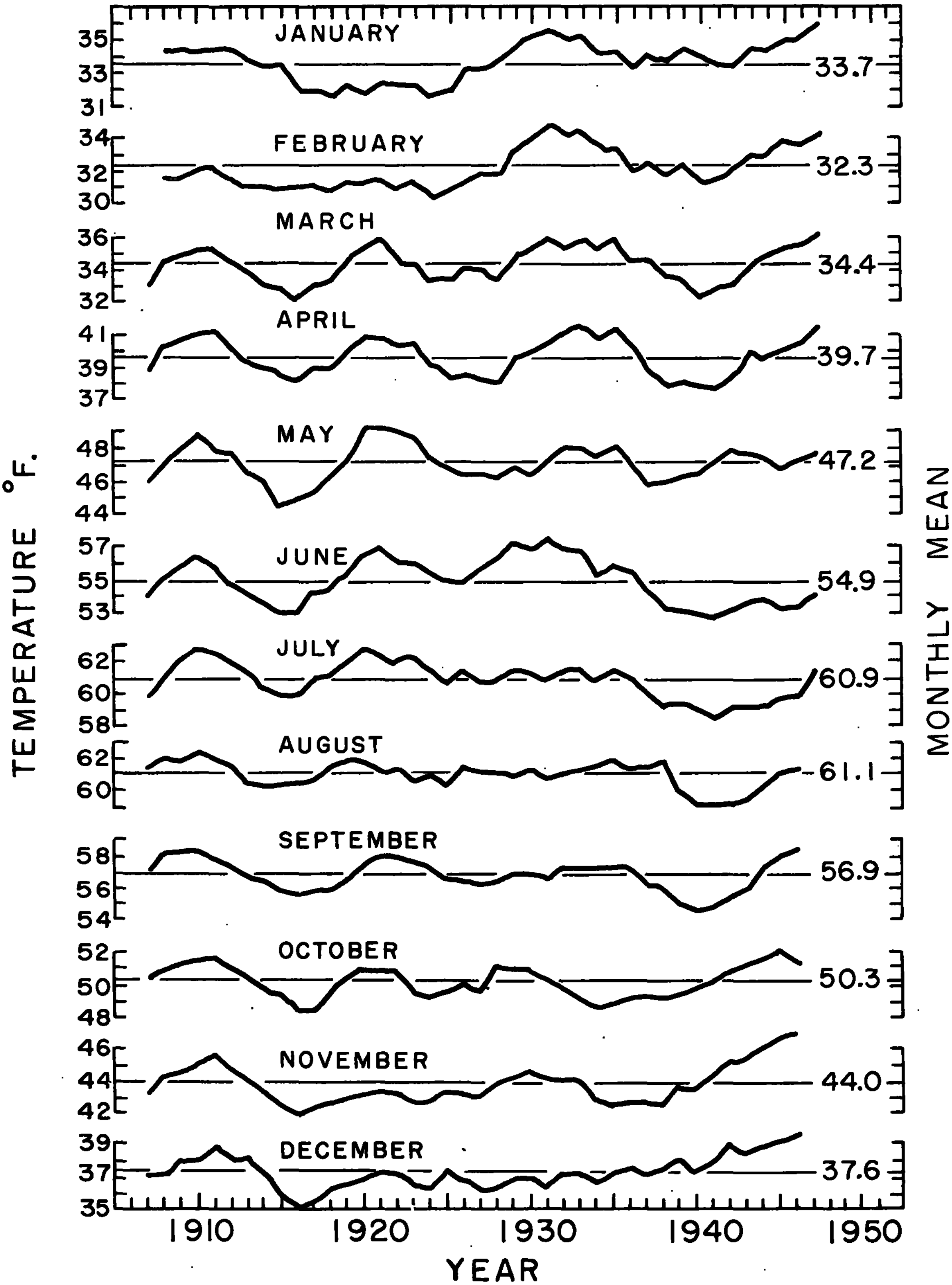

FIGURE 9.—Trends in surface water temperatures at Boothbay Harbor, Maine, for each month of the year, 1905–49. (Curves are 5-year moving averages.)

that the winters have been generally milder since 1932 and that a significant warming has occurred since 1945.

RELATION BETWEEN AIR AND SEA TEMPERATURES

Many sources of evidence indicate that the warming of the air began perhaps as early as 1850 and that air temperatures have been at a generally high level since 1900. Data on sea temperatures cover, for the most part, periods since 1900. Thus, we may be observing fluctuations in sea temperatures at a higher level than occurred in the earlier period. By examining the correlation between air and sea temperatures, the likelihood of this possibility may be determined.

The relation between Eastport air temperatures and Boothbay Harbor water temperatures for the month of January during the period 1906–49 is illustrated in figure 10. The correlation coefficient is 0.658, which is highly significant. The same relation using New Haven air temperatures is shown in figure 11. The correlation coefficient is 0.610, also highly significant. The relationships are not quite good enough to predict with accuracy the surface temperature from a given air temperature; however, the correlation is sufficiently high to conclude that these air temperatures are a rough index of the general level of surface water temperatures. On this basis we can assume that winter surface water temperatures prior to 1900 were generally lower than after that date.

Further confirmation of our conclusion that changes in air temperatures for the period prior to 1900 are generally indicative of changes in surface water temperatures is to be found in a series of water temperature records for Eastport, Maine, for the period 1878–87 (Moore 1898). These data are compared with air temperatures for the same period and with air and water temperatures at Eastport for the period 1941–50 (table 2). The general increase in air temperatures for each month between the two periods is faithfully reflected in a corresponding increase in water temperatures.

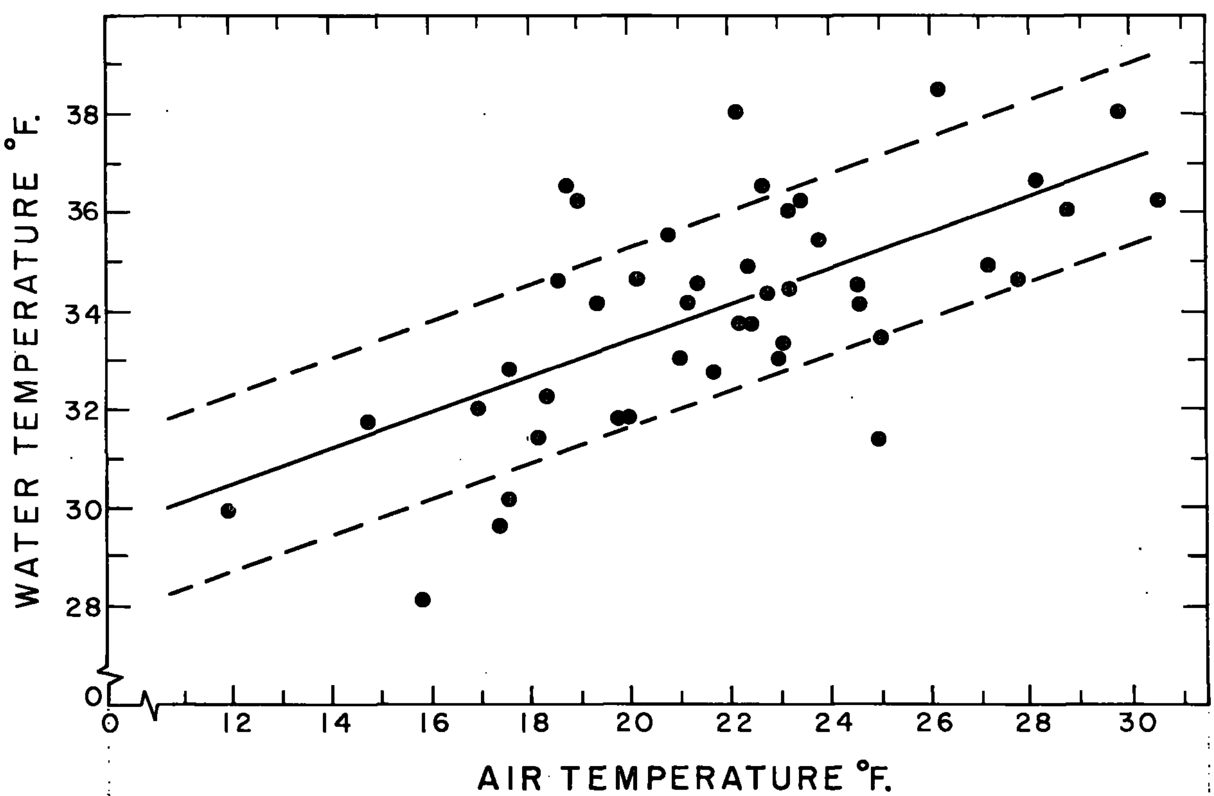

FIGURE 10.—The relation between Eastport, Maine, air temperatures and Boothbay Harbor, Maine, water temperatures for the month of January, 1906–49.

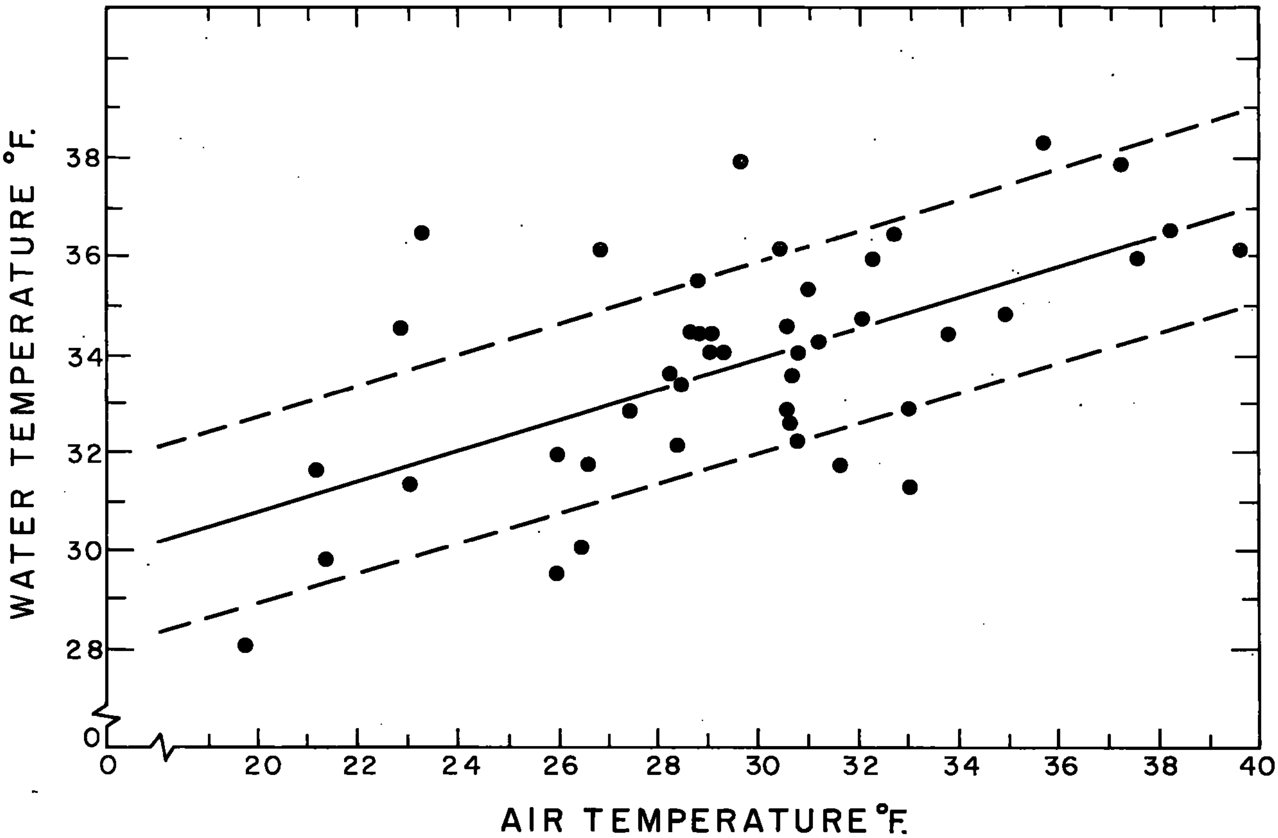

FIGURE 11.—The relation between New Haven, Conn., air temperatures and Boothbay Harbor, Maine, surface water temperatures for the month of January, 1906–49.

TABLE 2.—*Comparison of mean monthly water and air temperatures at Eastport, Maine, for the periods 1878–87 and 1941–50*

[Temperatures in °F.]

Month	Air temperatures		Difference	Water temperatures		Difference
	1878–87	1941–50		1878–87	1941–50	
January	20.30	21.62	+1.32	36.91	37.73	+0.82
February	22.26	22.48	+0.22	34.08	34.68	+0.60
March	28.08	31.20	+3.12	33.82	34.54	+0.72
April	38.51	39.42	+0.91	36.58	36.77	+0.19
May	47.44	48.28	+0.84	39.99	40.06	+0.07
June	54.78	55.35	+0.57	44.02	44.16	+0.14
July	60.67	61.13	+0.97	47.98	48.32	+0.34
August	60.50	61.64	+1.14	50.53	51.33	+0.80
September	55.89	56.80	+0.91	51.23	52.25	+1.02
October	47.34	48.87	+1.53	49.98	51.03	+1.05
November	37.01	39.40	+2.39	46.33	47.82	+1.49
December	25.82	29.39	+3.57	41.48	43.02	+1.54
Mean	41.55	42.96	+1.41	42.74	43.48	+0.74

TEMPERATURE TRENDS IN OFFSHORE WATERS OF GULF OF MAINE

Except for an initial pelagic period common to most marine fish, the more-important commercial species spend the larger part of their existence on the sea bottom, and most pelagic species are found at some time or other throughout the water column. If the trends shown in air temperatures and sea surface temperatures are superficial phenomena producing no important changes in the depths where the various species are found, any changes in distribution and abundance of species inhabiting these depths must be ascribed to causes other than temperature changes. In the following sections, hydrographic data collected at various Gulf of Maine stations between 1912 and 1954 are examined.

GULF OF MAINE TEMPERATURES, 1912–26

The observations recorded during the cruises of 1912 to 1926 (Bigelow 1927, pp. 522–701 and tables, pp. 978–1014) provide the only detailed information that has yet been published on the temperature of the offshore parts of the Gulf of Maine at different seasons and depths. These observations, therefore, must serve as the basis for a comparison between the temperatures of the water of the Gulf in recent years and during the period 1912–26. It seems appropriate, then, to commence this survey with a brief summary of the temperatures of the Gulf for the earlier period.

Depths to 150 meters

Late winter minimum.—The chief cause for the winter chilling that is so conspicuous a phase of the seasonal temperature cycle in the Gulf—reaching its climax some time in February—is the loss of heat by radiation from the surface of the sea during the part of the year when the overlaying air is colder than the water. Since the coldest winds in winter blow out over the Gulf from the quarter between west and north, surface temperatures fall as much as 4° to 5° lower along the western and northern margins of the Gulf than over the central basin or Georges Bank offshore (Bigelow 1927, p. 523, fig. 1). This is equally true whether the season is severe or mild. A few days of near-zero weather, with high west-to-north winds, at any time in late December, January, or February are enough to chill the water in enclosed situations all around the coastline of the Gulf to the freezing point of salt water, i. e., to about 28.9° F. at a salinity of 32°/₀₀. This is about the lowest temperature to be expected around the shoreline of the Gulf, except close to the mouths of rivers. How much ice actually forms under these conditions varies greatly from place to place, depending on local topography, on strength of tidal currents, on rapidity of interchange with the waters outside, and on the thoroughness with which the channels are kept open by passing vessels. For details in this respect concerning harbors, bays, and rivermouths along the coast from Provincetown, Mass., at the tip of Cape Cod, to the mouth of Passamaquoddy Bay, the reader is referred to the Coast Pilot, Atlantic Coast, section A (U. S. Coast and Geodetic Survey, 1918).

Ice has never been known to mass in any amount outside the outer islands and headlands north of Boston. But cases are on record of ice from neighboring harbors and from the shallower parts of Cape Cod Bay massing in heavy fields or windrows, sometimes as much as 10 feet thick, out in Cape Cod Bay (U. S. Coast and Geodetic Survey, 1918; p. 277). It was not unusual in February for the surface to chill below 30° F. there, and along the coast as far north as the offing of Boston.

Two such areas with negative temperatures developed in February 1925: one area off the Scituate-Marshfield shore (31°–32° F.), the other in the central part of Cape Cod Bay (30.9° at the surface on the 9th, and 29.2° at 17 meters) doubtless resulted from the ice that had extended a mile or more offshore south of Wellfleet on December 29, 1924 (Bigelow 1927; p. 655). The area occupied by water colder than 32° may have been more extensive still in Massachusetts Bay in 1934. That year the mean water temperature in Boston Harbor was only 29.8° for February, and a photograph taken from the open Cohasset coast on February 10 shows the pack ice reaching at least 1½ miles seaward. The severe winter of 1920 was of this same general type in the Gulf—to judge from readings of 33.4° at the surface and 32.6° at 50 meters off Boston as late as March 5—also the winter of 1923, when a mean water temperature of only about 30.2° in Boston Harbor for February was followed by vernal warming so tardy that the water off the Scituate shore was still only about 37° at the surface and 32.6° at 80 meters on the 18th of April.

In short, winters of the general order of severity represented by 1925 were not exceptional during the 2d to 4th decades of the 20th century, though they did not recur regularly. But the available record makes it most unlikely that the surface temperature ever falls below 32° to 33° F. for more than a few hundred yards out from tide line off the open coast of the Gulf anywhere to the north of Boston, even during the most severe winters. On February 7, 1925, for example, when the surface temperature was 31° inside Gloucester Harbor, it was 35° only 1 mile outside.

Readings of 32.9° to 34.8° F. taken in March 1920 (a tardy spring) at the 40-meter level—to which vernal warming had not yet penetrated—in the trough between Jeffrey's Ledge and the New Hampshire coast, and near Wood Island, Seguin Island, Great Duck Island, and Petit Manan Island off the Maine coast, point to a seasonal minimum of 32° to 35° all around the periphery of the Gulf northward and eastward from Cape Ann. In the more severe winters, this minimum includes the outer part of the open Bay of Fundy to judge from Mavor's (1923, p. 375) record of 34.6° at the surface and 34.2° at 10 meters, on February 7,

1917. A 40-meter reading by the *Albatross* of 34.8° some 12 miles off Yarmouth, Nova Scotia, on March 23, 1920, suggests similar temperatures along the west coast of Nova Scotia outside the headlands, except for a brief period in the spring when the cold drift from the east passing Cape Sable may temporarily chill the surface there to 32° (p. 311).

At the coldest time of the year, the water in the Gulf not only is nearly uniform in temperature vertically to a depth of 100 meters or so, but the underlying strata at equal depths (like the surface) out over the deep east-central basin and over Georges Bank offshore are some 3° to 6° warmer than the water closer in around the periphery of the Gulf—a contrast illustrated by the 40-meter and 100-meter charts for 1920 (Bigelow 1927, figs. 12 and 13). Consequently, the temperature of the bottom water is progressively higher passing offshore along any line normal to the general trend of the coast as the depth increases, reversing the situation characteristic of summer and autumn. Thus, any bottom-dwelling animals capable of active motion need only move a short distance down the slope into deeper water to escape the rigors of winter; and many do just this.

While any animal at tide line may be in water soupy with ice crystals and at freezing point, as at Sandy Neck, Barnstable, on February 7, 1901, the minimum temperatures on bottom farther out characteristic of winters as severe as those of 1920 and 1925 were about 32° F. in Cape Cod Bay and 32° to 33° northward and eastward from Boston along the 20-meter zone; about 33° to 36° along the 40- to 50-meter zone; and about 35.4° to 39.7° along the 100-meter zone all around the periphery of the Gulf. The only important exception is the sink off Cape Ann, where interchange with the warmer water of the open basin is barred by the surrounding sill, as evidenced by a 100-meter reading there of 34.7° on March 1, 1920, contrasted with 37.5° at this same depth on the slope offshore on February 23, and 38.6° a few miles to the southward on March 24. At 150 meters, the usual winter temperature was between 35° and 39° in the Cape Ann sink and between 42° and 43° in the open basin of the Gulf.

Readings of 36.6° to 37° F. at 70 to 90 meters on the eastern part of Georges Bank, March 11–13, 1920, show that the bottom water chills to about as low a value there as at equal depths around the basin to the northward. But it is doubtful whether bottom temperatures lower than about 40° ever spread to the southwestern part of the Bank, for the *Albatross* recorded a bottom reading of 46.5° there at 70 meters on February 22, 1920.

During the milder winters included in the period 1913–25, the surface probably did not chill below 35° anywhere along the open coast to the north of Boston, unless close in to tide line, to judge from water temperatures of 35° to 39° F., March 4–5, 1921, at stations scattered between the offings of Seguin Island and of Boston; and perhaps the temperature did not fall below 32° to 33° even in Cape Cod Bay. Readings of 35.1° to 35.4° from the 40-meter level downward in the 180-meter sink 15 miles off Gloucester on March 1, 1920, when contrasted with readings of 38.8° to 39° taken there on March 5, 1921, illustrate the temperature difference that is to be expected at comparable localities from winter to winter in the western side of the Gulf.

Yearly maximum.—The surface water is at its warmest sometime in August generally throughout the southern and western parts of the Gulf of Maine (as early as July in some years, particularly in enclosed situations, such as Boston Harbor), but not until sometime in September, or even early October in the northeastern part and in the Bay of Fundy region, where vertical mixing by tidal currents is more active. The regional differences in temperature, also, are much wider in the warm season than in the cold, often within short distances, for reasons the discussion of which would lead us too far afield.[1]

Because of regional differences in the rate of vertical mixing of water by tidal currents, the surface warms much more rapidly in the southwestern part of the Gulf, where the cold of the preceding winter is preserved in the underlying strata into autumn, than in the northeastern part, where the heat taken in at the surface is distributed more evenly downward as the season advances. As a consequence of this widespread contrast, combined with local differences caused by smaller-scale mixings and upwellings, the surface water temperature is some 3.5° to 7° higher in enclosed situations along the western coast of the Gulf, over an isolated pool in Cape Cod Bay, and over the western

[1] See an earlier paper in the Geographical Review (Bigelow 1928), for a general summary and a more extended account of the physical oceanography of the Gulf based on the cruises of 1912–26 (Bigelow 1927).

side of the general basin of the Gulf than it is close in along the western coastline; 14° to 15° higher than in the northeastern part of the Gulf in general; and 7° to 11° higher than over the shoaler and most tideswept parts of Georges Bank and of Nantucket Shoals. In the western part of the Gulf the 20- to 40-meter level is not at its warmest until well into September, the 50- to 70-meter level not until November, the 100-meter level not until late November or early December, and the 150-meter level not until December or even later. On the other hand, in the northeastern part of the Gulf the entire column of water warms at an almost uniform rate, down to at least 100 meters.

In August, when the surface is at its warmest in the western part of the Gulf, the 40-meter level is 5° to 6° colder and the 100-meter level about 4° colder there than in the northeastern part of the Gulf (Bigelow 1927, figs. 53 and 56), reversing the temperature relationship at the surface that is characteristic of that time of year. Since the surface begins to cool in early September in the western part of the Gulf, but not until a month or more later in the eastern, the regional differences in surface temperature decrease as the season advances, until by midautumn the surface is nearly uniform in temperature throughout the Gulf (varying only a degree or two from place to place); and so it continues until the following spring.

At the warmest season during the summers covered by the cruises of 1912 to 1926, surface temperatures ranged from about 64° to 68° F. (occasionally 1° to 2° higher) in Cape Cod Bay and over the western part of the basin; from 61° to 64° close in along the western coastline; from 50° to 53.5° in the northeastern part of the open Gulf in general and in the lower part of the Bay of Fundy; from 53° to 57° over the parts of Georges Bank where tides run the strongest; and from 57° to 61° over the shallower parts of Nantucket Shoals.

The seasonal maxima at deeper levels were as follows in the western part of the Gulf in general and in the lower Bay of Fundy, which cover the regional extremes (table 3).

TABLE 3.—*Seasonal temperature maxima in the western Gulf of Maine, 1912–26, and in lower Bay of Fundy, 1916–17*

[Temperatures in °F.]

Depth (meters)	Western Gulf of Maine		Lower Bay of Fundy [1]	
	Month	Temperature range	Month	Temperature range
20–40	Sept.	50–55.4	Oct.	47–50
50–70	Oct.–Nov.	46.4–48.2	Oct.	45.3–47.8
100	Nov.–Dec.	42.8–46.4	Nov.[2]	44.8–45.3
150	Dec.	42.8–45.5	Nov.–Dec.[2]	44–44.8

[1] Scaled from Mavor (1923, p. 375, table 8).
[2] No November data for 1917.

Depths greater than 150 meters

In the 180-meter sink off Cape Ann, the sill depth of which is about 75 meters, the alternate processes of vernal warming and of autumnal cooling affect the entire column of water from surface to bottom, though in lessening degree at increasing depths. During the winter of 1920–21, for example, the temperature at 150 meters fell from 44.6° F. on December 29, which could not have been much below the maximum for the year, to 39° on March 5, which certainly was close to the minimum for that winter. In the same year, almost as great a seasonal range (4.7°) was registered at 150 meters, between December 30 (44.5°) and March 5 (39.8°) in the 180- to 190-meter trench between Jeffreys Ledge and the coast, where free interchange over the bottom is hindered by an enclosing sill rising to within 120 to 125 meters of the surface. The seasonal difference was about twice as great as this (8.8°) between December 2, 1916 (43.9°) and April 9, 1917 (35°) at 175 meters in the 180- to 208-meter bowl at the mouth of the Bay of Fundy, where the depth of the sill is about 128 to 140 meters (Mavor 1923, p. 375, table 8).

The picture is not so clear for the deep bottom water of the open basin of the Gulf. The changes in temperature that take place there from time to time at depths greater than 150 meters are the combined result of such slight influence as the climatic cycle may exert from above modified or intensified, according to the season, by indrafts of water from the continental slope that enter via the deep channel between Georges and Browns Banks. (For a discussion of this general matter, see Bigelow 1927, p. 690.) High salinities, for example, made it clear that the higher mean temperatures recorded in late summer and autumn than were recorded in late winter or spring near the bottom in the eastern part of the basin during our early cruises (table 4) were the direct result of recent indrafts of this water from offshore. Readings of 47.1° F. at 200 meters and of 46.3° at

250 meters at a station in the southeastern part of the basin in July 1914 and of 46.7° and 47° at 190 meters in the northeastern part in August show that the temperature of the slope water moving inward at some intermediate level via the channel between Georges and Browns Banks is often higher than the reading recorded near the bottom. Readings near the bottom have ranged from 42.9° to 45° (average, 44.2°) at 4 stations in March and April 1920, July 1915, and July 1914.

TABLE 4.—*Mean temperatures recorded in Gulf of Maine at depths of 160 to 330 meters, by season*

[Recorded in 1912-16, 1919-21, 1923, and 1926. Temperatures in °F.]

Month	Western part of basin		Eastern part of basin	
	Mean temperature	Number of readings	Mean temperature	Number of readings
Feb.-Mar.	41.2	11	41.0	9
Apr.-May	41.8	9	41.4	6
June-July	42.0	3	45.9	7
Aug.-Sept.	43.1	10	43.7	11
Nov.-Jan.	41.4	4	44.5	1

Since it is the actual temperature with which we are primarily concerned in the present discussion, it is sufficient to add that the 71 readings taken at 160 to 330 meters in various parts of the basin, summarized in the preceding table, ranged between 38.4° and 47° F., with 54 of the 64 readings falling between about 40° and 44°. There is nothing in the record to suggest that the temperature of the deep bottom water within the basin of our Gulf has fallen appreciably below these limits, or risen above them, in any year since Gulf temperatures have been recorded.

TREND IN WATER TEMPERATURES BETWEEN 1912–26 AND 1953–54

For the period 1926 to 1953, our most instructive sources of information as to ups and downs of temperature around the shoreline of the Gulf of Maine are the mean monthly temperatures that have been reported by the United States Coast and Geodetic Survey for Boston since 1922 and for Eastport since 1930 (U. S. Coast and Geodetic Survey, 1951; with subsequent data contributed in advance of publication); the mean monthly temperatures for St. Andrews, New Brunswick, 1921 to 1947, tabulated by Hachey and McLellan (1948, p. 357); and the mean annual temperatures for that same port, 1921 to 1953, published by Lauzier (1954, p. 8, fig. 1). Lauzier (1952, p. 6), has already pointed out that "St. Andrews water temperatures reflect general water conditions over a large section of the Atlantic coast" of Canada. On geographic grounds, a shift in either direction at Boston that persists through several years may be expected to prove an equally reliable index to any upward or downward shifts that may have taken place in the western part of the Gulf in general.

At Boston, the mean temperature for the coldest month of the year did not show any long-term trend, either upward or downward, from 1922 through 1936. While it was higher for the winters of 1929 to 1933 (33°+) than for those of 1922 to 1926 (below 32°), it was again lower than 32° in 1934, 1935, and 1936, with means as low as 29.8° for 1934 and 1936. But the mean for the coldest month, which had averaged 31.7° for the 8-year period 1922–29, averaged 33.1° for the period 1930 to 1937, 32.6° for 1938 to 1945, 33.8° for 1946 to 1948, 36.7° for 1949 to 1951, and 36.5° for 1952 to 1954. Furthermore, there has not been a winter since 1944 when the mean water temperature for the coldest month has fallen below 32° in Boston Harbor, though this happened in 11 of the preceding 21 years.

Summer air temperatures, also, have clearly tended upward in Boston Harbor during the past 30 years (1922–53), whether expressed as the departure from the mean for July–September or as the mean for the warmest month for successive 4-year periods (table 5). Indeed there has not been a summer during the 13-year period 1941–53 when the mean temperature for the warmest month was not higher than it was in 8 of the 18 years from 1922 to 1940; while there has been only one summer (1948) since 1941 when the mean temperature was not at least as high as 66.6°, a level equalled only 6 times during the 19-year period 1922–40. Similarly, the mean temperature for the 2 warmest months combined, which was not above 65.3° for any 2 consecutive years between 1922 and 1941 (average, 64.1°) has been 66.5° or higher (mean, 67.1°) in every subsequent year, with the sole exception of 1948.

The mean water temperature for the year as a whole also has tended upward at Boston and by about the same amount (table 6). And while mean annual temperature is of little ecological significance in regions where water temperatures differ widely from season to season, it does have the advantage, as an index to long-term fluctuations, of smoothing out the short-period ups and downs that loom large when individual months are compared for different years.

TABLE 5.—*Mean air temperatures for warmest month of year at Boston to nearest degree, by periods, 1922–53*

[Temperatures in °F.]

Period	Mean air temperature	Period	Mean air temperature
1922–25	64	1938–41	65
1926–29	65	1942–45	67
1930–33	65	1946–49	68
1934–37	66	1950–53	67

TABLE 6.—*Mean water temperatures in Boston Harbor to nearest degree, by periods, 1922–53*

[Temperatures in °F.]

Period	Mean water temperature	Period	Mean water temperature
1922–25	48	1938–41	49
1926–29	49	1942–45	[1] 50
1930–33	50	1946–49	52
1934–37	49	1950–53	52

[1] Mean for period 1942–45 based on 3 years only, lacking data for 1944.

Water temperatures, similarly, have trended upward unmistakably since a cold period in the early 1940's at Eastport, a short distance within Passamaquoddy Bay (tributary to the lower Bay of Fundy), both for the warmest season and for the coldest (table 7), by about the same amount as at Boston (3°–4°). A mean of 51.9° (50.1°–53.8°) for the 2 warmest months combined, for the period 1930–41, contrasts with a mean of 53.7° (52.1°–54.6°) for 1949–53.

We also read in the annual report of the Fisheries Research Board of Canada for 1951 (p. 34) that

TABLE 7.—*Mean water temperatures for coldest and warmest months at Eastport, Maine, by 2-year periods, 1930–53*

[Temperatures in °F.]

Period	Mean temperature in—		Period	Mean temperature in—	
	Warmest month	Coldest month		Warmest month	Coldest month
1930–31	53.4	34.0	1942–43	50.9	32.4
1932–33	52.5	35.6	1944–45	52.6	34.4
1934–35	51.8	31.2	1946–47	53.7	34.5
1936–37	52.6	35.2	1948–49	52.9	35.1
1938–39	51.9	33.9	1950–51	53.3	37.4
1940–41	50.3	33.3	1952–53	53.3	37.1

surface water temperatures at St. Andrews, farther up the Passamaquoddy Bay "have shown a fairly definite upward trend for the past ten years, with temperatures in 1951 the highest in thirty years' records." Lauzier (1954, p. 7) also has recently remarked "that the waters of the (St. Andrews) area are undergoing a general warming since 1940." The ups and downs from year to year have not been great enough to mask this warming on Lauzier's graph of mean annual temperatures (p. 8, fig. 1), although the difference from one year to the next has been about as wide in extreme cases (up to about 3.5°) as the general upward trend has been from the early 1940's to the early 1950's. That this warming trend has extended eastward and northward to the waters along the outer coast of Nova Scotia and to the Magdalen shallows in the southern side of the Gulf of St. Lawrence is apparent from Lauzier's graph of mean yearly temperatures at Sambro Lightship, off Halifax, Nova Scotia, and from his tables of quarterly averages of surface temperatures there and at the Magdalen Islands, during the periods 1940–44 and 1949–53 (Lauzier 1952, p. 6, fig. 1; 1954, pp. 9 and 10, tables II and III).

COMPARISON OF TEMPERATURES FOR 1953–54 AND 1912–26

March–April

Since a colder period during the early 1940's, water temperatures have so clearly averaged some 2° to 4° higher at Boston Harbor, at Eastport, Maine, and at St. Andrews, N. B., than they had previous to about 1940–42 (p. 306) as to make the assumption reasonable that a corresponding temperature change had taken place offshore. Comparison of the bathythermograph records taken by the *Albatross III* during March 1953 with the temperatures recorded during our late winter and early spring cruises of 1913 to 1925 (p. 302) corroborate this assumption, at least for the upper 150 meters.

The water may not have been significantly warmer at the mouth of Massachusetts Bay and out in the basin in the early spring of 1953 than at that season in the warmer of the years included within the earlier period (table 8). The difference between readings—1.5° to 3° higher at neighboring localities on March 30–31, 1953, than on March 5, 1921—may be no greater than can be charged

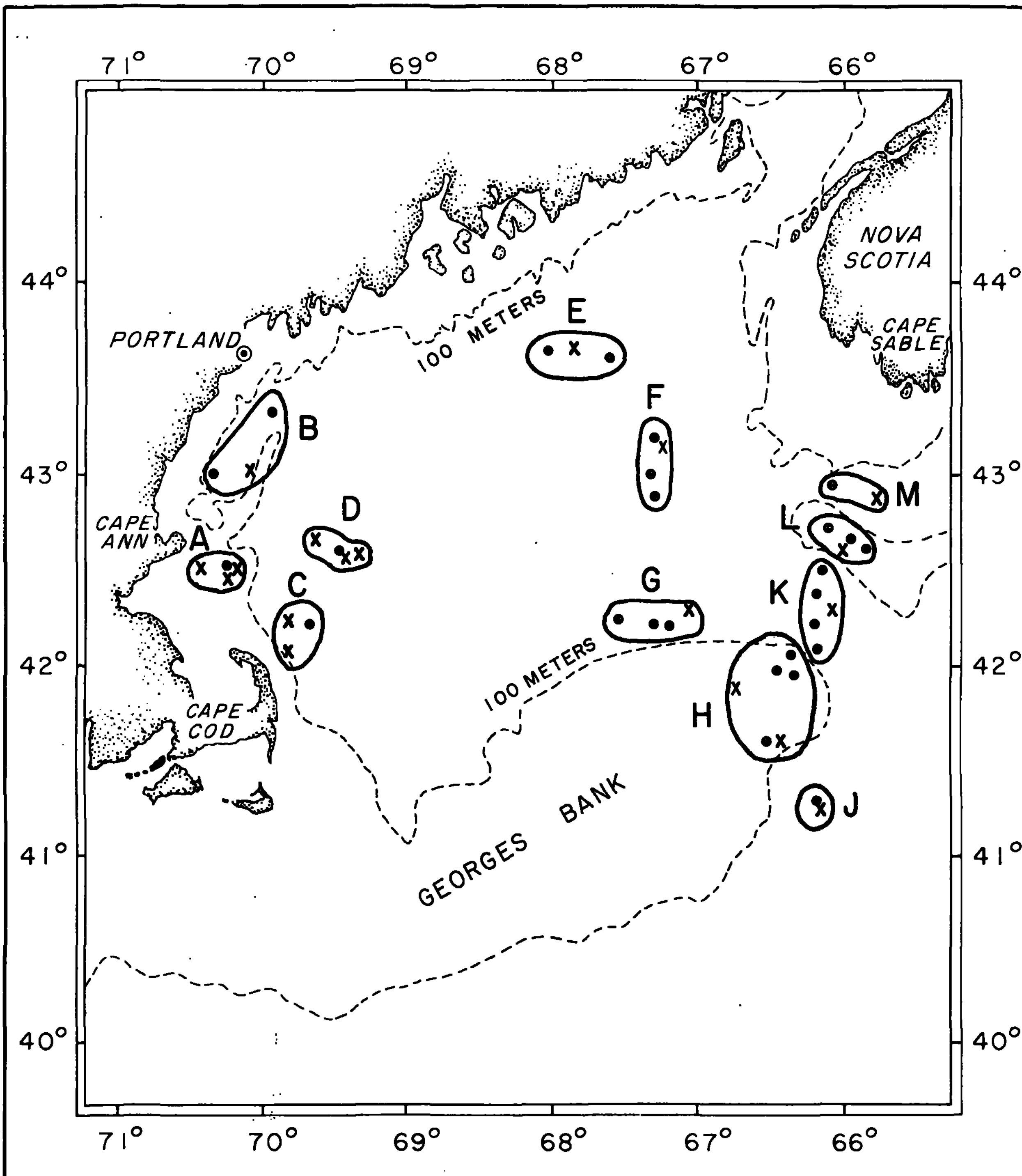

FIGURE 12.—Areas where comparable records of water temperatures were taken in March and May 1953 (dots) and in March of the earlier years of 1913, 1920, and 1921 (crosses).

against the warming to be expected during a 3-week period at that season. But the temperature off Gloucester was some 2° warmer from surface to bottom on March 31, 1953, than on April 3, 1913—a spring that was more fairly representative of temperature conditions prevailing 30 to 40 years ago than was 1921—and 3° to 5° higher than on either March 1 or April 9 of 1920, a relationship the reverse of what was to be expected on seasonal grounds, other things being equal.

TABLE 8.—*Water temperatures at various depths at the mouth of Massachusetts Bay*

[Area A, fig. 12. Temperature in °F.]

Depth (meters)	1913		1920		1921	1953
	Mar. 4	Apr. 3	Mar. 1	Apr. 9	Mar. 5	Mar. 31
0	37.2	39.3	36.5	38.0	38.5	41.4
20	37.2	39.3	36.5	36.5	38.5	41.2
40	37.4	39.3	35.4	38.6	38.6	41.4
100			34.7	38.8	38.8	41.0
120			34.8	38.9	38.9	41.1

Contrasts of the same order between 1953 and 1920 are demonstrated in table 9 for the stations shown in figure 13. In some instances, the difference in the dates would point to a relationship of the opposite order, other things being equal. In summary, observations taken at comparable dates and localities in March and April of 1920 and of 1953 show that the water in the open basin of the Gulf, outside the 100-meter line north of Georges Bank and in the channel between Georges and Browns Banks averaged some 2.7° to 4.4° warmer, in general, in March 1953 than in April 1920, at all depths from the surface down to 150 meters.

The comparison between early spring temperatures for 1953 with those for 1920 cannot be extended to Browns Bank (area L, fig. 12), for the Bank was not visited during the March cruise of 1953. Mean temperatures, it is true, were between 2° and 4° higher there, from surface to bot-

TABLE 9.—*Comparison of temperatures in the Gulf of Maine in 1920 and 1953, by areas*

[See fig. 12 for location of areas. Temperature in °F.]

Area and date	Temperature in depths of—						
	0 meters	20 meters	40 meters	80 meters	100 meters	135 meters	150 meters
Mouth of Massachusetts Bay (area A):							
April 9, 1920	38.0	36.5	38.6	38.8	38.9		
March 31, 1953	41.4	41.2	41.4	41.0	41.1		
Trough west of Jeffreys Ledge (area B):							
April 9, 1920	37.5	36.4	36.1		38.5	39.5	
March 22, 1953	41.0	41.0	41.0		42.5	44.0	
Off northern Cape Cod (area C):							
March 24, 1920	36.5	36.0	36.0		38.5		
March 24, 1953	41.1	40.5	40.5		41.5		
Western side of basin, off Cape Ann (area D):							
March 24, 1920	36.5	36.0	[1] 36.5		38.5		[1] 40.2
March 23, 1953	40.7	40.5	40.5		41.0		44.0
Off Mount Desert Island (area E):							
April 11, 1920	37.5	36.2	36.6		38.4		40.8
March 21, 1953	40.9	41.0	41.0		43.2		44.5
East-central part of basin (area F):							
March 23, 1920	38.5	38.1	38.4		39.7		40.8
March 21–23, 1953: Range 3 stations	38.7–41.6	39.0–41.3	41.0–42.5		43.5–44.0		[2] 44.5–45.5
Southeastern part of basin (area G):							
April 17, 1920	38.5	38.1	37.9		37.7		40.0
March 21–24, 1953: Range 3 stations	40.3–41.0	39.9–41.5	40.5–41.5		40.9–42.5		[3] 46.5
Eastern part of Georges Bank (area H):							
April 16, 1920: Range 2 stations	39.0–39.5	38.4–38.5	37.0–38.2	38.5–38.8			
March 29–April 1, 1953: Range 4 stations	41.8–42.3	42.0–42.5	42.2–42.5	[2] 42.2–42.4			
Southeastern slope of Georges Bank (area J):							
April 16, 1920	39.5	38.5	38.4		39.6		43.7
March 27, 1953	38.6	39.5	41.5		44.0		47.0
Channel between Georges and Browns Banks (area K):							
March 13 and April 16, 1920: Range 2 stations	33.3–33.3	37.2–37.6	37.7–37.8		42.6–43.7		42.6–44.3
March 23–30, 1953:							
Range 4 stations	38.2–42.2	38.5–42.0	39.5–42.0		41.5–44.5		
Range 3 stations							46.5–47.5
North of Georges Bank from the 100 meter line, and between Georges and Browns Banks:							
March 11–April 16, 1920:							
Range 15 stations	33.3–39.7		34.9–38.6		42.6–43.7		
Range 11 stations							42.6–44.3
March 19–April 1, 1953:							
Range 60 stations	38.1–42.6						
Range 57 stations			39.0–42.2		40.5–46.0		
Range 16 stations							44.5–47.5
Browns Bank (area L):							
April 16, 1920: Mean 4 stations	38.5	38.3	38.0	[3] 37.8			
May 3–5, 1953: Range 4 stations	39.4–42.0	39.8–42.0	41.5–42.1	[3] 42.0			

[1] Scaled from vertical graph for this station.
[2] 2 stations only.
[3] 1 station only.

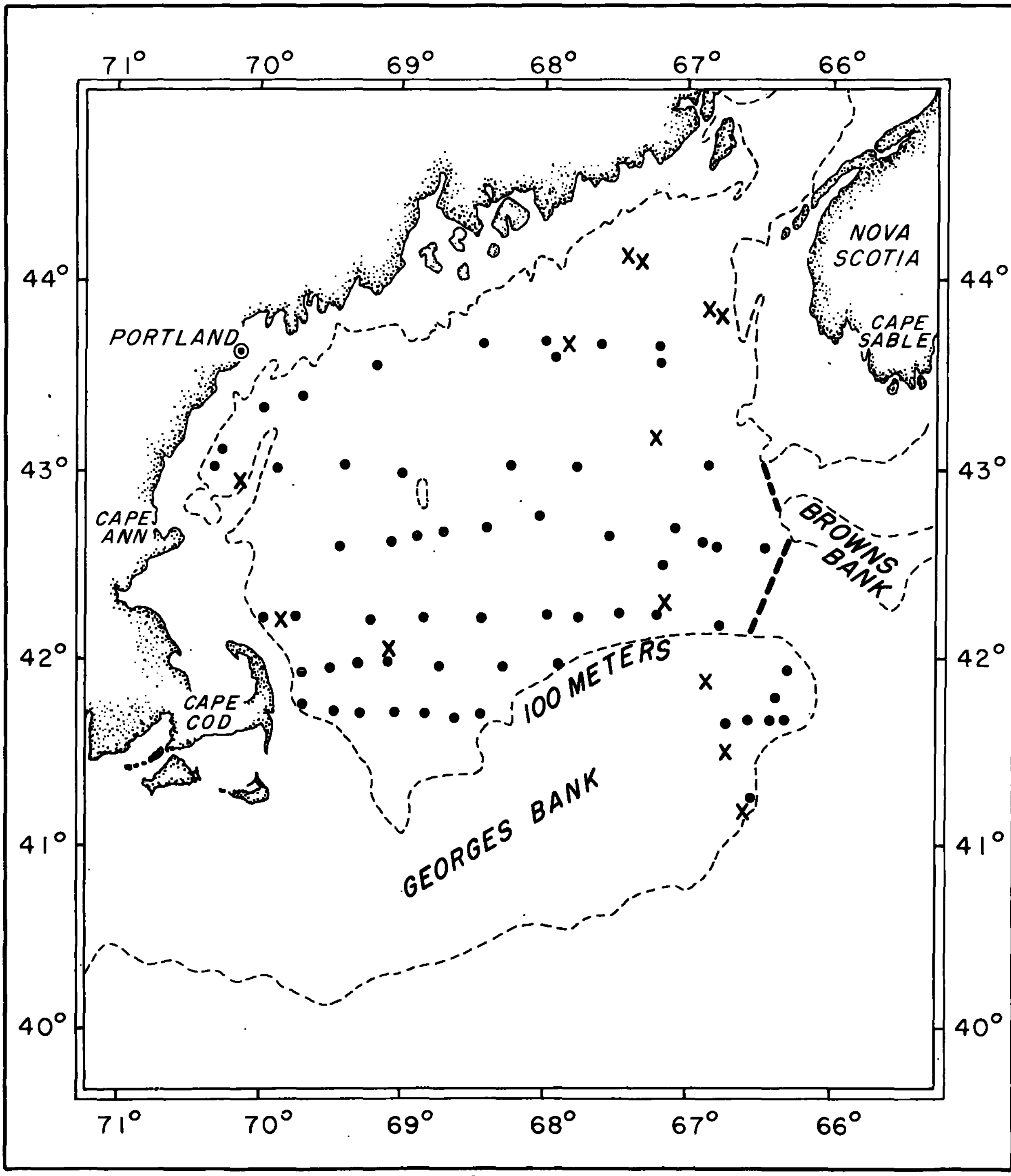

FIGURE 13.—Stations where the temperature was recorded on March 19–April 1, 1953 (dots) and on March 11–April 16, 1920 (crosses).

tom, on May 3–5, 1953, than on April 16, 1920 (table 9). But the difference between the two sets of observations is seemingly no wider than can be credited to the warming to be expected to take place over the Bank, in any given spring, during the 3-week interval between the dates when the observations were made in the 2 years. The difference, also, between slightly higher readings in the deep channel north of Georges Bank (area M, fig. 12) on March 23, 1953, than on the 20th of that month in 1920 (table 9), is no greater than is to be expected there from one spring to another during any run of years, depending on the relative severity of the preceding winter, and on the seasonal schedule and temperature of the Nova Scotian drift from the east. But bottom temperatures reported from Browns Bank in 1952, of about 41° to 43° F. between February 15 and March 18 and of about 39° to 46° between April 29 and May 11 (McLellan 1954, p. 408, figs. 2 and 3), contrasted with bottom readings there in 1920 of 38.1° on March 13 and of 37.8° on April 16, point to slightly warmer bottom water on Browns Bank in early spring in 1952 than in 1920. The surface, however, was about as cool in late March of 1953 as in 1920 over the east-central part of the basin, and about 1° colder than in 1920 over the southeastern slope of Georges Bank.

The existence of an area occupied by water as cold as 36° to 40° F., as outlined in the surface-temperature charts for the eastern part of the Gulf of Maine (fig. 14), shows that the responsible factor was the cold Nova Scotian drift, which had spread westward past Cape Sable before the last week of March in 1953 but did not do so until April in 1920, or, seemingly, in 1915 (Bigelow 1927: p. 554, fig. 25; p. 578). In the seasonal schedule of the drift, 1953 paralleled 1919, when a U. S. Coast Guard cutter on ice patrol reported a surface water temperature of 32° (but 38.7° to 41° in the underlying water) on March 29, 1919, in the east-central part of the basin of the Gulf (Bigelow 1927, p. 553) where the temperature was 38° to 40° at about the same date (March 23) in 1953.

The contrast in this connection between 1953 (a warm spring in the sea), on the one hand, and 1919 (a cold spring) and 1920 (a cold and tardy spring), on the other, is good evidence that the date on which the cold Nova Scotian drift affects the temperature of the surface beyond Cape Sable and the extent to which it does so are not correlated with the minimum to which water has chilled during the preceding winter in the Gulf of Maine, or with the relative forwardness of vernal warming there, but that they are governed by events along the Nova Scotian shelf to the eastward and within the Gulf of St. Lawrence.

In 1953, surface water slightly colder than 40° still occupied the area off Cape Sable (fig. 15) as late as the first week in May. The westward drift must have ceased soon thereafter, however, if it had not done so already, for the temperature of the surface water on Browns Bank had risen to 46.5°–48.5° by the last of May. It appears, thus, that any tempering effect mild air temperatures over the land mass in winter may have on water temperatures off southern Nova Scotia early in the following spring is counteracted more or less completely by the chilling effect of the drift from the east.

August–September

It is clear, from the evidence we have presented, that the waters of the Gulf from the surface down to 150 meters entered the season of vernal warming between 1° to 2° and 4° to 4.5° warmer in 1953 than in the period 1913–25, though perhaps no warmer than in the warmest of the years included within that period. The data also show that the temperatures of the Gulf continued about that much warmer during the summer of 1953, though with certain regional exceptions. In Boston Harbor, the mean temperature of the warmest month of 1953 (August, 67.2° F.) was about 2.6° higher than the corresponding mean (64.6°) for the 5-year period 1922–26. Similarly, Frank J. Mather III reported surface readings of 70.5° to 71.5° in the eastern side of Cape Cod Bay, with 70° in the central part, as early in 1953 as July 19. This contrasts with 64.6° recorded by the *Halcyon* for the center of the Bay on August 24, 1922, when the surface there was no doubt near its warmest for the year. In 1953, as late as the first week of September, the surface was still as warm as 68° to 70° over the southwestern part of the open basin of the Gulf, where 62.8° had been reported on August 4, 1913, 67.2° to 68.0° August 23–24, 1914, and 66.9° on August 12, 1926. Similarly the surface readings in the general offing of Cape Ann (area A, fig. 16) averaged about 2.7° higher at stations in August 1953 than at 15 stations in that same month in 1912, 1913, 1914,

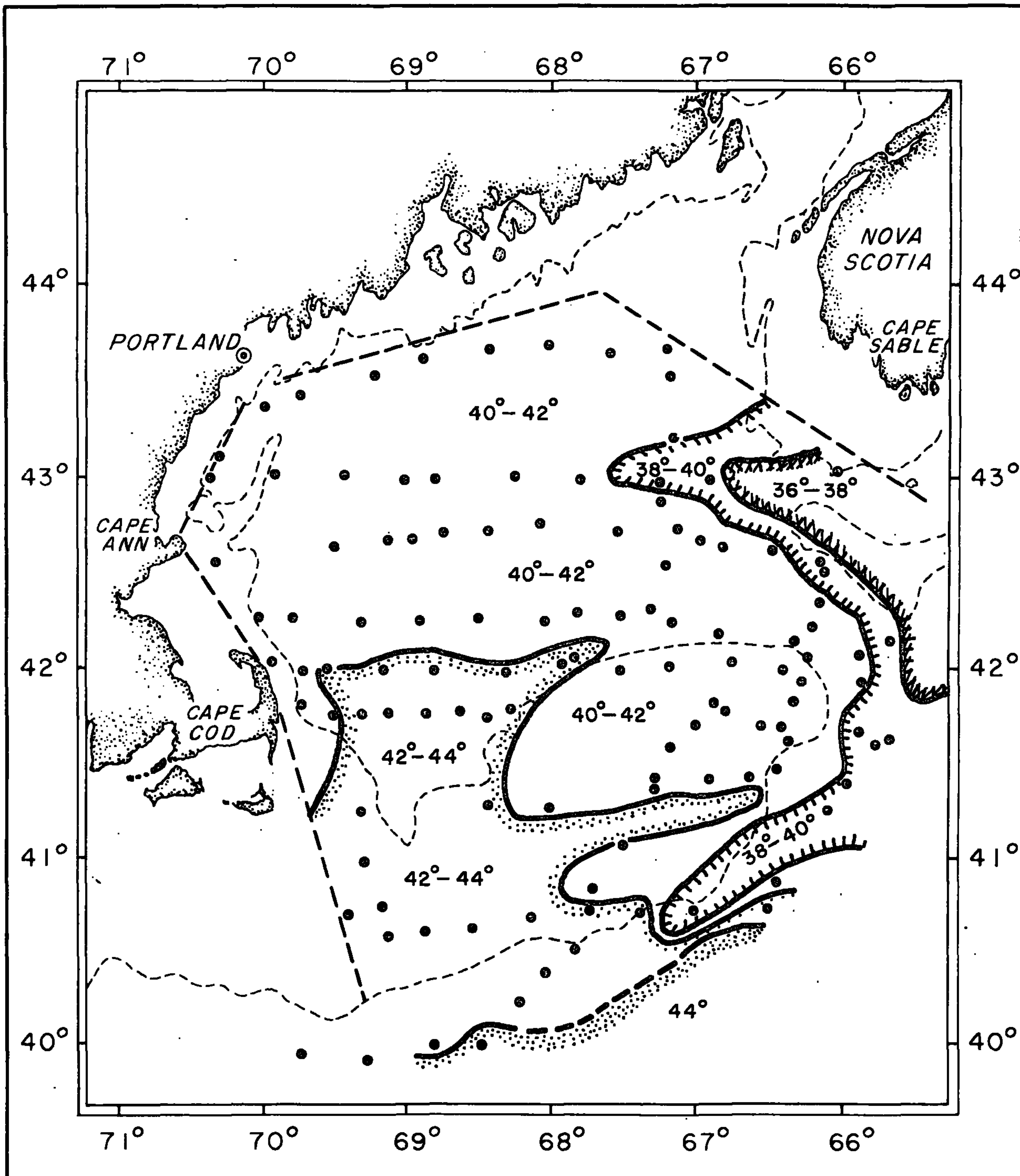

FIGURE 14.—Surface temperatures recorded in the Gulf of Maine, March 19 to April 1, 1953. Dots indicate location of observations. (Temperatures in degrees Fahrenheit.)

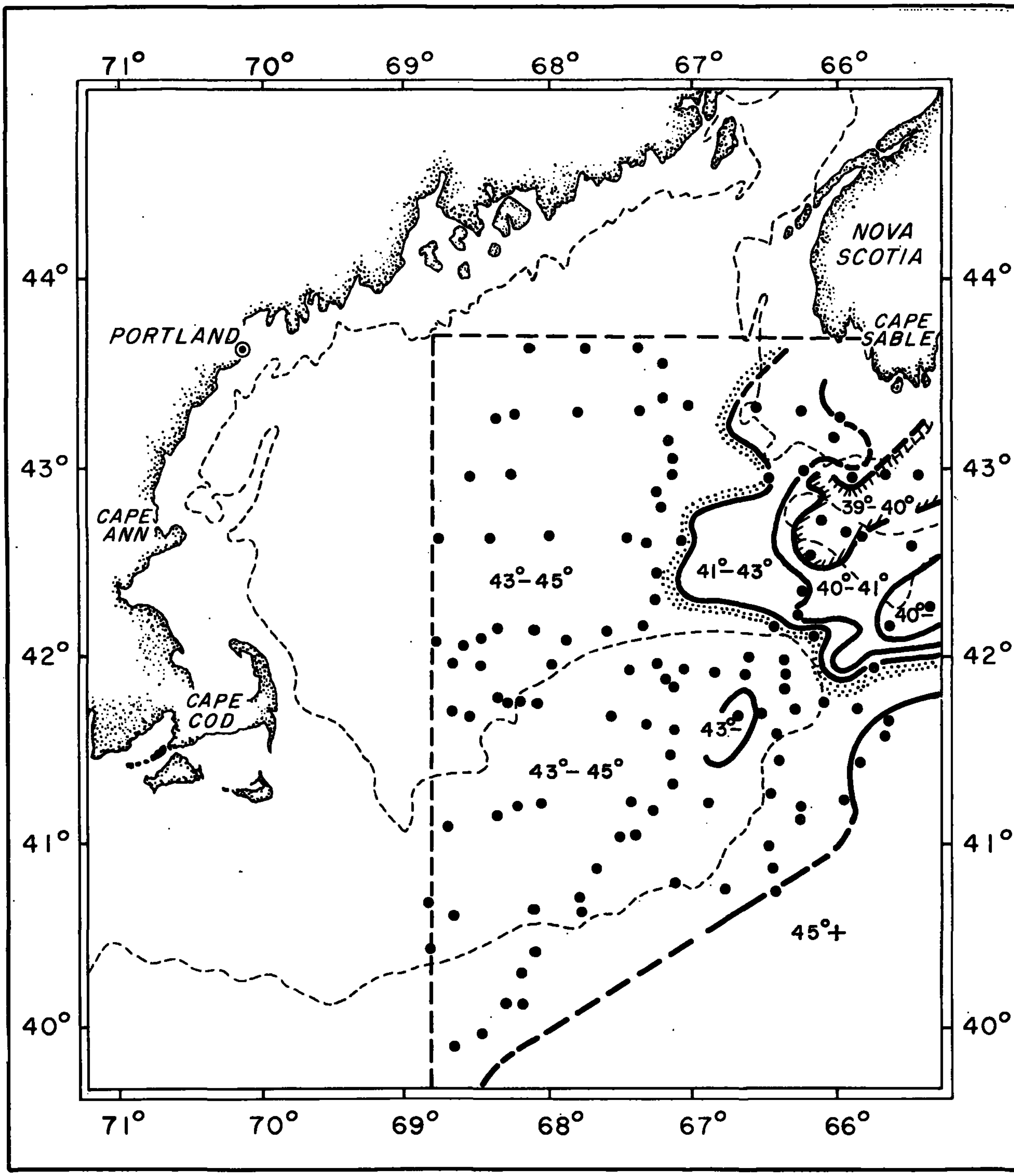

FIGURE 15.—Surface-water temperatures in the eastern part of the Gulf of Maine, April 24–May 8, 1953. Dots indicate location of observations. (Temperatures in degrees Fahrenheit.)

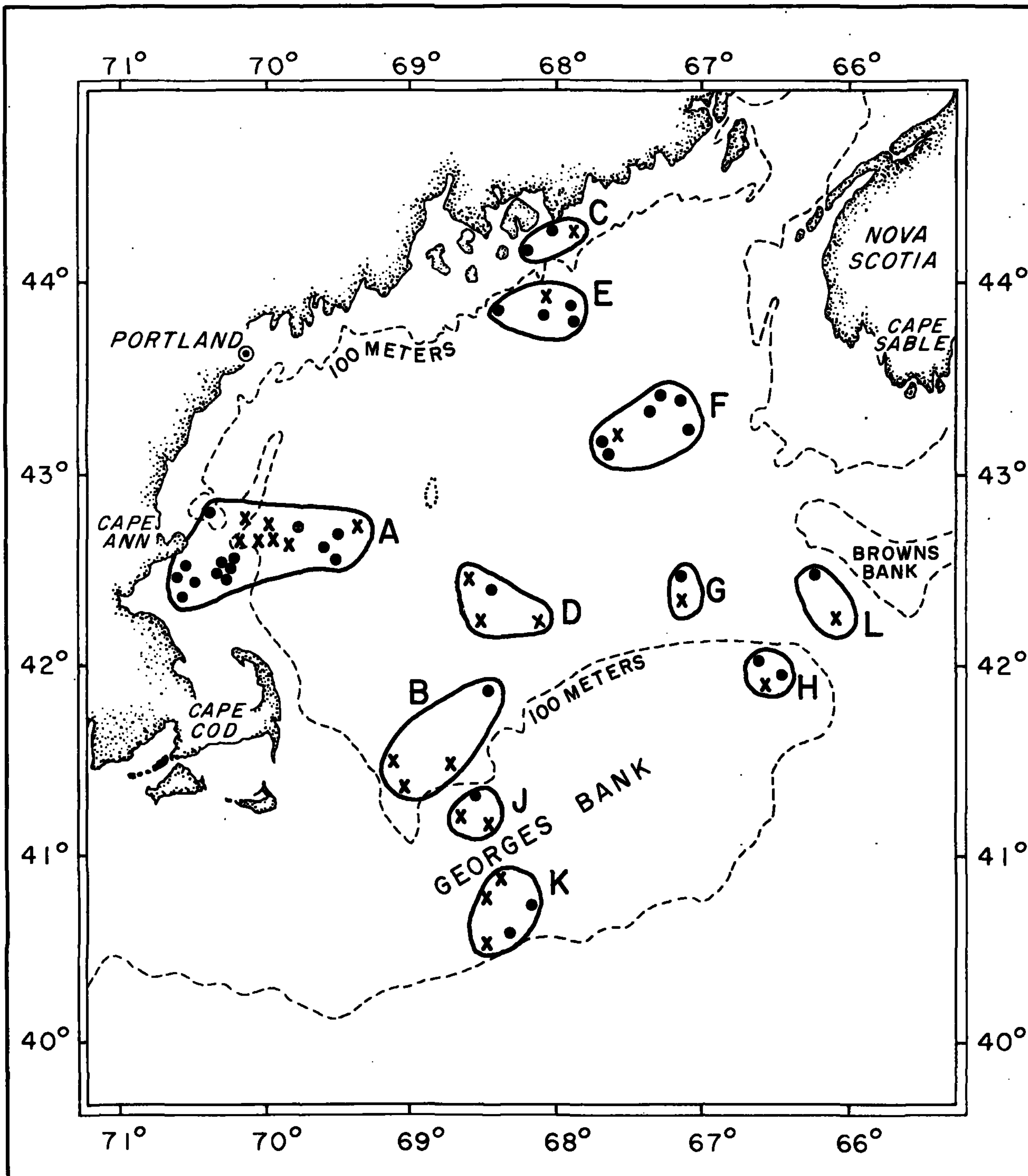

FIGURE 16.—Areas where comparable observations were taken in August and early September 1953 (crosses), and in late summer of earlier years (dots).

1915, 1923, and 1926. While the maximum temperature recorded in this particular area was as high (68°) for 1915 as for 1953, the average for the summer of 1953 not only was higher than any individual August reading for the earlier years, with three exceptions, but was about as much higher as comparable data for Boston Harbor.

Below-surface readings in the general offing of Cape Ann in August show that, while those for 1953 [2] overlap somewhat those for 1912 to 1926 both in the upper 40 to 50 meters and at the greatest depths sampled, the means for successive strata were consistently higher for 1953, with an overall difference averaging about 3.5° for the water column as a whole (table 10).

TABLE 10.—*August temperatures off Cape Ann, in 1953 and in earlier years, to nearest degree*

[Area A, fig. 16. Temperature in °F.]

Depth (meters)	Number of stations in—		Temperature range in—		Mean in—		Mean departure in 1953
	1912–26	1953	1912–26 [1]	1953	1912–26	1953	
0	15	8	60–68	65–68	63	66	+3
15–20	15	7	49–58	51–60	52	55	+3
40–50	15	7	41–46	46–47	44	47	+3
70–100	15	7	37–43	44–46	41	45	+4
110–130	15	5	38–41	44–45	39	44	+5
150–170	8	1	37–42	44–45	40	44	+4
180–274	5	1	41–45	43–45	43	44	+1

[1] Partly from direct readings; partly as scaled from graphs for the individual stations.

It is especially instructive that the water in the western side of the Gulf was between 1.5° and 5.7° warmer in 1953 than in 1926 (table 11), as the mean water temperature for the warmest month was almost precisely the same (67.2° and 67.3° F.) in both summers in Boston Harbor. Evidently the temperature at Boston for any one summer is not a reliable index to conditions in the open Gulf at that time of year, whether for the surface or for the underlying waters. Consequently, mean water temperatures for the warmest month as high as 67.3° to 68.9° in Boston Harbor in 1926, 1928, 1941, or 1944 do not necessarily mean that the open Gulf was as warm in any one of these summers as it was in 1953, following 4 years when the mean for the warmest month at Boston rose to 67.2° to 69.2° and the mean for the coldest month did not fall below 35.9° to 37.8°. On the other hand, it seems that the residual effects of a winter colder than usual may be expected to persist through the summer in the western side of the Gulf in the underlying strata of water. Such, at least, was the case in 1923, when the mean temperature of the water in Boston Harbor for the coldest month was 30.2°, following which the temperature at 80 to 155 meters in the partially enclosed sink off Cape Ann was 37.4° to 37.6° as late in the season as August 9, which contrasts with 40.1° to 42.8° there between the 9th and 31st of that month in 1913, 1914, 1915, and 1916 (4 stations).

[2] Readings for 1912 to 1926 taken by reversing thermometer, those for 1953 by bathythermograph.

TABLE 11.—*Water temperatures off Cape Ann in August 1926 and in August 1953*

[Area A, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 11, 1926	Aug. 19–20, 1953		Mean departure in 1953
		Temperature range	Mean	
0	64.4	64.6–68.0	65.9	+1.5
20	48.7	51.5–58.0	54.4	+5.7
40	42.4	47.2–49.0	47.9	+5.5
100	40.6	44.0–45.5	44.5	+3.9
180	40.5	44.0	44.0	+3.5

From the available information it appears likely that the contrast between August temperatures in 1953 and in the earlier summers of record, for the water column as a whole, was in general about as we have outlined around the western and northern slopes of the Gulf. In the southwestern part of the basin, for example, near the 100-meter line (area B, fig. 16; table 12), mean temperatures at 0, 40, 100, and 150 meters were 2.2° to 4.2° higher at 3 stations on September 6, 1953, than on August 23, 1914. The summer of 1953 was relatively warm, as is illustrated by the temperatures of the water, surface to bottom, along the eastern part of the coast of Maine and in the vicinity of Mount Desert Island (area C, fig. 16; table 13). Here the temperature was 1.5° to 3° higher on August 16, 1953, from the surface to near the bottom (37–40

TABLE 12.—*Water temperatures in southwestern part of basin in August 1914 and in September 1953*

[Area B, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 23, 1914	Sept. 6, 1953	
		Range [1]	Mean
0	67.2	69.0–69.9	69.6
40	43.8	46.5–49.5	47.5
100	39.6	43.5–44.0	43.8
150	41.7	43.7	43.7

[1] 3 stations.

meters) than on August 21, 1912, or on August 13, 1913, and between 3° and 8° higher than on August 5, 1923, a summer following a very cold winter. Temperature conditions were similar in the lower part of the Bay of Fundy, where readings of 12.5° C. (54.5° F.) at 25 meters and 12.3° C. (54.2° F.) at 75 meters for September 1953 contrast with September averages of 10.7° C. (51.2° F.) and 9.7° C. (49.4° F.) at these same depths for the period 1921–42.[3]

TABLE 13.—*Water temperatures near Mount Desert Island in August 1953 and in earlier years*

[Area C, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 21, 1912	Aug. 13, 1913	Aug. 5, 1923	Aug. 16, 1953
0	55	55	53.1	56
20	50.7	51.0	46.7	55.5
37–40	49.8	48.8	45	52.5

In the central and eastern parts of the Gulf, however, it was only in the underlying water layers that August-September temperatures were consistently higher in 1953 than in the earlier years of record, and even so, they varied considerably according to locality. Thus the surface in the central part of the basin (area D, fig. 16; table 14) averaged about 1° colder (3 stations) on September 6, 1953, than on August 23, 1914; whereas the underlying strata, to the greatest depth sampled, were 2.3° to 5.6° warmer in 1953 than in 1914. The situation was similar to the northward in the neighborhood of Mount Desert Rock (area E, fig. 16; table 15), where the readings at 40–150 meters were between 1° and 4.8° warmer on the average on August 16, 1953, than in any previous August of record, but where a recorded range of about 2.5° from year to year in the surface temperature was perhaps no wider than might be expected from one day to the next, from one stage of the tide to another, or within a short distance, in this region of strong tidal currents.

TABLE 14.—*Temperatures in central part of basin in August 1914 and in September 1953*

[Area D, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 23, 1914	Sept. 6, 1953		Mean departure in 1953
		Temperature range [1]	Mean, 1953	
0	66.5	64.6–66.6	65.5	−1.0
40	46.1	51 –53	51.7	+5.6
100	39.1	44.5–46	45.0	+5.9
150	41.2	44.2–47.0	45.5	+4.3
175	43.2	44.5–46.5	45.5	+2.3

[1] 3 stations.

TABLE 15.—*Water temperatures off Mount Desert Rock in August 1953 and in earlier years*

[Area E, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 13, 1913 [1]	Aug. 13, 1914 [2]	Aug. 6, 1923 [1]	Aug. 20, 1926 [2]	Mean 1913–26	Aug. 16, 1953	Departure in 1953
0	55.0	55.9	55.0	57.5	55.9	56	+0.1 to −1.5
20	49.7	50.5	49.5	53.9	50.9	52	+2.5 to −1.9
40	47.5	47.2	45.5	48.6	47.2	50.5	+1.9 to +5
100	45.6	44.9	40.0	42.1	43.2	48.0	+2.4 to +8
150	44.3	42.9	41.2	42.9	42.8	46.5	+2.2 to +5.3
175	43.6	44.5			44.1	45.5	

[1] Readings scaled from vertical graph for this station.
[2] Readings scaled in part from vertical graph for this station.

In the eastern side of the basin, near the Nova Scotian slope (area F, fig. 16; table 16), the readings for 1953 were 1.4° to 4.0° higher than the combined means for 1912, 1913, 1914, 1915, and 1926, for the water column as a whole. But the surface was slightly the warmest in 1914, the 25–40 meter stratum of nearly the same temperature in 1953 as in 1913, and the bottom water at 220 meters of nearly the same temperature in 1953 as in 1912. It is doubtful, also, whether the differences between the readings for August 18, 1953, and those for July 23, 1914, and August 9, 1926, are indicative of any general periodic trend for the southeastern part of the basin, near the source of the indrafts of slope water (area G, fig. 16; table 17). While the 100- to 150-meter stratum was warmer in 1953 than in 1926 and the 20- to 40-meter stratum was 3.6° to 4.1° colder in that summer than in 1926, the bottom stratum was some 2° to 3° warmer in 1914 than in either 1926 or 1953.

TABLE 16.—*Water temperatures in eastern side of basin in August 1953 and in earlier years*

[Area F, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 14, 1912	Aug. 12, 1913	Aug. 13, 1914	Aug. 20, 1926	Mean 1912–26	Aug. 17, 1953	Mean departure in 1953
0	59	60.5	63.5	61.9	61.2	62.6	+1.4
25–40	47.7	51.1	43.5	43.9	46.6	50.0	+3.4
90–100	45.3	42.0	41.5	40.1	42.2	46.2	+4.0
145–150	45.3	42.0	42.9	41.2	42.9	45.2	+2.3
200	[1] 45.3	[1] 42.6	[1] 42.5	42.4	43.2	45.2	+2.0
220	45.3	42.6	42.5		43.8	45.2	+1.4

[1] Scaled from vertical graph for this station.

[3] Information supplied by letter by Dr. A. H. Leim, Director, Atlantic Biological Station, St. Andrews, N. B., for Prince station 5, midway between Campobello Island and The Wolves.

TABLE 17.—*Water temperatures in southeastern part of basin in 1953 and in earlier years*

[Area G, fig. 16. Temperature in °F.]

Depth (meters)	July 23, 1914	Aug. 19, 1926	Aug. 18, 1953
0	59.5	61.9	61.7
20	[1] 53	62.1	58.0
40	50.0	55.6	52.0
100	49.2	42.3	45.0
150	48.8	[1] 43.1	46.5
200	47.1	43.9	44.0
250	46.3	[1] 43.7	[2] 43.8

[1] Scaled from vertical graph for this station.
[2] Deepest reading was at 241 meters.

Any continued alteration in temperatures for the summer-autumn period on Georges Bank is of special interest, because of the productivity of the Bank as a fishing ground. Unfortunately, the records are not clear in this respect, because the readings for 1914 and 1926 were taken so much earlier in the season than were those for 1953 that somewhat lower values at the surface and higher temperatures below the surface were to be expected in 1953 than in the earlier summers, quite apart from any year-to-year fluctuation. This seasonal progression is illustrated by the temperatures taken on the eastern end of the Bank (area H, fig. 16; table 18) July 23, 1914, August 13, 1926, and September 13, 1953. But the mean temperature for the water column as a whole—nearly 8° lower in mid-August of 1926 than in mid-September of 1953—at least suggests that the summer of 1953 not only was warmer on this part of the Bank, but that it was as much warmer as were the western and northern parts of the Gulf.

TABLE 18.—*Water temperatures on eastern part of Georges Bank in September 1953 and in earlier years*

[Area H, fig. 16. Temperature in °F.]

Depth (meters)	July 23, 1914	Aug. 13, 1926	Sept. 13, 1953
0	52	64	61.1
20	[1] 51	51.7	60
40	[1] 51.4	46.0	54.5
60	[1] 51.4	[2] 44.7	54.5
70	---------	43.3	54
Approximate mean	51.6	49.3	57.0

[1] Scaled from graph for this station; readings at 30 meters and at 55 meters.
[2] Scaled from graph for this station; readings at 40 meters and at 70 meters.

On the western part of Georges Bank, movements of the waters are so complex that wide differences in temperature within short distances, even on the same day, are not unusual. Readings at a pair of stations about 10 miles apart on the northwestern end of the Bank (area J, fig. 16; table 19) September 5, 1953, and at a second pair about 17 miles apart, on the southwestern end (area K), September 3–4, afford a striking example of this regional irregularity. Under such circumstances the danger is obvious of mistaking regional or short-term variations for year-to-year differences, when temperatures for different summers are compared. The present case is further complicated by the seasonal rise in temperature to be expected during the 5- to 6-week period between the dates of observation for 1914 (July 20), for 1916 (July 23), and for 1953 (September 3–5). Perhaps the most that can be said is that mean temperatures, which were some 6° higher in the upper 20 meters and some 4° higher at 40 to 50 meters in early September of 1953 than they were in late July of 1914 and of 1916 (table 20) on the western part of the Bank (areas J and K combined, fig. 16), are at least compatible with the somewhat higher temperatures that prevailed in the inner parts of the Gulf in 1953, as appears more clearly from the serial observations previously discussed (p. 306).

TABLE 19.—*Regional variation in water temperatures on northwestern and southwestern parts of Georges Bank*

[Areas J and K, fig. 16. Temperature in °F.]

Depth (meters)	Northwestern Georges Bank		Southwestern Georges Bank	
	Station A	Station B	Station A	Station B
0	64.2	60.0	65.8	63.3
20	61.7	52.0	55.0	60.2
40	61.1	46.7	51.5	60.2
50	61.1	45.8	51.4	60.2
70	61.1	45.0	51.2	[1] 60.2
Mean	61.7	49.5	54.7	60.7

[1] Deepest reading was at 67 meters.

TABLE 20.—*Water temperatures on western part of Georges Bank in 1953 and in earlier years*

[Areas J and K combined; fig. 16. Temperature in °F.]

Depth (meters)	July 20, 1914 and July 23, 1916			Sept. 3–4, 1953			Mean 1914 and 1916	Mean 1953
	Number of stations	Maximum temperature	Minimum temperature	Number of stations	Maximum temperature	Minimum temperature		
0–20	4	65.5	52.0	5	65.8	52	54.8	61.1
40–50	4	56.3	50.1	5	62.5	45.9	52	56.3

In the eastern channel between Georges and Browns Banks (area L, fig. 16; table 21), the readings were about 2° lower at the surface for September 12, 1953, than for July 24, 1914, but they were consistently higher, thence downward, with a maximum difference of 5.3° between the 2 series of readings at 120 meters, which was the deepest level at which the temperature was recorded in 1953. In the underlying strata this contrast is of the order to be expected from the difference between the dates when the observations were taken in the 2 years. Furthermore, it may be no greater than can be explained on this basis, especially in view of the difference in the positions, for the 1953 station was about 21 miles farther out along the channel than the 1914 station, i. e., that much nearer the reservoir from which deep water enters the channel from the continental slope. Neither is the lower surface temperature for 1953 a safe index to the year-to-year fluctuation, for the surface had no doubt cooled 2° to 3° by the date of observation, whereas in 1914 the temperature was recorded when the surface was nearing its warmest for the year. Unfortunately, we have no salinity information for the 1953 station, which is the only reliable index to the amount of water from the continental slope that is entering the Gulf on any given occasion, or that had recently done so.

TABLE 21.—*Water temperatures in the eastern channel between Georges Bank and Browns Bank in 1914 and in 1953*

[Area L, fig. 16. Temperature in °F.]

Depth (meters)	July 24, 1914	Sept. 12, 1953	Mean departure in 1953
0	59.2	57.0	−2.2
20	52.0	53.5	+1.5
40	48.7	52.2	+3.5
100	47.9	51.2	+3.3
120	[1] 47.2	52.5	+5.3

[1] Scaled from vertical graph for station.

The *Albatross III* established only one station on Browns Bank inside the 50-fathom contour (area L, fig. 12) during her August–September 1953 cruises and recorded a bottom temperature of 50.9° F. on September 12 at 90 meters. This is slightly higher than the bottom temperatures reported by McLellan (1954, p. 410, fig. 4; p. 412, fig. 6) of about 42.8° to about 48° August 16-27, 1950, and of about 42.8° to slightly above 48° August 14–September 5, 1952. A bottom reading by the *Grampus*, July 24, 1914, of 47.3° is too close to McLellan's to suggest that any long-term alteration of significance had taken place in the summer temperature of the bottom water on Browns Bank during the intervening 36 years.

The comparison between temperature conditions in the Gulf of Maine in August and early September of 1953 and in the earlier summers of record may be summed up as follows:

The entire water column down to 150 meters was warmer on the western side of the Gulf and around the northern periphery including the lower Bay of Fundy in 1953 than in the period 1912–26. This upward shift in temperature in 1953 as compared with 1922 amounted to 5° to 6°, at least, in Cape Cod Bay; to some 2° to 4.5° from surface to 150 meters off Cape Ann; to 1.5° to 3° from surface to 40 to 60 meters near Mount Desert Island; and to about 2° to 2.5° in the lower part of the Bay of Fundy at depths of 25 meters and greater. The upward shift in temperatures may have been as great in the eastern part of Georges Bank as in the western side of the Gulf, though differences in the dates when these observations were taken prevent definite comparison. Available data are at least compatible, with somewhat higher summer temperatures in 1953 than in previous summers on the western part of Georges Bank (p. 317).

In the central and northeastern parts of the basin of the Gulf, at depths greater than 40 meters, the temperature was about as much warmer in 1953, compared to the period 1912–26, as it was farther to the north and west. We have no information to indicate any definite shift in temperature, either upward or downward, in the upper 10 meters or so, if allowance is made for differences in the location of the stations where the readings were taken and in the season and the stage of the tide when the observations were made in the different years. Thus, the surface was warmest in 1914 both in the central part of the basin and in the eastern side near the Nova Scotian slope, but warmest in 1926 in the northeastern part near Mount Desert Rock. Readings taken August 1953 in the extreme southeastern part of the basin near the rising slope of Georges Bank were intermediate between those taken July 1914 and August 1926, at all depths from the surface down to 260 meters. Evidently, the effects on water temperatures of differences from year to year in air temperatures are masked in this region by the control exerted by warming by water from the continental slope, on the one hand, and by chilling by the cold water that spreads westward past Cape Sable in the spring, on the other.

Unfortunately, the August data for 1953 (fig. 17) fail to show whether the transition from surface temperatures as high as 57° to 65° F. off Massachusetts Bay to as low as 54° to 57° along the eastern part of the coast of Maine was as abrupt as the transition was from higher to lower temperatures in the area that the *Grampus*

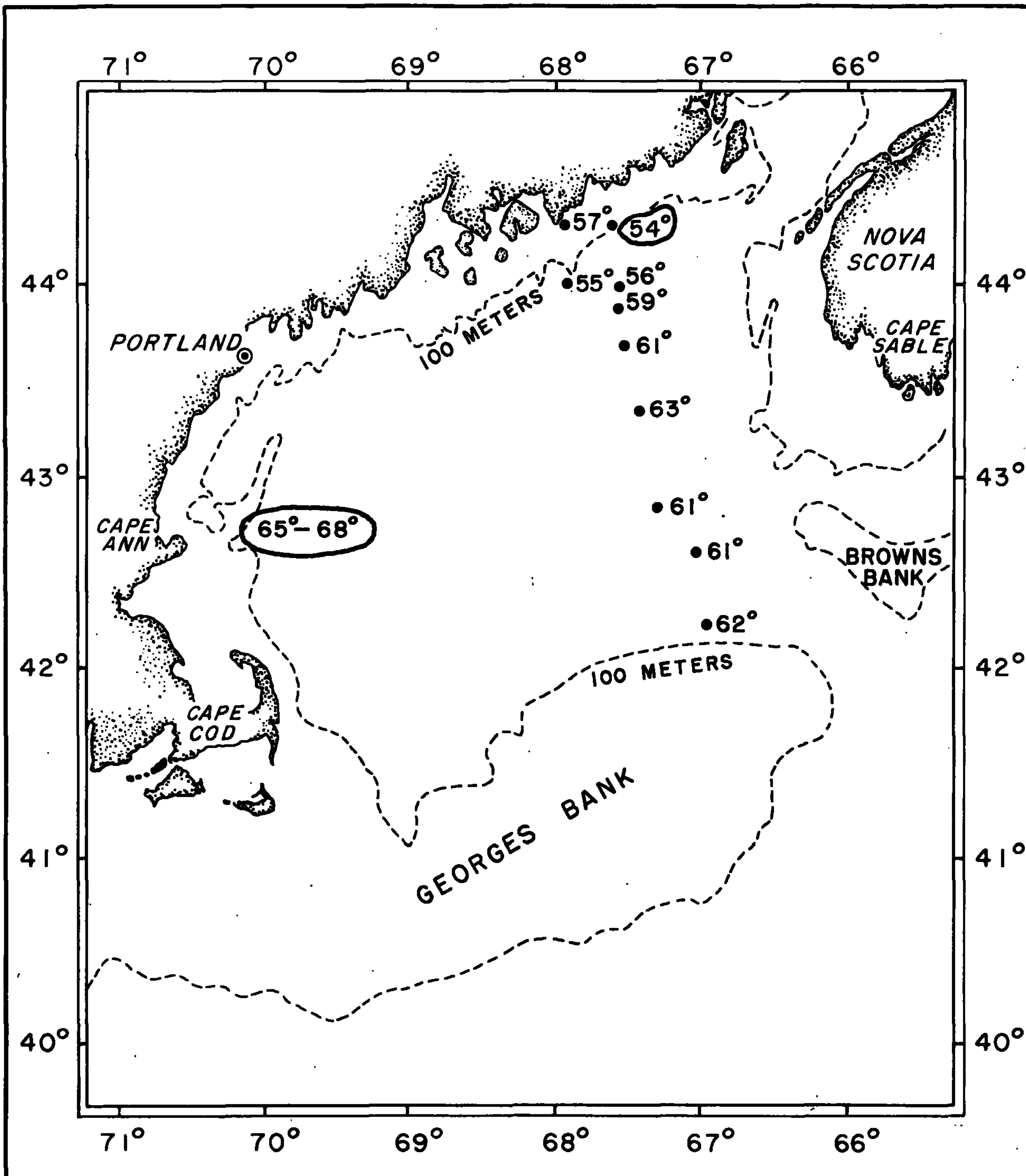

FIGURE 17.—Surface temperatures recorded, August 12–19, 1953. (Temperatures in degrees Fahrenheit.)

crossed in the offing of Portland, Me., in 1913, and a few miles farther eastward in 1923 (Bigelow 1927, p. 589, fig. 47). A question of more general interest, from the ecological standpoint, is whether the higher summer temperatures of recent summers, as compared with those of the earlier years of record, have appreciably weakened the barrier to the eastward spread of warm-water animals that was formerly set by the low surface temperatures that extended southward across the shelf from the elbow of Cape Cod and from the region of Nantucket Shoals. (For a general discussion of this temperature barrier, see Parr 1933, pp. 26–34 and 87.)

There is no apparent reason, so far as summer-early autumn temperatures are concerned, why any species able to maintain itself in the upper 20 meters or so of water along the coast westward from Cape Cod during the first decade of the present century should not have been able to do so in the southwestern part of the basin of the Gulf and in Cape Cod Bay in 1953, for maximum surface temperatures were about as high there that year as they had averaged at Woods Hole, in Vineyard Sound, or in Buzzards Bay, during the period 1902–07 (table 22). Indeed, it had been known long before the upward shift took place that certain shallow, partially enclosed basins on the coasts of New Hampshire and of Maine—where the renewal of water from outside is slow—are warm oases, so to speak, where more-or-less permanent populations of warm-water animals exist, which do not range regularly north of Cape Cod along the open coast. The oysters that support a local fishery in Great Bay, N. H., and the hard clams (*Venus*) of Casco Bay and other Maine localities fall in this category, while the oysters of the southern shallows of the Gulf of St. Lawrence are a more striking example often cited.

TABLE 22.—*Surface water temperatures, in southwestern part of Gulf of Maine and westward from Cape Cod, in 1953 and in 1902–07*

[Temperatures in °F.]

Locality	Date	Number of stations	Surface temperature: Maximum	Minimum	Mean
1953:					
Boston Harbor	August				67.2
Cape Cod Bay [1]	July 19		71.5	70	[1] 70.7
Southwestern basin Gulf of Maine	Sept. 5–6	8	70	68	69
1902–6: Woods Hole [2]	August		74.5	63	69.7
1907:					
Vineyard Sound [2]	Aug. 16–29	40	68.6	61.9	64.7
Buzzards Bay [2]	Aug. 19–29	27	71.5	62.7	67.9

[1] For details, see text above.
[2] From Sumner, Osburn, and Cole, 1913a; pp. 39 and 47.

The upward shift in summer temperatures has involved the coastal belt along southern New England as well as the waters north and east from Cape Cod, the difference between the southwestern part of the Gulf and westward from Cape Cod being of about the same magnitude as formerly. This situation is illustrated by mean temperatures for the 2 warmest months combined for 1950 to 1953, of 65° to 67.2° F. at Boston contrasted with 69.7° to 71.7° at Woods Hole; also, by the distribution of the surface isotherms to the eastward and to the westward of Cape Cod for early September 1953 (fig. 18). The contrast, too, between higher temperatures to the west and lower to the east, was not only about as great outside the islands (4° to 10° at the surface, 4° to 6° at 15 meters), in September 1953 as in the earlier summers of record, but the transition from the one to the other in the general offing of Nantucket Island and of Nantucket Shoals was almost as abrupt (compare fig. 18 with Bigelow 1933, fig. 35). No temperatures were taken in 1953 on Nantucket Shoals, but it is a matter of common knowledge that the surface there may be as much as 7° to 8° colder in summer than it is over the smoother bottom to the southward. This difference is the result of the active upwellings caused by the strong tidal currents that run over the shoals and around them. (For further details, see also Bigelow 1927, p. 595, and Parr 1933, p. 31.)

Continuity between the warm water of Nantucket Sound and surface temperatures nearly as high in the southwestern part of the Gulf north of Georges Bank is similarly interrupted by areas of low temperature, caused by strong tidal currents running over the shoals that front more than three-fourths of the total breadth of the eastern exit from the Sound. In late August of 1925, for example, surface temperatures were 3° to 8° lower on Round Shoal (53° to 59° F.) than on Stellwagen Bank at the mouth of Massachusetts Bay (61°) or on Jeffreys Ledge off Cape Ann (62°). (See Bigelow 1927, p. 1012, table 18.) No data were obtained for the eastern end of the Sound in 1953, but the regional temperature relationship was doubtless of the same order

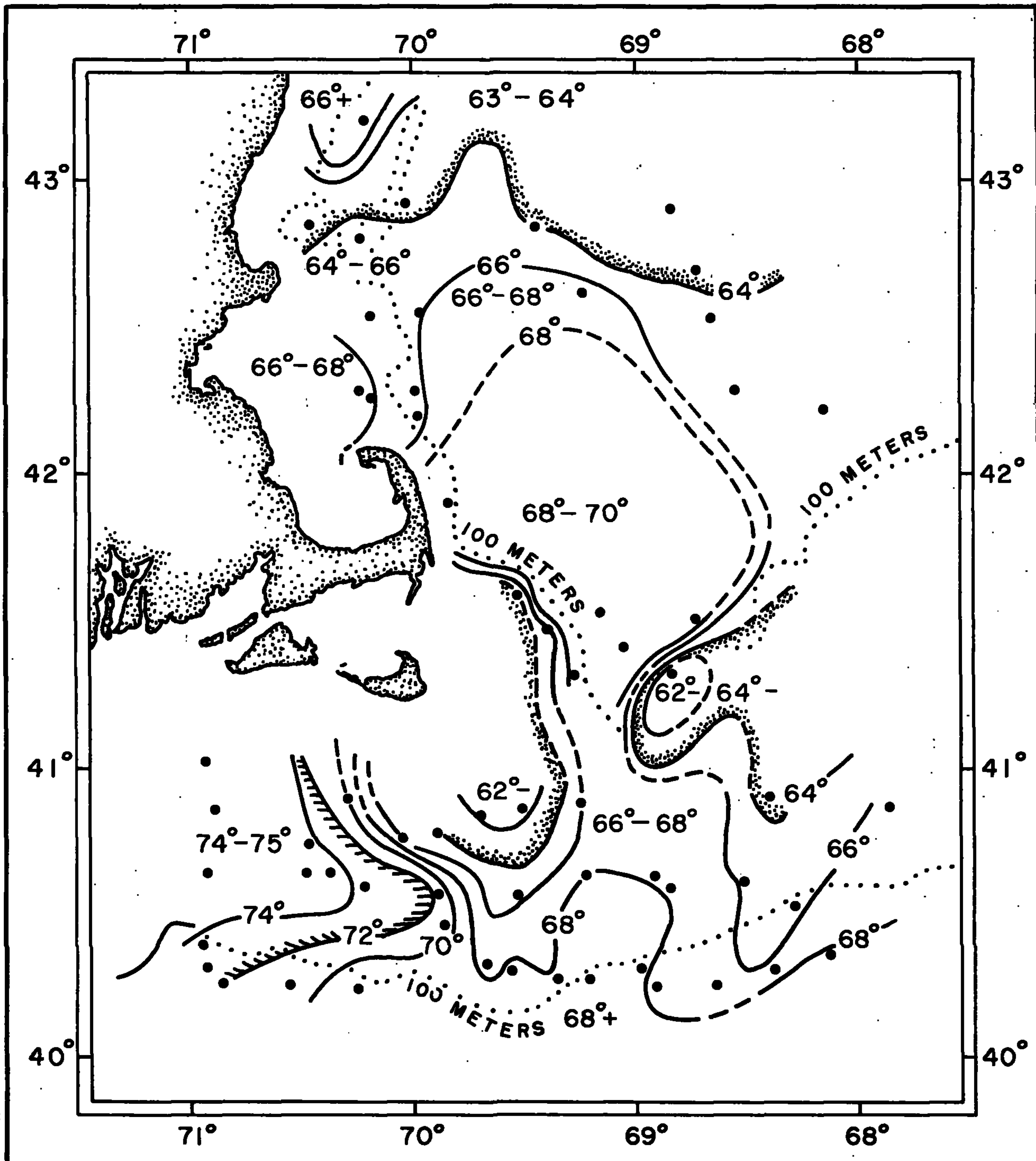

FIGURE 18.—Surface temperatures in the southwestern part of the Gulf of Maine and southward from the Martha's Vineyard-Nantucket region, September 1–13, 1953. Dots mark the locations where temperatures were recorded. (Temperatures in degrees Fahrenheit.)

that summer, for the tidal currents run as strong over the shoals and around them today as they did of old. Also, while the transition in temperature from west to east off Nantucket is not as abrupt at depths greater than 10 to 15 meters as at the surface, the temperature averaged 10° to 12° lower in the southwestern part of the basin of the Gulf in early September 1953, even at 30 meters, than abreast of Martha's Vineyard (table 23).

TABLE 23.—*Temperatures at 30 meters and at 45 to 50 meters off southern New England and in the southwestern part of the basin of the Gulf of Maine, September 1–13, 1953*

[Temperatures in °F.]

Locality	At 30 meters			At 45–50 meters		
	Number of stations	Temperature range	Mean	Number of stations	Temperature range	Mean
South of Martha's Vineyard	13	53°–66°	61.4°	13	51°–56°	57.5°
South of Nantucket	14	52°–63°	58.1°	9	51°–56°	55.3°
Southwestern basin of Gulf	12	41°–56°	49.1°	8	45°–47.3°	46.0°

The Nantucket boundary thus seems still to be a definite one for animals living within 10 to 15 meters of the surface and requiring summer temperatures higher than about 64°, while the low temperatures of the southwestern part of the Gulf similarly hinder expansion toward the northeast of animals that may be dependent on maximum yearly temperatures upwards of say 55° to 60° F. and that are restricted at the same time to depths of 25 to 30 meters or more. But there is no apparent reason why any animal, demersal or pelagic, that ranges indifferently between 10 and 50 meters (as many do), and that thrives in summer-autumn temperatures down to say 55° to 60°, should not now range freely between the offing of southern New England and the southwestern part of the Gulf, though confined to a narrower depth-zone in the Gulf.

The possibilities of faunal interchange between the head of Buzzards Bay and Cape Cod Bay via the Cape Cod Canal must also be borne in mind, though we have no definite evidence as to the role the canal may actually play in this regard.

Autumnal progression

In the western side of the Gulf, the surface was at its warmest for the year at about the same time in 1953 (middle to late August) as in earlier summers of record.

No readings were taken in the Gulf in 1953 later than the middle of September; consequently, comparison of maximum temperatures for that year with those for previous summers cannot be extended to the underlying water, where maximum temperatures are reached progressively later in the season at increasing depths. The dispersal of heat downward, by the increasingly active vertical mixings that are characteristic of early autumn, seems at first to have followed the same schedule in 1953 as in earlier years, however; for while the surface off Cape Ann (area A, fig. 16; table 24) cooled, on the average, about 1.4° between mid-August and September 9–10, the underlying waters down to 100 meters had meantime warmed by some 2.5° to 3.3°. Hence, it may be assumed that when the maximum temperatures of the year were reached at successive depths, they were at least 2° to 3° higher in the western part of the Gulf in 1953 than was usual during the period 1912–26. Reduced to concrete terms, the vertical equalization of temperature characteristic of November, which took place at about 48° at the mouth of Massachusetts Bay in 1912 (Bigelow 1927, p. 980, table 4, station 10047), took place at about 50° to 51° there in the autumn of 1953. No information is available, yet, as to the autumnal progression of temperature for the eastern side of the Gulf in 1953.

TABLE 24.—*Temperatures off Cape Ann in August and September, 1953*

[Temperatures in °F.]

Depth (meters)	August 12–15			September 9–10			Mean departure in September
	Number of stations	Temperature range	Mean	Number of stations	Temperature range	Mean	
0	7	64.6°–68°	65.9°	5	63°–66.1°	64.5°	−1.4°
15	7	52.0°–58.0°	56.6°	5	55°–65.5°	59.3°	+3.3°
45	7	47°–49°	48.0°	5	47°–51°	50.5°	+2.5°
100	7	43.6°–45°	44.4°	3	45.5°–50.5°	46.9°	+2.5°
150	1	44.5°	44.5°	1	44.5°	44.5°	0

Winter 1953–54

Data for the winter of 1953–54 are confined to bathythermograph readings taken February 16–22, by the *Asterias* of the Woods Hole Oceanographic Institution, at a grid of 22 stations covering the Massachusetts Bay region. It is probable that the temperature had risen fractionally above the winter minimum by that time, for the mean was 0.7° higher for February 1954 in Boston Harbor (36.6° F.) than for January (35.9°).[4] But the following comparison (table 25) between the temperatures taken February 16–18, 1954, and those taken both 10 days earlier and 10 days later in the season in 1925 shows that winter chilling was not as severe in the Bay to the southward of Boston in 1954 as in 1925. The overall difference between the 2 years for the southern part of the Bay as a whole was between 2° and 5°. More striking, the temperature seems not to have fallen as low as 33° anywhere in the open Bay at any depth in 1954, whereas it fell there (locally) in 1925, almost to the freezing point of salt water as it has in sundry other winters in the past (p. 303). Also, readings at 2 stations in the northern side of the Bay averaged 2° to 3° higher, surface to bottom, on February 18, 1954, than on February 13, 1913, or on March 4, 1921—which were among the warmer of the winters that fell within the period of our earlier surveys (table 26). The minimum, also, seems certainly to have been no lower in the Bay in 1954 than in 1953, and may have been slightly higher, for while readings taken in the Bay averaged about 1° lower on February 18, 1954, than on March 31, 1953 (table 27), a somewhat greater difference than this, but of the same order, might have been expected between the two sets of readings, on seasonal grounds.

TABLE 25.—*Maximum and minimum water temperatures in Massachusetts Bay Region, southward from the offing of Boston Harbor and seaward to a line from Cape Ann to the tip of Cape Cod, in February, 1925 and 1954*

[Temperatures in °F.]

Date	Number of stations	Surface temperature		Bottom temperature		Minimum temperature at any depth
		Maximum	Minimum	Maximum	Minimum	
1925:						
Feb. 6–7	15	36.7	30.7	36.7	30.9	29.2
Feb. 24–28	7	36.1	34.0	36.2	34.3	34.0
1954: Feb. 16–18	18	39.2	33.9	40.1	34.8	33.9

TABLE 26.—*Surface and bottom temperatures in northern side of Massachusetts Bay in 1954 and in earlier years*

[Temperatures in °F.]

Date	Number of stations	Surface temperature	Bottom temperature
Feb. 13, 1913	1	37.1	37.6
Mar. 4, 1921	1	36.0	36.6
Feb. 18, 1954	2	38.8–39	39.2–40.8

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

TABLE 27.—*Water temperatures in Massachusetts Bay, in 1953 and 1954*

[Temperatures in °F.]

Date	Number of stations	Temperature range surface to bottom	Mean
Mar. 31, 1953	2	41–41.3	41.2
Feb. 18, 1954	4	39–40.7	39.3

This close correspondence between the winter temperatures of Massachusetts Bay in March 1953 and in February 1954, added to the consistently high level reached by the mean water temperature for the coldest month in Boston Harbor as far back as 1949 (year-to-year range, 35.9°–37.8° F.), shows conclusively that we are dealing here with a situation that has already persisted through 5 winters, not merely with 2 warm winters in succession, such as have been known to interrupt the succession of colder winters in the past (p. 303). It is of special interest that through the winter of 1954, as during the preceding summer, the western side of the Gulf should have continued some 2° to 3° warmer than in earlier years, for the mean temperature in Boston Harbor was lower for that January (35.9°) than it had been for any month since February 1951. This with current reports of more ice than for many winters past in the partially enclosed situations along the coast of Maine, following severe weather in January, raises the question whether the upward shift in winter temperatures may have passed its climax in our Gulf.

CHANGES IN ABUNDANCE AND DISTRIBUTION OF MARINE ANIMALS

Although valuable statistics on the landings of many marine species have been collected since 1887, for the most part these records are not continuous prior to about 1930. It is not possible, therefore, to show long-term trends and fluctuations, except for a few species. Changes in fishing methods, efficiency, and effort, as well as changes in market conditions, tend to obscure the relations which may exist, so that one must frequently make general comparisons, based on minor fluctuations that may be related to environmental conditions when the major upward or downward trends may be due to other factors.

FLUCTUATIONS IN MACKEREL

Landings of mackerel on the east coast of the United States from 1804 to 1930 have been estimated by Sette and Needler (1934). Their estimates for the period 1804–81 are based on records of inspection of barrels of mackerel in Massachusetts (Goode et al., 1884). Landings for the period 1878 to 1904 were available from the reports of the Boston Fish Bureau. Since 1893, landings at the principal New England ports have been published by the United States Bureau of Fisheries and its successor, the Fish and Wildlife Service. Except for the period 1804 to about 1820 when the fishery was beginning, the fluctuations in catch appear to reflect fluctuations in the abundance of mackerel.

In figure 19, landings of mackerel are plotted against annual deviations in air temperature at New Haven that occurred 3 years earlier than the landings. Both curves are smoothed by 5-year moving averages. There is a marked tendency for rising temperatures to be associated with good catches 3 years later, the reverse with falling temperatures.

From 1820 to 1890, four major peaks occurred in mackerel landings, each associated with a period of higher temperature. The degree of association of landings with temperature may be determined by correlating the unsmoothed data, that is, correlating the landings in an individual year with the annual temperature deviation occurring 3 years earlier. When this is done, the highly significant correlation coefficient of 0.554 is obtained for the 71-year period. Since air temperatures are not perfectly correlated with water temperatures and since it is the actual water temperature which may be expected to influence the mackerel, possibly a much higher correlation would be obtained if water temperatures were available.

Following the high point reached in mackerel landings during the 1880's the catch declined rapidly and has never since reached its former high levels. From 1820 to 1890 the average annual catch was about 89 million pounds; between 1891 and 1950 it was about 33 million pounds. We see nothing in the temperature record to account for this change in abundance, although the former

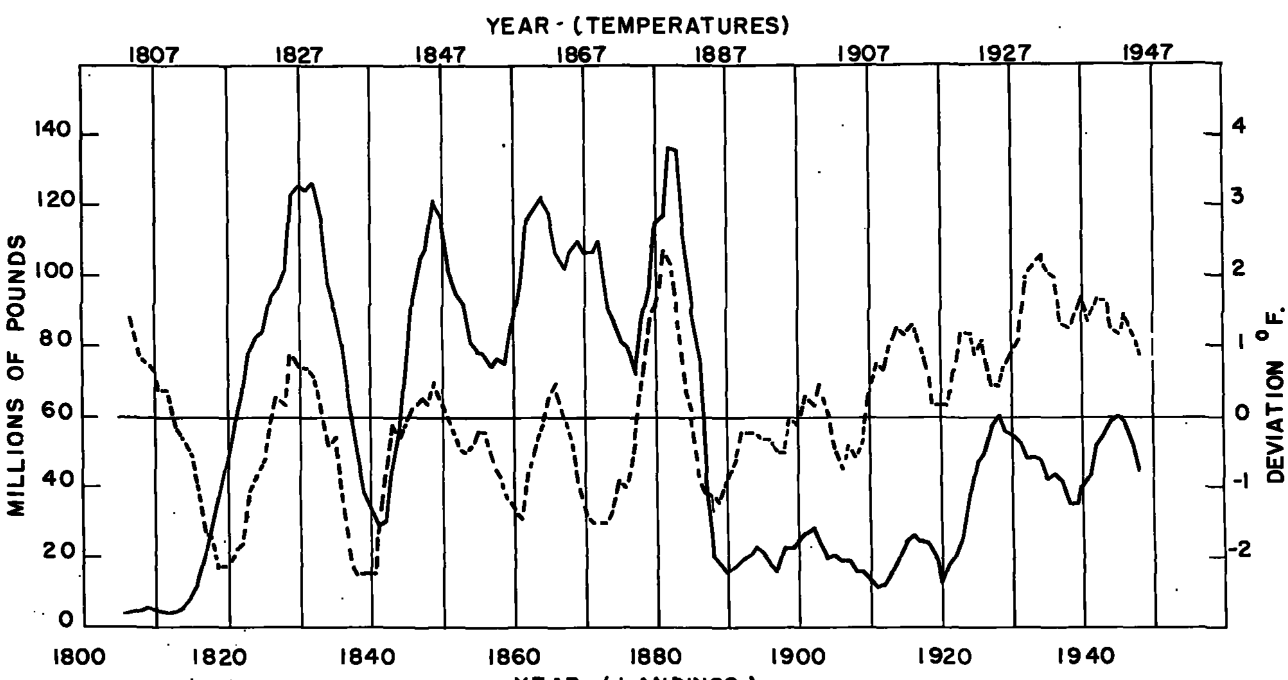

FIGURE 19.—Landings of mackerel, 1804–1950, in New England (solid line) compared with annual deviations in air temperatures at New Haven, Conn., occurring 3 years earlier than the landings. (The curves are smoothed by 5-year moving averages.)

fluctuations in mackerel landings indicate that this decline was almost certainly due to natural causes rather than to fishing.

After 1890 and to about 1925, there is a weak tendency for the mackerel landings to vary with temperature. After 1925 the landings are quite out of phase with temperature fluctuations, although both are at a much higher level than at the beginning of the period. The correlation between landings and temperature deviations for the period 1890–1954 is 0.207, which is about at the 10-percent level of significance (0.211).

The spawning of mackerel, on both the eastern and western sides of the Atlantic, appears to take place from south to north as temperatures reach a fairly well-defined critical level during the vernal warming (Allen 1897–99; Orton 1920; Sette 1943). The length of the incubation period is greatly affected by the temperature of the waters in the surface layer. Sette reported that eggs hatch in 2 days at 70° F. and in 8½ days at 50° F., and that the rate of development of the larvae also depends to some extent on the temperature. He estimated the survival rate of the 1932 year class during its planktonic existence to be in the order of magnitude of only 1 to 10 fish per million of newly spawned eggs. The period of planktonic life is shortened in warmer waters, and there is experimental evidence (Worley 1933) that the rate of mortality is less at higher temperatures. Therefore, relatively minor differences in the temperature of the waters in which mackerel develop may produce wide fluctuations in the strength of the year classes. Furthermore, the spawning of mackerel in the western North Atlantic is largely confined to a coastal belt 10 to 30 miles in width (Sette 1943), where fluctuations in water temperatures may be expected to show greater correlation with land air temperatures than would water temperatures farther offshore.

The influence of sea temperature on the movements of mackerel has been documented by Sette (1950). With regard to the appearance of mackerel in the spring, and the northward advance, Sette considered that temperature has a limiting rather than a causal influence, water colder than 7° to 8° C. (44.6°–46.4° F.) acting as a barrier (op. cit., pp. 292–294). With a general warming of coastal waters, one might expect earlier arrival and later departure dates. Unfortunately, data on times of first arrival and corresponding temperature data are too fragmentary to determine this directly, but possible indication that this has occurred is shown in the monthly landing statistics for Gloucester. Between 1901 and 1935, no landings of mackerel in April are shown in the Gloucester landings. Between 1935 and 1950, April landings of mackerel appear in 5 of the 15 years. Between 1901 and 1930, December landings of mackerel at Gloucester appear in 9 of the 25 years for which statistics are reported. From 1932 to 1950, December landings appear in 14 of the 19 years reported. Prior to 1939, no landings of mackerel are shown for the month of January. Between 1939 and 1950, January landings are reported for 7 of the 12 years.

We have no satisfactory hypothesis to explain the great fluctuations in mackerel landings over the period of record; however, it is rather clear that the behavior of the mackerel is governed to a considerable degree by temperature. Data covering fairly long periods of time show that the mackerel has responded to fluctuations and trends in temperature, but in a manner sufficiently complex to suggest the operation of other, perhaps indirect, factors.

FLUCTUATIONS IN LOBSTERS

Between 1940 and 1945, annual lobster landings in Maine increased from 7.6 million to 19.1 million pounds—a 250-percent increase and nearly three times the average landings made during the 1920's. Since 1945, the Maine catch has averaged about 19 million pounds, a level not exceeded since the 1880's. The increase in lobster landings was observed not only along the coast of Maine but also in Massachusetts, in the Bay of Fundy, and in western Nova Scotia over about the same period.

Such a widespread increase in lobster landings suggests an environmental change making possible the survival of greater numbers of lobsters to catchable sizes. Tagging experiments in Maine and length-frequency data collected by the Fish and Wildlife Service over the period 1939 to 1947 indicate that mortality rates remained very constant over the period of increase so that the increased catch was caused by an increase in abundance rather than by an increase in the amount of fishing. The only change in the environment known to have occurred was a general warming of coastal and offshore water. We shall, therefore, attempt to relate changes in lobster landings to changes in temperature.

A complete record of annual landings of lobsters since 1904 is available for Rhode Island in the annual reports of the Rhode Island Commissioners of Inland Fisheries (1904–35), and from federal statistics for recent years. These data, smoothed by 5-year moving averages, are presented in figure 20 together with January–July differences in water temperatures at Boothbay Harbor, 1906–49. The Boothbay Harbor data, previously shown in figure 8, page 299, have been given an additional smoothing by a moving average of 3. Temperatures at Boothbay Harbor were used for this comparison because they were the only ones available which cover the period of these lobster landings. It has already been pointed out that trends in air and surface water temperatures are quite similar over an extensive range along the Atlantic coast.

Temperature and landing data indicate a direct relation between water temperature and the availability of lobsters, a relation recently pointed out by Martin [5] for lobster catches in Canada. It is to be noted, however, that the curve of water temperatures in figure 20 represents a tendency toward warming of water conditions along the Atlantic coast in recent years, especially during the winter months, and that the catch of lobsters in Rhode Island has declined in the face of this warming. The relationship discovered by Martin is the reverse: Canadian lobster catches are greater in warmer years.

Lobster landings for the Middle Atlantic States, for Massachusetts, and for Maine are presented for the years since 1918 in figures 21, 22, and 23. The downward trend in landings for the Middle Atlantic States is similar to that occurring in Rhode Island, while the trends in Massachusetts and Maine have been upward over the same period.

[5] Martin, W. R., Long-term prediction based on climatic changes. Manuscript presented at a meeting of the Committee on Biological Investigations, Annual Meeting of the Fishery Research Board of Canada, January 1953. 9 pp.

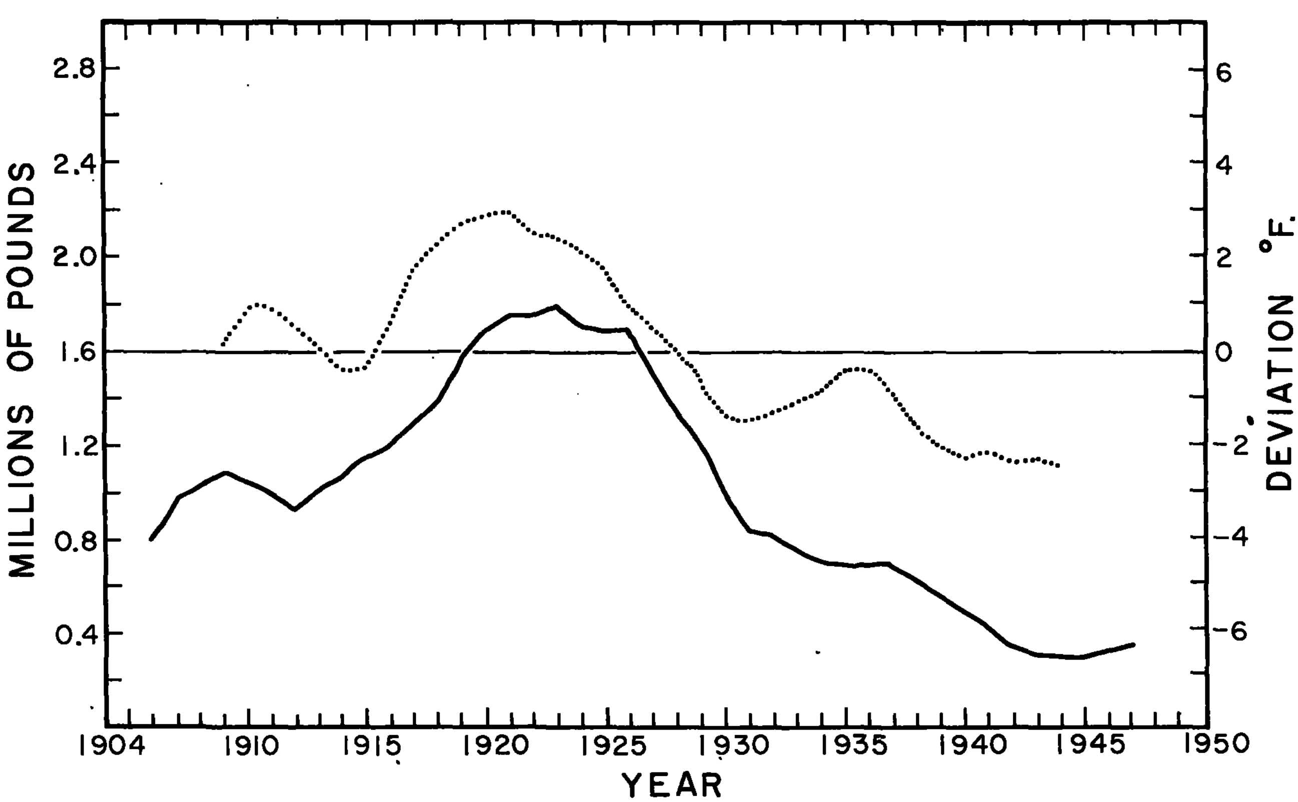

FIGURE 20.—Landings of lobsters in Rhode Island, 1904 to 1949, as 5-year moving averages (solid line), and January–July differences in surface water temperatures at Boothbay Harbor, Maine, as deviations from the mean difference (dotted line).

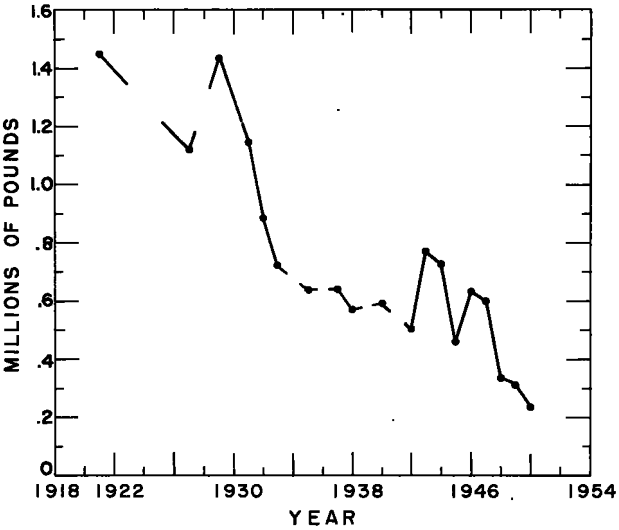

FIGURE 21.—Landings of lobsters in the Middle Atlantic States, 1921 to 1950.

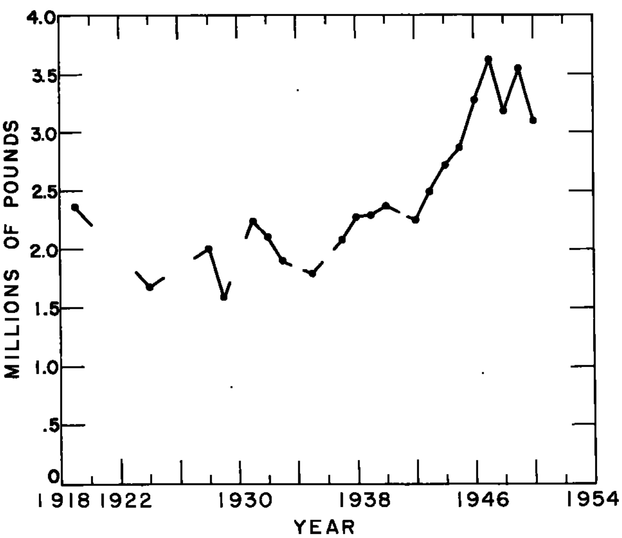

FIGURE 22.—Landings of lobsters in Massachusetts 1919 to 1950.

Consideration of these data, together with the Canadian trends, suggests that there are optimum conditions for lobsters and that these optimum conditions ceased to exist in the area south of Cape Cod about the middle of the 1920's. This hypothesis also implies that conditions began improving in the area north of Cape Cod about 1940 and that this improvement has continued to the present time.

Monthly landings of lobster have been reported in Maine since January 1939. The availability of monthly surface water temperatures at Boothbay Harbor over the greater part of this period affords a means of further investigation of the relation of water temperatures to lobster catches.

Figure 24 shows monthly lobster catches in Maine, plotted against the corresponding mean surface water temperatures, for the months of Oc-

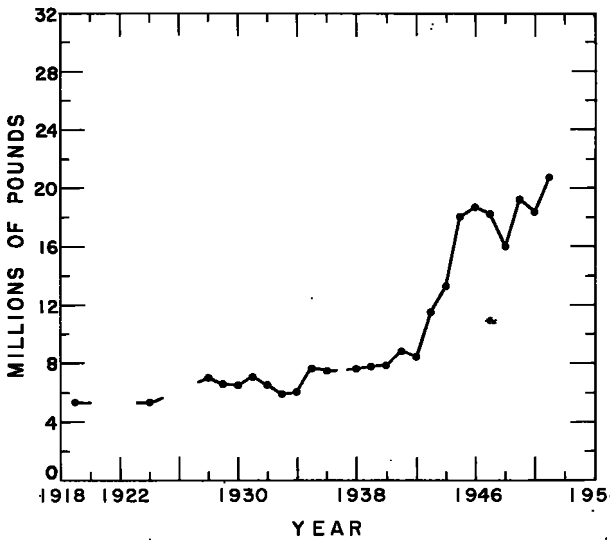

FIGURE 23.—Landings of lobsters in Maine, 1919 to 1951.

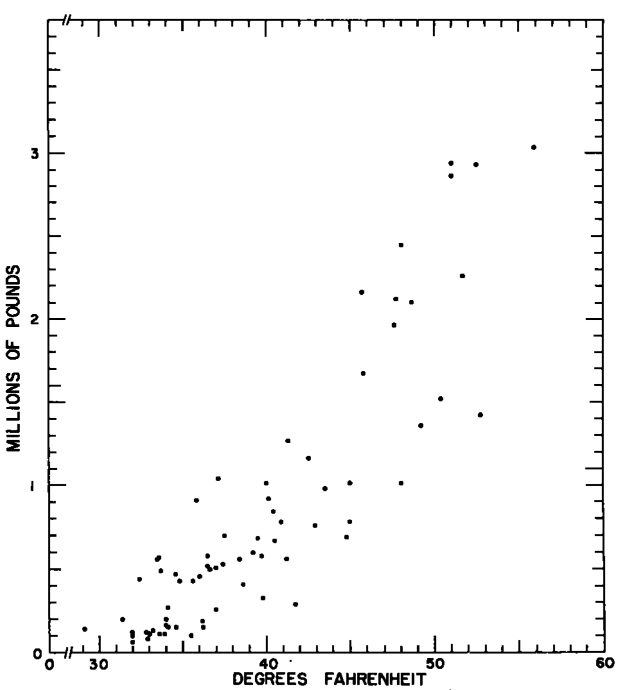

FIGURE 24.—Monthly catches of lobster in Maine plotted against corresponding mean surface water temperatures at Boothbay Harbor for the months of October through April, 1939 to 1949.

tober through April for the years 1939 to 1949. If we take the logarithm of the catch and correlate it with the temperature, we obtain a correlation coefficient of 0.854 with 72 degrees of freedom, a highly significant result.

In figure 25, the Maine lobster catches for the months of May through September, 1939 to 1948, are plotted against the corresponding mean monthly surface water temperatures. The relation between catch and temperature for this period was similar to that for the months of October through April, 1939 to 1949, although obviously the monthly catches in summer occurred at a considerably lower level than would be predicted from the winter relationship. The correlation between log catch and temperature is 0.548, which is also highly significant.

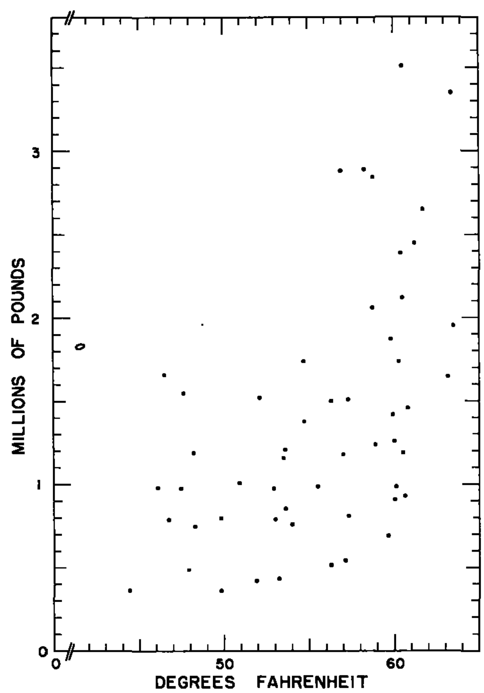

FIGURE 25.—Monthly catches of lobster in Maine plotted against corresponding mean surface water temperatures at Boothbay Harbor for the months of May through September, 1939 to 1948.

These data are inadequate to show that lobsters are less available during the summer months when temperatures are highest, or that an optimum temperature is exceeded during the summer months. Lobsters begin molting in the western part of Maine in May, the process continuing more or less progressively eastward along the coast until late September. Males molt earlier than females, marked changes in the proportion of the sexes are observed in the catch during the molting period, and the molting of females is attended by mating activities. During this period availability decreases. Although availability is usually high following molting, principally because of the recruitment of lobsters that were under legal size before they molted, the increased catch, combined with the soft-shelled condition, following the molt, usually results in a decline in market price. For these reasons, fishing effort and the resulting catches may not reflect true availability during the summer months.

A reasonable objection to the foregoing analysis is that the high degree of correlation between lobster catch and water temperature is based on total catches by months and not on catch per unit-of-effort. The correlation may, therefore, reflect the greater amount of fishing during the warmer months rather than the greater availability of the lobster.

Although some data on fishing effort by months have been collected in Maine since 1939, the reliability of the data has never been established through adequate analysis. If the data on effort for the period 1939–46 are used, no correlation between catch per unit-of-effort and temperature is apparent; however, for the years 1939–42, a highly significant correlation between monthly catch per unit-of-effort and temperature is obtained. The discrepancy appears to result from a rapid rise in the abundance of lobsters in Maine over the period 1943–46, so that the catch per unit-of-effort corresponding to a given temperature is changing each year. During the period 1939–42, the annual catches did not vary greatly, thus the monthly catches indicated availability rather than abundance. Although the annual catches since 1946 have attained a fair level of stability, monthly effort data are not available.

Whatever the reasons for the significance of the relation between monthly catch and monthly temperature, it is, of course, evident from figure 24 that the relationship cannot be expected to hold for temperatures much higher than 50° F. A month with an average surface temperature of 65° F. would, for example, yield a catch about equal to the average annual catch in recent years. Disregarding the effect of molting on availability, it is apparent that temperature, if the significant factor, can increase availability up to but not beyond the actual abundance.

FLUCTUATIONS IN WHITING

Statistics on landings of silver hake, or whiting (*Merluccius bilinearis*), prior to 1937 are scattered and the period since 1937 is hardly long enough to attempt to relate in detail fluctuations in catch corresponding to changes in temperature. A comparison of landings shows, however, a striking decrease in the catch in areas south of Cape Cod and a corresponding increase in New England areas. The trends in whiting landings resemble those observed in lobster landings north and south of Cape Cod.

The increase in landings of whiting in Massachusetts and in Maine is undoubtedly due in part to better market conditions and to increased facilities for freezing. Although the price of whiting increased sharply in 1943, the trend since has been downward. The decrease in landings south of Cape Cod cannot be explained in terms of changes in these factors; indeed, the scarcity of whiting since 1948 has apparently led to a sharp increase in the price (fig. 26).

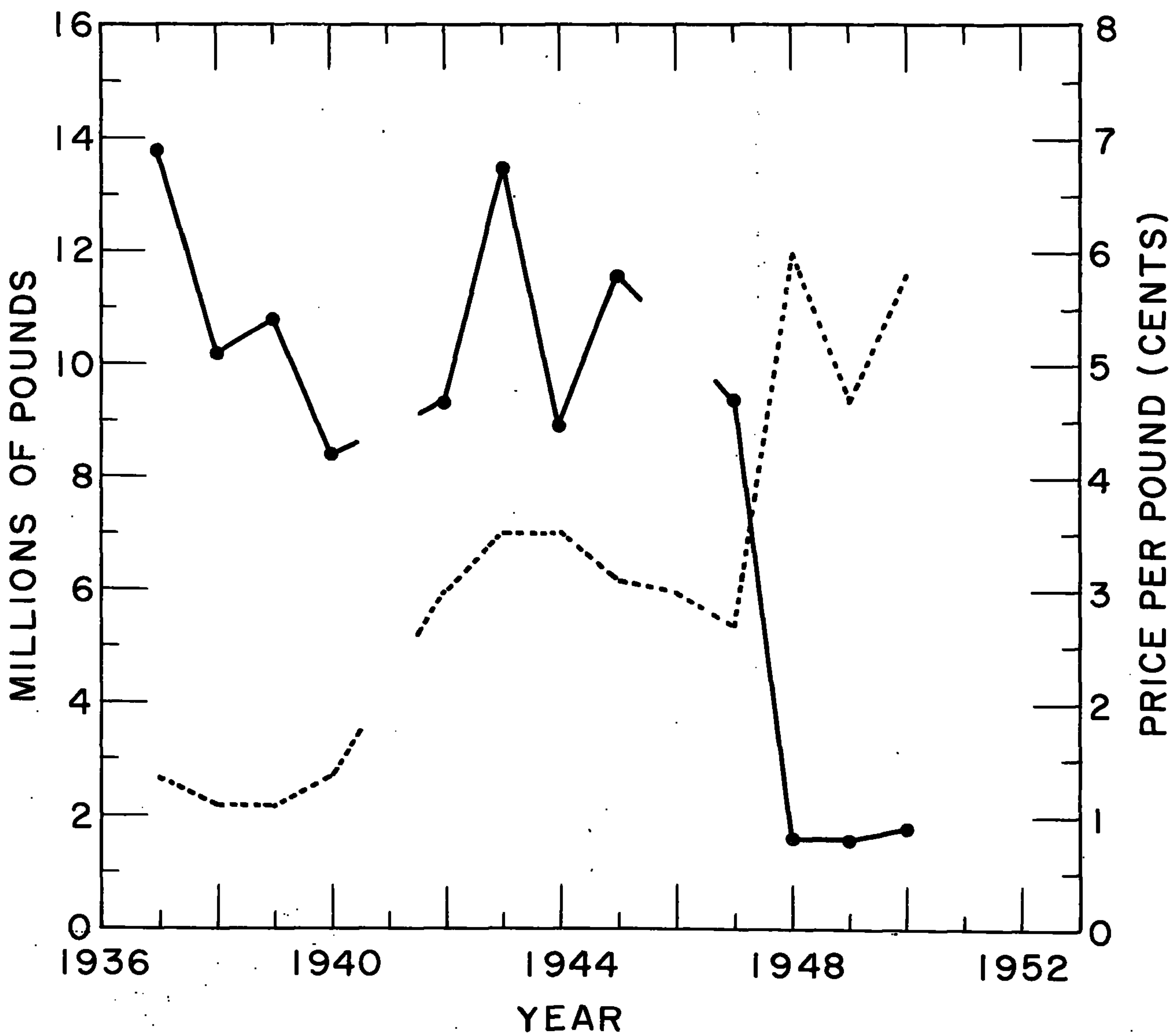

FIGURE 26.—The New York-New Jersey whiting catch (solid line) and the price received (broken line), 1937 to 1950.

Whiting landings for New York and New Jersey are shown in figure 26 together with the average price per pound for the years 1937 to 1950. A downward trend in landings is evident to 1947 with a precipitous drop in 1948. Whiting catches remained at a low level in 1951 and 1952. The decline in whiting catches has not been accompanied by any decline in fishing effort or in demand—the price has, in fact, increased. A substantial part of the whiting catch is made in stationary pound nets. These nets catch a variety of species, so that their successful operation does not depend entirely on a particular species. The whiting catch of pound nets has suffered a decline which corresponds in magnitude to the total catch of whiting by all gear. The pound-net fishery in New Jersey, for example, averaged about 4.8 million pounds of whiting annually from 1942 to 1945. In 1948 and 1949, the catches were 168,100 and 354,600 pounds, respectively. Whiting vessels from Gloucester which formerly found it profitable to fish in the New York–New Jersey area during the summer months are reported to do so no longer because of the scarcity of whiting.

While a general increase in landings of whiting is found for the period 1937–50 for New England as a whole, due to increased landings in Massachusetts and Maine, the catch declined in Connecticut and Rhode Island. Landings for Connecticut and Rhode Island have followed almost identical fluctuations (fig. 27). They rose suddenly between 1942 and 1943, perhaps because of the price increase in 1943, but then declined more or less consistently to their earlier level. Landings in Maine and Massachusetts are shown in figure 28, together with Maine prices. Although prices increased in 1942 and 1943, there was no corresponding increase in landings. Maine prices have since declined from the high of 2.5 cents per pound in 1943 to about 1 cent in 1952, but the catch in Maine increased during the same period from 2 million pounds to 22 million pounds.

An interesting fact is that while the total Massachusetts landings of whiting have increased since 1937 the pound-net catch has decreased (fig. 29). Thus the catch per pound net for the period 1937–42 averaged 78,775 pounds, but since 1943 only 22,783 pounds.

Bigelow and Welsh (1925) stated that the silver hake (whiting) was strictly a summer fish

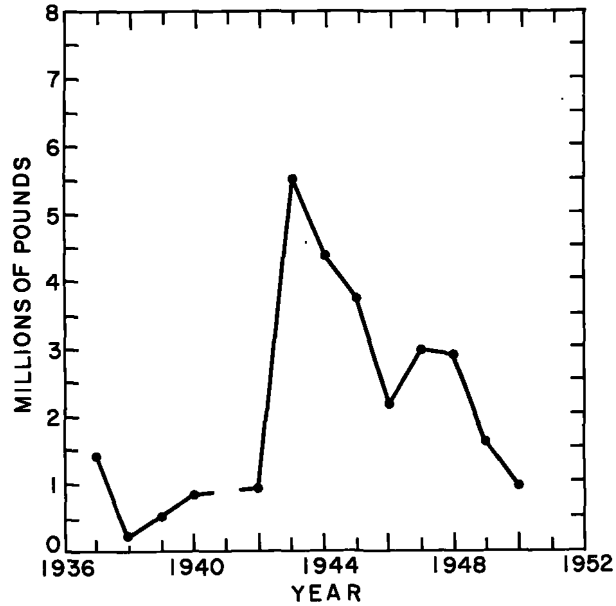

FIGURE 27.—Connecticut-Rhode Island whiting catch, 1937 to 1950.

in the Gulf of Maine, sometimes appearing in the Massachusetts Bay–Cape Ann region as early as the last week in March and regularly striking there by May, and they noted this applies equally to Georges Bank where the first whiting were taken by otter trawlers from April 27 to 29 in 1913. They further stated that the fish vanished from coastwise waters and from the offshore fishing banks sometime in late autumn and that, probably, the fish did not winter in the deep basin of the Gulf of Maine, but withdrew from it altogether at the approach of cold weather.

With reference to the relative abundance of whiting to other fishes on Georges Bank, Bigelow and Welsh, reporting on the otter-trawl investigations of 1913, stated that during the period April to September the average catch per trip was about 14,000 haddock to 1,800 whiting. Gloucester fishermen recall the former seasonal occurrence of whiting on Georges Bank and in the Gulf of Maine.

If the whiting was once strictly a summer fish in the Gulf of Maine, a conclusion generally accepted at one time (Bigelow and Welsh, 1925; Schroeder 1931), this is not the situation today. Bigelow and Schroeder (1953) point out that some whiting are now caught in the Gulf of Maine in winter and that whiting perhaps always have wintered in the deeper parts of the Gulf. It is

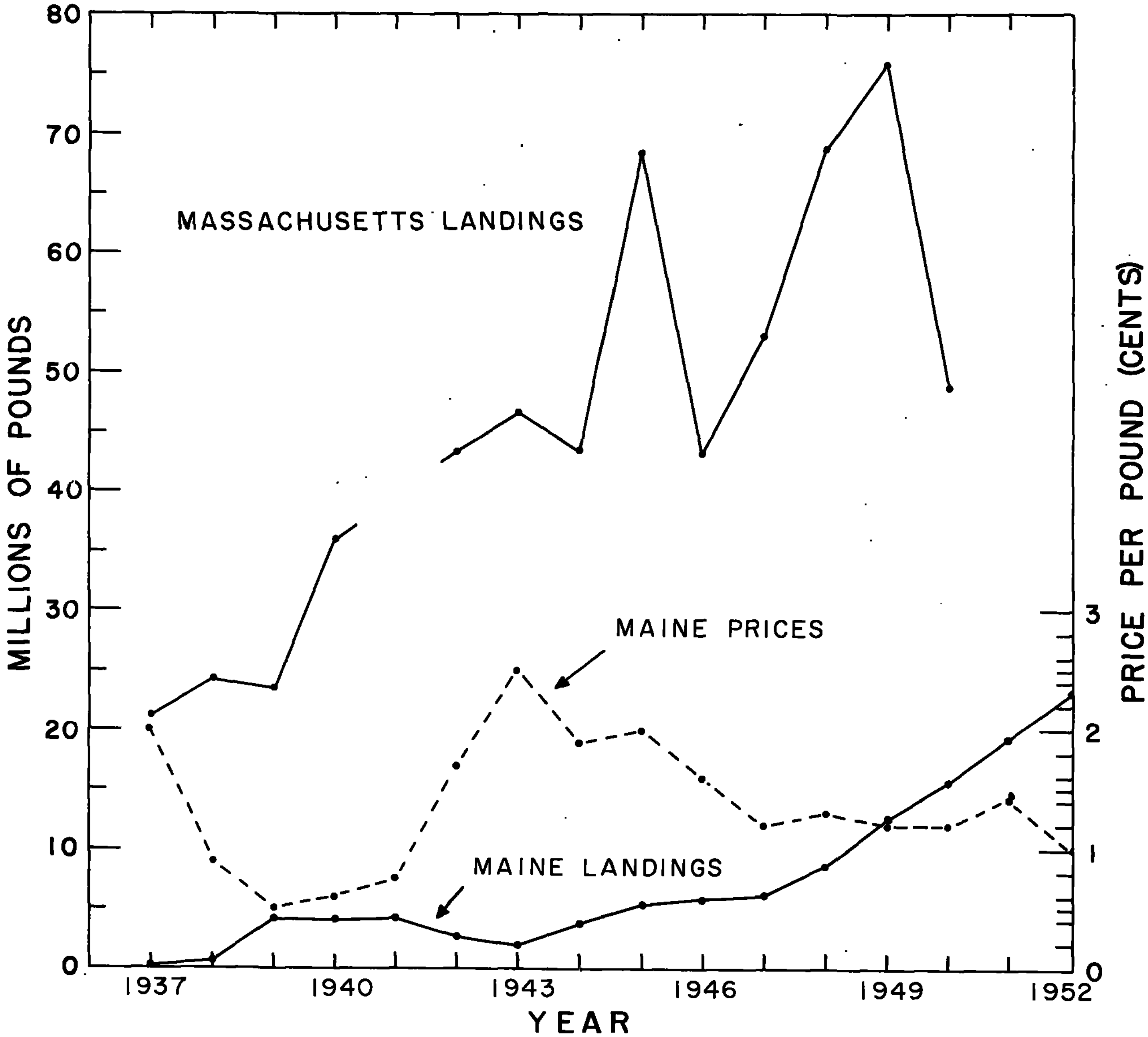

FIGURE 28.—Landings of whiting in Massachusetts (1937–50) and the landings and price per pound of whiting in Maine (1937–52).

not possible to decide, on the basis of the available data, whether this is true. It is probably safer to assume that some whiting have always wintered in the deeper parts of the Gulf, which waters were not fished until after 1937 when redfish boats began operations. These boats do not ordinarily save any of the whiting they catch, so that whiting in the catches might have gone unnoticed for a number of years.

Cursory examination of the weigh-out sheets of vessels landing at the port of Gloucester in January, February, and March, 1952, indicates that small whiting boats can make consistently good catches during these months in subareas XXII E, which lies off the coast of Massachusetts, and XXII D, which lies off the coast of western Maine. The weigh-out sheets also show that whiting appears in small amounts, but regularly, as incidental catch for boats fishing in subareas XXII F and G. (See Rounsefell 1948, for a description of statistical areas.)

A partial list of whiting landings at Gloucester

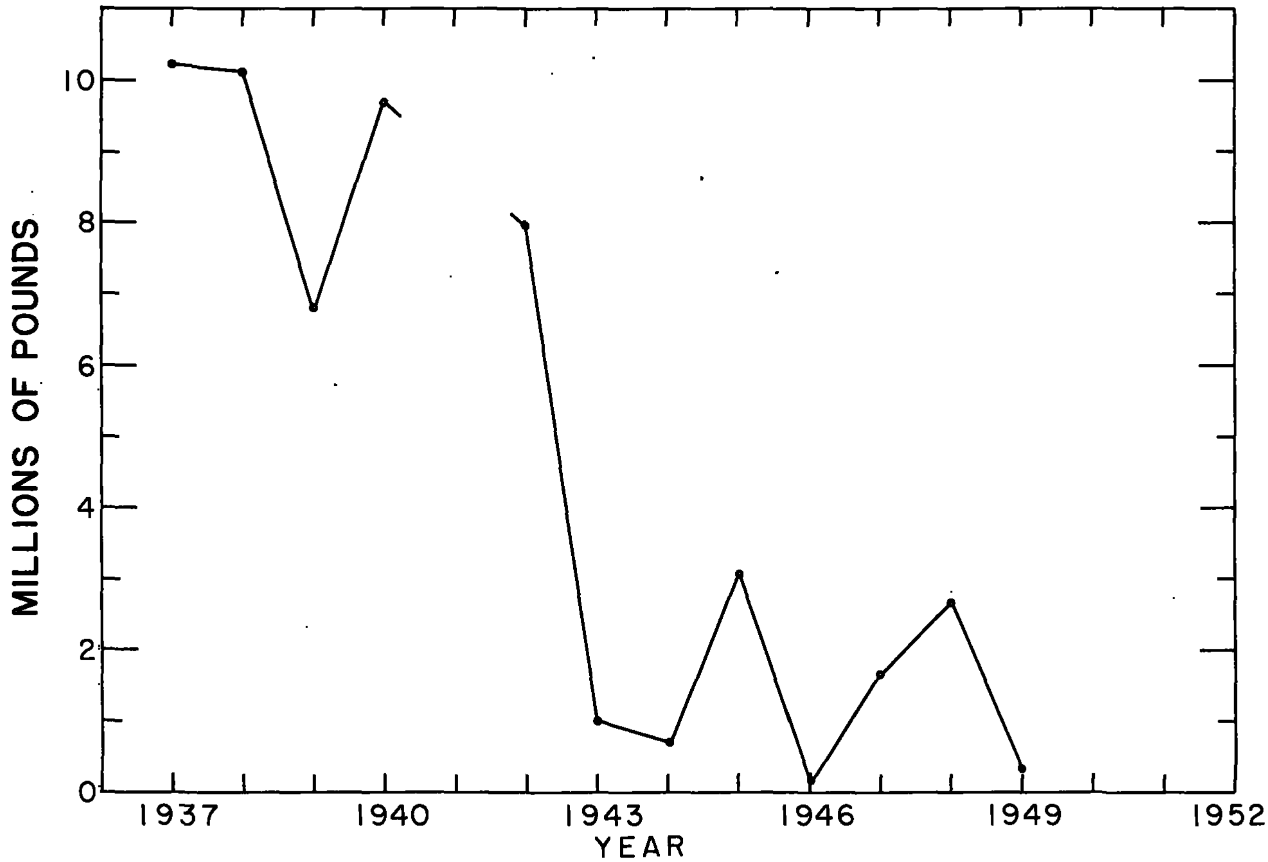

FIGURE 29.—The catch of whiting by pound nets in Massachusetts, 1937 to 1949.

is shown in table 28 for the months of January and February 1952. This list includes trips in which whiting predominated in the catch, and the take of many of the trips consisted almost entirely of whiting. This is not to say, however, that whiting were not caught and landed by other vessels fishing in the same area. This fact is important, for the fishing for species other than whiting has been pursued in these areas for many years.

The maximum depth of water in subarea XXII D is about 120 fathoms and in subarea XXII E about 150 fathoms. The larger part of both subareas is less than 80 fathoms deep. It is unlikely that these boats fished in the deeper waters, not only because no redfish appear in the catches but also because the deeper water, which lies more distant from port, probably could not be profitably fished in a 1-day trip.

To determine more exactly the depths in which whiting are caught during the winter months, interview sheets for the port of Provincetown were examined for January 1953. These sheets are prepared by a port interviewer and show, for each trip, the approximate position and the range of depths in which the vessel fished, as well as the weigh-out. Of 41 trips in which whiting were landed by small otter trawlers, 25 percent of the fishing was in depths of 30 fathoms or less, 50 percent was in depths of between 30 and 55 fathoms, and 25 percent was in depths of between 55 and 70 fathoms. All of the trips were made to subareas XXII E and XXII G.

Examination of monthly landing records in Maine shows that whiting may be landed in any month of the year, although the landings during January, February, and March are small compared to the summer landings. These whiting probably do not come from the deeper waters of the Gulf of Maine, for these depths are fished only by the redfish boats, and the fishermen rarely trouble to save whiting when they encounter them.

Recent data on the abundance of whiting in relation to other species on Georges Bank are

TABLE 28.—*Landings of whiting at Gloucester, Mass., in January and February 1952*

Subarea and date	Type of gear [1]	Length of trip (days)	Catch (pounds)
Subarea XXII D:			
Jan. 6	Medium otter trawler	1	4,050
10	do	1	2,600
14	do	1	4,500
15	do	1	3,600
23	do	1	3,550
Feb. 3	do	2	9,600
9	do	1	12,450
11	Small otter trawler	1	16,400
17	do	1	7,675
17	Medium otter trawler	1	3,875
27	do	1	2,285
27	do	1	7,600
Subarea XXII E:			
Jan. 3	Small otter trawler	1	900
4	do	1	9,375
4	Medium otter trawler	1	1,000
5	Small otter trawler	1	9,000
10	Medium otter trawler	1	800
10	do	1	1,400
10	Small otter trawler	1	1,740
14	do	1	380
15	Medium otter trawler	2	6,750
15	do	1	4,130
15	Small otter trawler	1	3,000
16	Medium otter trawler	1	300
21	do	1	525
28	Small otter trawler	1	7,450
Feb. 2	do	1	7,350
8	do	1	2,500
18	Medium otter trawler	1	3,500
28	do	1	4,050

[1] Small otter trawler, 5 to 50 gross tons; medium otter trawler, 50 to 150 gross tons.

available from the otter-trawl investigations conducted there during the summers of 1948 to 1951 by the U. S. Fish and Wildlife Service. These investigations showed whiting to be the most abundant fish in the catches, outnumbering haddock by 164 to 100, as contrasted with about 1 whiting to 8 haddock in 1913 (p. 330). The predominance of whiting in 1948 to 1951 was not due merely to its unusual abundance in depths or areas where haddock are not found, for in subarea XXII J at depths between 30 and 60 fathoms, a favored fishing area of the commercial haddock fleet, haddock outnumbered whiting by only about 1.5 to 1.

Even allowing some latitude for the incompleteness of earlier observations, the evidence indicates major changes in the distribution and habits of whiting since Bigelow and Welsh (1925) described the distribution of the species. If one advances the hypothesis that there has been a general warming of coastal waters, which is indicated, the pattern of observed changes may be explained, at least in part. According to this hypothesis, the coastal waters south of Cape Cod have become too warm for whiting to be present in abundance. Since the warming may be expected to be more pronounced close inshore where the pound nets are located, the decline will be first noted here, as in New York and New Jersey where this fish has practically disappeared from pound-net catches and in Massachusetts where the catch per pound net has declined to about one-third its former magnitude. The presence of whiting in the Gulf of Maine during winter months is probably due to a general melioration of winter conditions as indicated by January temperatures at Boothbay Harbor, Me., and at St. Andrews, N. B.

It might be objected that, as whiting tolerate a wide range of temperatures, the available data are not sufficient to explain the observed changes in distribution. We are not certain that this is a valid objection. The possibility that whiting may be able to tolerate the complete range of temperatures in the areas under consideration does not necessarily indicate that there are not optimum conditions which they prefer and seek.

Even given optimum temperature conditions, whiting require food and the presence or absence of food will, of course, affect their distribution. Aside from the consideration that any fish may become adjusted to certain optimum environmental conditions because these conditions are related to its food supply, a temperature factor controlling distribution may be removed only one step from a direct relationship, according to this hypothesis.

FLUCTUATIONS IN MENHADEN

Occasional small menhaden catches have been reported for Massachusetts, but not farther northward, since this fish reappeared in abundance for the single year 1922 after an almost complete absence from about 1900. Its presence north of Cape Cod was noted in Maine waters in 1945, when small numbers were caught and used for lobster bait; in 1948, 24,000 pounds were taken, and in 1949, 5,000,000 pounds. In 1951, 7,000,000 pounds were landed at Gloucester, and in 1952, landings at the same port amounted to 26,000,000 pounds (Maine Coast Fisherman, 1952).

The actual abundance of menhaden north of Cape Cod since 1945 is not accurately reflected by catch figures. The catch in Maine in 1949, for example, was largely due to the presence of menhaden seiners from the southern fleet (Maine Coast Fisherman, 1949). Local vessels have not been equipped for menhaden seining and New

England conservation laws have made the operation of out-of-state vessels difficult within the 3-mile limit where menhaden schools are most abundant (Bunker 1951).

It is impossible to state to what extent the warming of inshore waters, as indicated by records of surface temperatures at Woods Hole, Boothbay Harbor, and St. Andrews, has affected the reappearance of menhaden north of Cape Cod. According to Bigelow and Schroeder (1953), 50° F. is the coldest water temperature this fish will tolerate. Menhaden were reported abundant in the Eastport area prior to about 1840–45 (Goode 1879, p. 78), but they were not present in that area during the warm period of the 1870's when the menhaden fishery in the Boothbay Harbor region was at its height. In 1876, records of surface water temperatures at Eastport (Goode 1879, p. 291) show average July and August temperatures of 47.2° and 50.2°, respectively, which are sufficiently low to indicate unfavorable conditions for menhaden. In the same year, surface temperatures at Portland, Me., about 30 miles west of Boothbay Harbor, show July and August temperatures of 66.7° and 63.9°, respectively, so that the presence there of menhaden would not be surprising, as far as temperature conditions are concerned. It must be pointed out, on the other hand, that surface water temperature records at Boothbay Harbor over the period 1906–49 show that temperatures in that area have probably been sufficiently high for the presence of menhaden every year (see appendix table 1, p. 344).

The presence or absence of a migratory species such as menhaden north of Cape Cod during the summer months is not necessarily determined by the inshore conditions where the fish is commonly caught, but may be determined by other conditions along its migratory route. Unfavorable conditions along the way may act as a barrier (see Role of Temperature in Faunistic Changes, p. 338).

FLUCTUATIONS IN YELLOWTAIL FLOUNDER

During the 1940's, a productive yellowtail flounder (*Limanda ferruginea*) fishery developed on the southern New England fishing grounds, from Nantucket Shoals westward to Long Island (Royce, Buller, and Premetz, MS.[6]). In 1942, production of yellowtail amounted to more than 60 million pounds, but the catch fell away rapidly to about half that amount by 1944, and by 1949 to about 10 million pounds. It is natural under such circumstances to ascribe the decline to overfishing, but Royce and his coworkers found none of the usual symptoms of overfishing in the extensive biological data collected during the rise and fall of this fishery. Paralleling the decline in catches of yellowtail on the southern New England banks was the increase in catches on the southwestern part of Georges Bank from about 72,000 pounds in 1942 to more than 10 million pounds in 1949.

Royce et al. point out that there have been at least three significant changes in the faunal composition of the area used by the yellowtail flounder fishery during the 1940's. The Nantucket Shoals area produced many haddock during the 1920's, the catch amounting to 13,000,000 pounds in 1928. These workers also point out that the haddock were caught in the same location and at exactly the same depth range which subsequently produced yellowtail. They explain why yellowtail could not have been abundant during the period of the haddock fishery and also show that haddock were scarce on these same grounds during the period of the yellowtail fishery. Also significant is the fact that during the period of the haddock fishery yellowtail eggs and larvae were abundant to the south and west off the coast of New Jersey in areas where no yellowtail were found in numbers during the 1940's, at which time the demand for yellowtail was at its height.

With the decline in abundance of yellowtail, the fishermen turned to "trash" species. The production of this fishery from the southern New England grounds, and largely from the same depths and locations where yellowtail were formerly caught, amounted to about 70,000,000 pounds in 1950—approximating the peak landings of yellowtail at the height of that fishery.

Royce, et al.[6] state that—

> Such changes in the habitat of a few species of fish must be evidence of more fundamental changes in the environment and the entire complex of animal populations. In seeking an explanation we note that the known geographical range of both haddock and yellowtail extends only a little south of the southern New England grounds but much farther to the north * * *. We notice, too, a retreat of the haddock from the grounds west of Nantucket Shoals northeasterly to Georges Bank in the early 1930's

[6] Royce, William F., Raymond J. Buller, and Ernest D. Premetz. 1956. Conservation of the yellowtail flounder *Limanda ferruginea*. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D. C. (Unpublished MS.)

and a subsequent retreat of the yellowtail from off the New Jersey coast in the 1920's to off southern New England in the early 1940's and then to Georges Bank about 1949 * * *. Perhaps these retreats have occurred because of the warming of the area, which has been reported by Conover (1951).

NORTHWARD EXTENSION OF SOUTHERN SPECIES

A great many reports of the northward extension of the ranges of southern species have appeared in scientific literature since the 1930's. This may be attributed in part to an increased number of interested observers, but on this basis we would expect a nearly equal number of records of the southward extension of northern forms. We have noted only a few such southern extensions of range and only two in recent years: halibut landed March 13, 1946, near Reedville, Va. (Walford 1946), and four specimens of the Arctic cod (*Boreogadus saida*) taken from a trap net in late January and February 1951, in Mirimichi Bay, N. B. (McKenzie 1953).

In many localities, especially southward from Cape Cod, reports of southern forms became more frequent in the 1930's, a decade of peak air temperatures in the present warm cycle in the Northern Hemisphere (Willett 1950). At Sandy Hook Bay, for example, where observations of fish fauna were made for many years, three new records (although not new northern records) were reported by Breder and Nigrelli (1934) for 1932: the halfbeak (*Hyporhamphus roberti*), the gray snapper (*Lutianus griseus*), and the cutlassfish (*Trichiurus lepturus*). These workers comment on the rather unusual influx of southern species into that area during the summers of 1933 and 1934. They note that the cow-nosed ray (*Rhinoptera bonasus*) was more common than ever before observed, the round pompano (*Trachinotus falcatus*) was unusually abundant, and the gizzard shad (*Dorosoma cepedianum*) was first recorded in Sandy Hook Bay in October 1933.

During the same decade, we note the occurrence of the striped mummichog or killifish (*Fundulus majalis*) (p. 340) and the short big-eye (*Pseudopriacanthus altus*) in Massachusetts Bay, the latter not having been reported there since 1859; and of the butterfish (*Poronotus triacanthus*) in the Gulf of the St. Lawrence (Hoar 1937, Needler 1938); while a new northern record was established for the sting ray (*Dasyatis say*) (Smith and Griffin, 1939). Merriman (1939), commenting on the occurrence of southern species in Connecticut waters in 1937, stated that "It seems probable that abnormally high temperatures in the summer of 1937 were responsible for the unusual variety of southern species so far north."

The unusual number of records of the white shark (*Carcharodon carcharias*) in the Gulf of Maine (Schroeder, 1938, 1939; Bigelow and Schroeder, 1953) is associated with the warming during this period. Schroeder (1939) describes this as an "unusual occurrence" since "scarcely a dozen specimens" had been reported during the past century.

It would be interesting to know if there have been any changes in the southern ranges of marine animals in New England and Middle Atlantic coast waters, especially of the more northern forms. Unfortunately, there seems to be a paucity of observations bearing on this. It is perhaps of significance that the capelin (*Mallotus villosus*) has not been reported from the Gulf of Maine since 1919, the spotted wolffish (*Anarhichas minor*) since 1927, the shanny (*Leptoclinus maculatus*) and the Arctic shanny (*Stichaeus punctatus*) since 1930, while the staghorn sculpin (*Gymnocanthus tricuspis*) and the spiny lumpfish (*Eumicrotremus spinosus*) have not been recorded since the last quarter of the 19th century. Reports of these species, which have been found in the Gulf at one time or another together with a number of others occurring in Nova Scotian waters, might well be expected in recent years, if such reports depended merely on the number and assiduity of observers.

The trend, which began in the early 1930's, of an increased frequency of reports of southern species in more northerly waters has continued up to the present time. The following records, though by no means a complete listing, are some of the more interesting occurrences of recent years.

BUTTERFLY RAY (*Gymnura altavela*). Considered very rare on the Atlantic coast, a single specimen was recorded at Point Judith, R. I., in 1949 (Arnold 1951).

ATLANTIC ROUND HERRING (*Etrumeus sadina*). Appear sporadically along the coast south of Cape Cod and are likely to come in schools, as happened at Long Island, N. Y., in 1890 (Bean 1903, p. 191) and Woods Hole in 1905 and 1908 (Sumner, Osburn, and Cole, 1913b, p. 741). Records in the Gulf of Maine prior to 1930 apparently are based on observations of one specimen or only a few specimens. In 1937, round herring appeared in numbers at Campobello Island, N. B., at the mouth of Passamaquoddy Bay (Bigelow and Schroeder, 1953, p. 88). During August and September 1952, it was common in the Gulf of Maine along the coast as far east as Digdequash, N. B.; Scattergood (1952a and 1953) estimates that at least 210,000 pounds were landed. The fish was again present along the Maine coast during the summer of 1953.

Atlantic lizard fish (*Synodus foetens*). Reported as relatively abundant in southern New England in the summer of 1949 (Arnold 1951). This fish is rare north of South Carolina (Breder 1948).

Striped mummichog, or killifish (*Fundulus majalis*). A resident population has become established in Great Bay, N. H. (Jackson 1953). This fish was not recorded in Great Bay until April 1950, although records of the fishes of this region have been kept since 1908 (Jackson 1922). (See p. 340.)

Striped mullet (*Mugil cephalus*). Jackson (1953) reports 14 taken at the mouth of Oyster River in Great Bay, N. H., between October 4 and 18, 1951. Bigelow and Schroeder (1953, p. 306) state that mullets are common as far north as New York, less so to Woods Hole, but so rarely do they stray past Cape Cod that there are only a half dozen records of them in the Gulf of Maine—each based on an odd fish.

Sea horse (*Hippocampus hudsonius*). Two specimens were reported from the Maine coast in October 1953 (J. B. Glude, personal communication). The specimens were collected by G. W. Coffin. The first specimen was obtained from a lobster fisherman at Kennebunk, Me., who found it in a lobster pot; the second was found clinging to a lobster-pot buoy rope at Pumpkin Ledges outside Boothbay Harbor on October 18, 1953. The specimens were identified by Dr. Roland Wigley and are on file at the Woods Hole Laboratory of the Fish and Wildlife Service. Bigelow and Schroeder (1953, p. 316) state that—

> The sea horse is not common much beyond New York. Only a few are found each year about Woods Hole, chiefly in July, August, and September, and they so rarely stray past the elbow of Cape Cod that we have found only one definite (Provincetown) and one dubious (Massachusetts Bay) record of its capture in the inner parts of the Gulf of Maine, dead or alive, and one record for Georges Bank.

Frigate mackerel (*Auxis thazard*). Was reported in great numbers in the vicinity of Point Judith, R. I., in August 1949 (Arnold 1951). Landings are reported for Massachusetts and Rhode Island for the years 1945 to 1950 and for the Middle Atlantic States for 1948 to 1950. Sumner, Osburn and Cole (1913b, p. 749) state that the fish is apparently rare in the vicinity of Woods Hole; Bigelow and Schroeder (1953) do not list it in the Gulf of Maine fauna. The capture of one specimen in a fish trap at Barnstable in Cape Cod Bay (F. J. Mather III, personal communication) in 1954 apparently is the first record of this fish north of Cape Cod.

Striped bonito (*Euthynnus pelamis*). One specimen was obtained from a fish trap at Barnstable in Cape Cod Bay in 1954 (F. J. Mather III, personal communication). The only previous record in the Gulf of Maine is for Provincetown in 1880 (Bigelow and Schroeder, 1953, p. 336).

Little tuna (*Euthynnus alletteratus*). Between 200 and 300 captured in a trap at Barnstable in the autumn of 1948 (Bigelow and Schroeder, 1953, p. 337) and 28 were taken from a trap in Cape Cod Bay in September 1949 (Schuck 1951a). These are first records for this fish in the Gulf of Maine.

Common bonito (*Sarda sarda*). Scattergood (1948) reports a 310-mm. specimen collected from a herring weir on the southeast side of Campobello Island at the entrance to Passamaquoddy Bay, thus establishing a new record for the Gulf of Maine.

Tuna (*Thunnus thynnus*). Although the tuna is a regular visitor to the Gulf of Maine, the young fish seem to have entered the southwestern part of the Gulf in much greater numbers during the past few summers than previously, although the local stock of large adults has not shown a corresponding increase.

King mackerel (*Scomberomorus regalis*). This southern fish was once described as "not very common on our Atlantic coast" (Jordan and Evermann, 1896). Although sporadic in the statistics of landings for the Middle Atlantic States since 1877, it has appeared in the landings with increasing frequency in recent years. It is reported in Middle Atlantic States landings for the years 1931, 1933, 1937, 1946, and 1948 to 1954. The species is not reported from any of the New England

States for any of the years between 1919 and 1931 in which annual surveys of fish landings were made. It is reported for Massachusetts in 1931 and 1946 and for Connecticut in 1935 and 1946.

COMMON DOLPHIN (*Coryphaena hippurus*). Was reported from Cape Cod Bay in August 1949 (Schuck 1951b) and in July 1951 (Bigelow and Schroeder, 1953). The first record for the Maine coast was reported by Scattergood (1953) when a specimen was captured at Cape Elizabeth, Me., in 1952. There are no records for the Gulf of Maine before 1930.

KINGFISH (*Menticirrhus saxitalis*). Scattergood (1948) reports a 47-cm. specimen removed from the mouth of a hair seal (*Phoca vitulina*) taken in a fish trap at West Point on the east side of Casco Bay, on August 2, 1941.

FILEFISH (*Alutera ventralis*). One specimen taken October 30, 1948, in 46 fathoms off Martha's Vineyard. Previously reported from the Tortugas region by Longley (Arnold 1949).

SEA BASS (*Centropristes striatus*). A specimen taken in a lobster trap in the fall of 1950 at Corea, Me., and identified at the University of Maine (Maine Coast Fisherman, 1950b).

WOOD BORER (*Xylophaga dorsalis*). Previously unreported on the coast of Maine, this wood borer caused extensive damage to lobster traps in the Mount Desert area in the winters of 1949 and 1950. It has since extended its range east and west (Dow 1950; Maine Coast Fisherman, 1950a, 1951).

SEA HARE (*Tethys protea*). A specimen was captured in a lobster trap off Woods Hole, Mass., in October 1953 (Hahn 1953). Two more were found on the beach of Nonamesset Island on December 15, 1953 (newspaper report), and J. Rankin (personal communication) found more than 20 in the area during the same period.

TUBE CRABS (*Pinnixa* and *Polyonyx*). In 1911, *Pinnixa chaetopterana* was the common commensal living in the tubes of *Chaetopterus pergamentaceus* (Sumner, Osburn, and Cole, 1913a). At the present time this crab is rare in the Woods Hole region, having been replaced by the southern form *Polyonyx macrocheles* (J. Rankin, personal communication).

GREEN CRAB (*Carcinides maenas*). Extension of the range of the green crab north and east from Cape Cod since 1874 to Passamaquoddy Bay in 1952 has been described by Scattergood (1952b). The documentary evidence gathered by Scattergood establishes the slow progression of the species from Provincetown in the 1870's to Casco Bay by 1905. Proctor's (1933) survey of the marine fauna of the Mount Desert region in 1933 does not list the green crab. Rathbun (1930) gives the range as New Jersey to Thomaston, Maine; she (1929) does not list the green crab among the Canadian Atlantic fauna.

As Scattergood (1952b, p. 6) points out, there were ample opportunities for the transportation and transplantation of this crab northerly by lobster smacks as early as Civil War times and by sardine carriers since 1900:

> The mere transportation of the crabs to other areas evidently did not assure their establishing populations there. Conditions for the survival and successful reproduction have to be present or new and permanent crab populations will not develop. Evidently such conditions were not always present in many Maine areas, for if the environment had been favorable, green crabs would have been established along the entire Maine coast before the early 1900's. If we knew what environmental changes have been necessary for the recent increased abundance and the greater dissemination of the green crab, we would probably understand why the crabs were not more common in Maine waters at an earlier time.

Since little is known about the life history and biology of the green crab, it is not possible to say what changes in the environment have made possible the greatly increased abundance of this crab northward to Passamaquoddy Bay. Wallace and Glude (1952) present a number of observations indicating that exceptionally severe winters with heavy ice along the shore kill the green crab. If this is true, then the higher temperatures in recent winters seem sufficient to account for the northward extension of the range of the green crab. Examination of surface water temperatures for the months of January and February at Boothbay Harbor (appendix table 1) shows, for example, that the average temperature for the period 1906–30 was 32.3° F.; for the period 1931–49, the January-February temperatures averaged 34.2°; for the period 1945–49, the average was 35.1°—a most remarkable increase when one considers the effect on ice conditions along the intertidal zone. Prior to 1930, monthly averages below 32°, indicative of shore ice conditions, occurred with considerable frequency in the months of January, February, and March, so that it may well have been impossible for green crabs to establish permanent populations. Since 1930, months with temperatures below 32° have been rather infrequent, and the persistent spread of the green crab northward would seem to indicate that sufficient numbers have survived the more severe winters to assure a more or less permanent population in the northern part of its range.

ROLE OF TEMPERATURE IN FAUNISTIC CHANGES

We doubt whether any marine biologist today would dispute that temperature of the water is the factor chiefly responsible for setting geographical boundaries to the ranges of marine animals along the seaboard of eastern North America. Consequently, any alteration in the temperature or any continuing trend, either upward or downward, would be of great importance both ecologically, and from the commercial fisheries standpoint, if the alteration in temperature is wide enough and if it persists long enough to affect successful reproduction of the species or the well-being of the individual.

Air temperature records, and the more limited sea temperature records, show that the warming trend since 1900 has not been steady, but rather has been interrupted by periods of cooling (fig. 1). In general, the amplitude of these fluctuations has shown a marked decrease since about 1880—the result largely of rises in the minima. The pattern of increase within years also shows that the winter minima have risen while the summer maxima have increased relatively more slowly. The amplitude of fluctuations in winter temperatures has, however, been quite wide (fig. 4).

These characteristics of the warming trend are important in considering the kind of faunistic changes which might be expected to result. Among the possible changes, we may consider the following categories:

1. Establishment of resident populations north of Cape Cod of species that formerly were summer migrants.
2. Northern extension of ranges of resident populations already established north of Cape Cod.
3. Northern extension of ranges of summer migrants.
4. Changes in seasonal movements and distribution of permanent residents.
5. Changes in dates of arrival and departure of summer migrants.
6. Geographical changes in the abundance of permanent residents.

In boreal latitudes, where the air climate is rigorous in winter but warm in summer, causing a wide seasonal difference in temperature of the water (as happens in the Gulf of Maine), the critical questions are, How cold is the water during the coldest month of the year? and How warm is it during the warmest month? Perhaps it is not amiss to remind the reader that the mean temperature for the year as a whole plays only a minor role in this regard in the Gulf, or in similar situations in general, except perhaps in the case of species that live at depths so great that they pass their entire lives within a very narrow temperature range.

We recognize, then, that changes in categories 1 and 2 depend primarily on the ability of the animal in question to withstand winter conditions, since temperatures suitable for spawning, though necessary, are not alone sufficient for the establishment of resident populations. In category 3, the primary factor is undoubtedly the degree of summer warming, and may depend on conditions during only 1 or 2 months in the year, without reference to any overall trend in temperature. Categories 4, 5, and 6 depend to a much greater extent on the complex of conditions in all seasons of the year and on secular trends in temperature.

It has long been common knowledge that no shoal-water animal could maintain a permanent population in estuarine situations around the shores of the Gulf, or even close in along the open coast, unless it were either hardy to temperatures nearly as low as the freezing point of salt water or able to escape the severity of winter by moving a few fathoms deeper along the sloping bottom. As an illustration, the mean for the coldest month was below freezing point of fresh water in 9 winters between 1922 and 1942 at Boston, Mass., and in 3 winters between 1934 and 1943 at Eastport, Maine. But there has not been a winter since 1948 when the local fauna was exposed to a mean temperature lower than 36° F. for as long as a month either in Boston Harbor or at Eastport—localities which taken together are representative of the western-northern periphery of the Gulf.

Since the temperature of the water at the coldest season is progressively higher from the shore seaward all around the Gulf, not only at any given level but downward over the bottom as well, it is safe to say that in no winter since 1948 has any animal living as deep as 20 to 40 meters (whether on the bottom or in the mid-depths) anywhere in the Gulf been in danger of chilling if resistant to temperatures as low as 34° to 35° F., while any animal resistant to 38° to 40° has been safe at 100 meters anywhere in the open basin of the Gulf. A majority of the members of the fauna, whether bottom-dwelling or free-swimming, living along the middle Atlantic coast and shelf at these depths are no doubt as hardy as this or they would not maintain permanent populations there.

Consequently, there is nothing apparent in winter temperatures such as may be assumed to have prevailed in the Gulf during the last 5 years or so to hinder the free interchange in shoal water of animal populations of the Gulf of Maine and of the coastal belt along southerly New England, New York, and perhaps New Jersey. This is in line with Parr's findings (1933, p. 87), based on a great number of temperatures taken at lighthouses and lightships, 1928 to 1930, that in winter the shallow belt along the mid-Atlantic coast was "equally in open continuity with the waters north of Cape Cod." This despite the fact that the mean temperature of the coldest month of the year at Boston was 3° to 4° lower during the period covered by Parr's observations (32.9°–33.6° F.) than during the past 5 years, 1948–52 (35.9°–37.6°).

Notwithstanding this continuity of conditions and the increase in winter temperatures, the qualitative composition of the fish fauna is not uniform from north to south around Cape Cod in winter. We find, for example, that of some 30 species reported in the commercial landings in the New York–New Jersey area in January and February, 1952–54, only 8 are found north of Cape Cod in winter and they are permanent residents. Of the 7 leading species in these landings, only 1, the whiting (*Merluccius bilinearis*) is reported in commercial landings north of Cape Cod in winter. On the other hand, 4 of these 7 species are common north of the Cape in summer and the other 3 have been reported north of the Cape at one time or another. There is, then, little evidence that the increase in winter temperatures has altered the general distributional pattern of the fish fauna in the Gulf, with the possible exception of the whiting which has appeared in the commercial catches in winter only in recent years (p. 329).

On the other hand, we do not know of any animal native to the Gulf, even among the cold-season spawners, that requires a temperature lower than 34° to 36° or so, either for its successful reproduction or for any other stage in its life history. Winter temperatures higher now than formerly can thus be classed as an improvement, from the faunistic standpoint, except perhaps for accidental strays from more-northerly seas that might reach the Gulf more often during colder periods, and might survive longer there, for instance, the Greenland shark and the capelin.

Since it is not possible to determine whether some whiting have always wintered in the deeper parts of the Gulf, we cannot say that any marine animal formerly not found north of the Cape in winter has become a year-round resident under category 1 (p. 338). Sea temperatures and the commercial-landing data (p. 329), however, indicate that the whiting falls within category 4, since it appears safe to assume that this fish has always been a permanent resident of the Gulf.

Evidence, too varied for analysis here, makes it likely that the spread of some animal populations from the south and west past Cape Cod toward the north and east into the Gulf of Maine is bounded more effectively by the distribution of temperature during the warmer part of the year than by regional differences in the degree to which the coastal waters chill in winter. Since the great majority of the adult animals of our middle Atlantic seaboard can survive in water that is as cool as the western side of the Gulf in summer, if not as cool as the northeastern side, the critical need here is for water warm enough for normal numbers to reproduce successfully. The oyster, surviving in a temperature close to the freezing point for a considerable period but requiring a temperature of 68° F. or higher for spawning, illustrates this category; the quahaug, or hard clam (*Venus mercenaria*), spawns successfully only in a temperature of about 68° to 70° but winters successfully where the water chills to 34° to 35°.

Despite the higher temperatures that have prevailed of late, the fauna of the Gulf—shoal water as well as deep—is composed today of much the same assemblage of species of fish and of invertebrates as the fauna was half a century ago, indeed, as it was in the 1600's when Captain John Smith (1616, pp. 188, 196) and William Wood (1634, pp. 35–40) reported the abundance along the coasts of New England of cod, "frost fish" (tom cod), haddock, hake, cusk, striped bass, "pearch" (cunners), halibut, mackerel, smelts, herring, shad, eels, skates, lobsters, crabs, clams, "muscles" (mussels), "periwinckles," and oysters—the last, of course, in enclosed bays.[7]

Corresponding to this conservatism of the Gulf of Maine fauna, in general, no conspicuous fish or invertebrate that is common along the coast west and south of Cape Cod, but which had not maintained a regular population within the Gulf previous to the recent upswing in temperature, is shown to have established itself there as a permanent resident since the upswing. The weakfish (*Cynoscion*), the scup (*Stenotomus*), the toadfish (*Opsanus*), and the blue crab (*Callinectes*) are among those species that would be expected to have so established themselves in the Gulf.

The northward extension of the range of the striped mummichog (*Fundulus majalis*) to Great Bay, N. H., must be considered as falling in category 2 (p. 338) rather than 1, for it had probably established itself north of Cape Cod by 1939 (Bigelow and Schroeder, 1953), possibly by way of the Cape Cod canal (Schroeder 1937). Here again one must be cautious in attributing this extension to increases in winter temperatures subsequent to 1939 for it may merely represent the surmounting of a physical rather than a thermal barrier.

The green crab (*Carcinides maenas*)—whose recent extension northward and explosion, so to speak, in population is rather fully documented (p. 337)—seems to have been resident earlier north of Cape Cod, at least locally. The tautog (*Tautoga*), whose status from year to year is followed with interest by local anglers, has not been more plentiful north of Cape Cod of late than in previous summers, perhaps even less so. The occurrence of the various tropic strays (p. 335) may depend on short-term, and perhaps superficial, conditions that may have occurred frequently during the summer in the past, the present increase being distinguished chiefly by high temperatures sustained over periods of several years. In consequence, we might now expect more frequent records and greater numbers, but few unique occurrences.

[7] The identities of the New England fishes listed by Smith as "Pinacks" and "Mullet" are not clear.

SUMMARY

1. A long-term upward trend in air temperatures in New England is evident from the record. The increase has been greatest for the winter months.
2. Upward trends in winter sea temperatures are shown for St. Andrews, N. B., Boothbay Harbor, Maine, and Woods Hole, Mass. The correlation of January water temperatures at Boothbay Harbor with January air temperatures at New Haven, Conn., and Eastport, Maine, indicates a long-term upward trend in surface temperatures corresponding to that for winter air temperatures.
3. Hydrographic data for the Gulf of Maine in 1953 and 1954 indicate an increase of from 1° to 5° F. throughout the water column since the period 1912–26 for most parts of the Gulf.
4. Northward shifts in the abundance and distribution of some important commercial species are indicated by a study of landing statistics and other data. These species include the mackerel, lobster, menhaden, whiting, and yellowtail flounder.
5. Numerous southern species of fishes and other marine forms have extended their recorded ranges northward since 1930. At least two of these, the striped mummichog and the green crab, have established resident populations north of their earlier recorded ranges. But the recent upswing in temperature has not been accompanied by any obvious general alteration in the composition of the fish or invertebrate fauna of the Gulf of Maine region.

REFERENCES CITED

ALLEN, E. J.

1897–1899. Report on the present state of knowledge with regard to the habits and migrations of the mackerel (*Scomber scomber*). Jour. Marine Biological Association of the United Kingdom, vol. V (n. s.), pp. 1–40.

ARNOLD, EDGAR L., JR.

1949. Unusual occurrence of fish on New England banks. Copeia, No. 4, pp. 299–300.

1951. Northward dispersal of warm-water marine fishes in southern New England during the summer of 1949. Copeia, No. 1, pp. 87–88.

BEAN, TARLETON H.
1903. Catalogue of the fishes of New York. New York State Museum, Bull. 60, Zoology 9. 784 pp.

BIGELOW, HENRY B.
1927. Physical oceanography of the Gulf of Maine. Bull. U. S. Bureau of Fisheries, vol. 40 (1924), Part 2, pp. 511–1027.
1928. Exploration of the waters of the Gulf of Maine. Geographical Review, vol. 18, No. 2, pp. 232–260.
1933. Studies of the waters of the continental shelf, Cape Cod to Chesapeake Bay. I. The cycle of temperature. Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Papers in Physical Oceanography and Meteorology, vol. 2, No. 4. 135 pp.

BIGELOW, HENRY B., and WILLIAM C. SCHROEDER.
1953. Fishes of the Gulf of Maine. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 74, vol. 53. 577 pp. (First revision.)

BIGELOW, HENRY B., and WILLIAM W. WELSH.
1925. Fishes of the Gulf of Maine. Bull. U. S. Bureau of Fisheries, vol. 40 (1924), Part 1. 567 pp.

BREDER, CHARLES M., JR.
1948. Field book of marine fishes of the Atlantic coast from Labrador to Texas. 332 pp. G. P. Putnam's Sons. New York and London.

BREDER, CHARLES M., JR., and R. F. NIGRELLI.
1934. Fish notes for 1933 and 1934 from Sandy Hook Bay and other New York localities. Copeia, No. 4, pp. 193–195.

BUNKER, JOHN.
1951. Pogie fishermen snarled with cease and desist orders. Maine Coast Fisherman, vol. 6, No. 2, p. 3. September.

CLAYTON, H. HELM.
1927. World weather records. Smithsonian Miscellaneous Collections, vol. 79. 1199 pp.
1934. World weather records, 1921–1930. Smithsonian Miscellaneous Collections, vol. 90. 616 pp.

CLAYTON, H. HELM, and FRANCES L. CLAYTON.
1947. World weather records, 1931–1940. Smithsonian Miscellaneous Collections, vol. 105. 646 pp.

CONOVER, JOHN H.
1951. Are New England winters getting milder? Weatherwise, vol. 4, No. 1, pp. 5–9. February.

DOW, BOB.
1950. Trap destruction by borers increases in some areas. Maine Coast Fishermen, vol. 5, No. 3, p. 4. September.

FRIDRIKSSON, ARNI.
1949. Boreo-tended changes in the marine vertebrate fauna of Iceland during the last 25 years. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. 125 (IB2), pp. 30–32.

GOODE, G. BROWN.
1879. The natural and economical history of the American menhaden. U. S. Commission of Fish and Fisheries, Report of the Commissioner for 1877, pp. 1–529. 30 plates.

GOODE, G. BROWN, JOSEPH W. COLLINS, R. E. EARLL, and A. HOWARD CLARK.
1884. Materials for a history of the mackerel fishery. U. S. Commission of Fish and Fisheries, Report of the Commissioner of Fisheries for 1881, pp. 91–531.

HACHEY, H. B., and H. J. MCLELLAN.
1948. Trends and cycles in surface temperatures of the Canadian Atlantic. Jour. Fisheries Research Board of Canada, vol. 7, No. 6, pp. 355–362.

HAHN, JAN.
1953. Strange sea hare found on Cape Cod. Maine Coast Fisherman, vol. 8, No. 5, p. 1. December.

HERMANN, FREDE.
1953. Influence of temperature on strength of cod year-classes. Conseil Permanent International pour l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 31–32. Copenhague.

HOAR, WILLIAM S.
1937. The occurrence of *Poronotus triacanthus* in the Gulf of St. Lawrence. Copeia, No. 4, p. 238.

INTERNATIONAL COMMISSION for the NORTHWEST ATLANTIC FISHERIES.
1954. Statistical Bulletin, vol. 2 for the year 1952. Halifax, N. S.

JACKSON, C. F.
1922. Ecological features of Great Bay, New Hampshire, and a preliminary checklist of its fish. Ecology, vol. 3, No. 1, pp. 48-54.
1953. Northward occurrence of southern fish (*Fundulus*, *Mugil*, *Pomatomus*) in coastal waters of New Hampshire. Copeia, No. 3, p. 192.

JENSEN, AD. S., and PAUL M. HANSEN.
1931. Investigations of the Greenland cod (*Gadus callarias* L.). With an introduction on the history of the Greenland cod fisheries. Conseil International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. LXXII (I). 41 pp.

JORDAN, DAVID S., and B. W. EVERMANN.
1896–1900. The fishes of North and Middle America. U. S. National Museum, Bull. No. 47, Parts 1–4. 3313 pp.

KINCER, J. B.
1933. Is our climate changing? A study of long-time temperature trends. Monthly Weather Review, vol. 61, No. 9, pp. 251–259. September.

LAUZIER, LOUIS.
1952. Recent water temperatures along the Canadian Atlantic coast. Fisheries Research Board of Canada, Progress Reports, Atlantic Coast Stations, No. 53, pp. 5–7. April.
1954. Recent surface water temperatures along the Canadian Atlantic Coast. Cold years-warm years. Fisheries Research Board of Canada, Progress Reports, Atlantic Coast Stations, No. 58, pp. 6–10. April.

LOOMIS, ELIAS, and H. A. NEWTON.
1866. On the mean temperature, and on the fluctuations of temperature, at New Haven, Conn., Lat. 41° 18′ N., Long. 72° 55′ W. of Greenwich. Trans. Connecticut Acad. Arts and Sciences, vol. 1, Part 1, Art. V, pp. 194–246.

McKENZIE, R. A.
1953. Arctic or polar cod, *Boreogadus saida*, in Miramichi Bay, New Brunswick. Copeia, No. 4, pp. 238–239. November.

McLELLAN, H. J.
1954. Bottom temperatures on the Scotian shelf. Jour. Fisheries Research Board of Canada, vol. 11, No. 4, pp. 404–418.

MAINE COAST FISHERMAN.
1949. 21 southern boats are now fishing Maine waters. Vol. 4, No. 1, p. 3. July.
1950a. Sleuths hunt method to kill lobster trap borers. Vol. 5, No. 5, p. 16. November.
1950b. Vol. 5, No. 6, p. 14. December.
1951. Vol. 5, No. 7, p. 1. January.
1952. Vol. 7, No. 5, p. 1. December.

MAVOR, JAMES W.
1923. The circulation of water in the Bay of Fundy. Part 2. The distribution of temperature, salinity and density in 1919 and the movements of water which they indicate in the Bay of Fundy. Biological Board of Canada, Contributions to Canadian Biology (n. s.) vol. 1, No. 18, pp. 353–375, plates 5–10.

MERRIMAN, DANIEL.
1939. Notes on some marine fishes from Connecticut, with comments on the scales of *Elops saurus*. Copeia, No. 2, pp. 113–114. July.

MITCHELL, J. MURRAY, JR.
1953. On the causes of instrumentally observed secular temperature changes. Jour. Meteorology, vol. 10, No. 4, pp. 244–261. August.

MOORE, HENRY F.
1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. U. S. Commission of Fish and Fisheries, Rept. of the Commissioner for the year ending June 30, 1896, pp. 387–442.

NEEDLER, A. W. H.
1938. *Poronotus triacanthus* in Malpeque Bay, Prince Edward Island. Copeia, No. 2, p. 96.

ORTON, J. H.
1920. Sea-temperature, breeding and distribution in marine animals. Jour. Marine Biological Association of the United Kingdom, vol. XII (1919–1922), N. S., pp. 339-366.

PARR, A. E.
1933. A geographic-ecological analysis of the seasonal changes in temperature conditions in shallow water along the Atlantic coast of the United States. Bull. Bingham Oceanographic Collection, vol. 4, Art. 3. 90 pp.

PROCTOR, WILLIAM.
1933. Biological survey of the Mount Desert region. Part 5. Marine fauna. 402 pp. Wistar Institute of Anatomy and Biology. Philadelphia.

RATHBUN, MARY J.
1929. Arthropoda, Decapoda. Biological Board of Canada, Canadian Atlantic Fauna. 38 pp.
1930. The cancroid crabs of America of the families Euryalidae, Portunidae, Atelecyclidae, Cancridae and Xanthidae. U. S. National Museum, Bull. 152. 609 pp.

RHODE ISLAND COMMISSIONERS OF INLAND FISHERIES.
1904–1935. Annual reports made to the General Assembly.

ROUNSEFELL, GEORGE A.
1948. Development of fishery statistics in the North Atlantic. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept. No. 47. 27 pp. February.

SCATTERGOOD, LESLIE W.
1948. Notes on some Gulf of Maine fishes. Copeia, No. 2, pp. 142–144. June.
1952a. Round herring appear on coast from West Point to Digdequash. Maine Coast Fisherman, vol. 7, No. 3, p. 8. October.
1952b. The distribution of the green crab, *Carcinides maenas* (L.) in the northwestern Atlantic. Maine Dept. of Sea and Shore Fisheries, Fisheries Circular No. 8, pp. 2–10. Augusta, Me. October.
1953. Notes on Gulf of Maine fishes in 1952. Copeia, No. 3, p. 194–195. August.

SCATTERGOOD, LESLIE W., PARKER S. TREFETHEN, and GARETH W. COFFIN.
1951. Notes on Gulf of Maine fishes in 1949. Copeia, No. 4, pp. 297–298.

SCHROEDER, WILLIAM C.
1931. An account of the fishes dredged by the Albatross II along the continental slope south of New England in February and March, 1929. Copeia, No. 2, pp. 41–46.
1937. Records of *Pseudopriacanthus altus* (Gill) and *Fundulus majalis* (Walbaum) from the Gulf of Maine. Copeia, No. 4, p. 238.
1938. Records of *Carcharodon carcharias* (Linnaeus) and *Pseudopriacanthus altus* (Gill) from the Gulf of Maine, summer of 1937. Copeia, No. 1, p. 46.
1939. Additional Gulf of Maine records of the white shark *Carcharodon carcharias* (Linnaeus) from the Gulf of Maine in 1937. Copeia, No. 1, p. 48. March.

SCHUCK, HOWARD A.
1951a. Northern record for the little tuna, *Euthynnus alletteratus*. Copeia, No. 1, p. 98.
1951b. New Gulf of Maine record for occurrence of dolphin, *Coryphaena hippurus*, and data on small specimens. Copeia, No. 2, p. 171.

SETTE, OSCAR E.
1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part 1: Early life history, including growth, drift, and mortality of the egg and larval populations. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 38, vol. 50 (1950), pp. 149–237.
1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part II. Migrations and habits. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 49, vol. 51 (1952), pp. 249–358.

SETTE, OSCAR E., and A. W. H. NEEDLER.
1934. Statistics of the mackerel fishery off the east coast of North America 1804 to 1930. U. S. Department of Commerce, Bureau of Fisheries, Investigational Rept. No. 19. 48 pp.

SMED, JENS.
1949. The increase in the sea temperature in northern waters during recent years. Conseil Permanent International l'Exploration de la Mer, Rapports et Procès-Verbaux, vol. 125 (IA2), pp. 21–25.
1953a. Monthly anomalies of the surface temperature in areas of the northern North Atlantic in 1952. Conseil Permanent International l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 16–19.
1953b. Variation of the surface temperature in the Northern North Atlantic during 1876–1952. Conseil Permanent pour l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 19–21.

SMITH, CAPTAINE JOHN.
1616. The generall historie of Virginia, New England and the Summer Isles. 2 vols. London. From London edition of 1629. Republished by Franklin Press, Richmond, Va., W. W. Gray, printer, 1819, 1 vol., 282 pp.

SMITH, HUGH M., and ROBERT A. GRIFFIN.
1939. A sting ray (*Dasyatis say*), new to England. Copeia, No. 4, pp. 236–237. December.

SUMNER, FRANCIS B., RAYMOND C. OSBURN, and LEON J. COLE.
1913a. A biological survey of the waters of Woods Hole and vicinity. Bull. U. S. Bureau of Fisheries, vol. 31 (1911), Part I, pp. 1–544.
1913b. A biological survey of Woods Hole and vicinity. Bull. U. S. Bureau of Fisheries, vol. 31 (1911), Part II, pp. 547–860.

TÅNING, Å. VEDEL.
1949. On changes in the marine fauna of the North-Western Atlantic area, with special reference to Greenland. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. 125 (I B1), pp. 26–29.

UNITED STATES COAST AND GEODETIC SURVEY.
1918. United States Coast Pilot. Atlantic Coast. Section A, Serial No. 99. 305 pp.
1951. Surface water temperatures at tide stations, Atlantic Coast, North and South America. Special Publication 278. 57 pp.

UNITED STATES WEATHER BUREAU.
1941–1953. Climatological data. New England. Annual Summaries, U. S. Department of Commerce, Washington, D. C.

WALFORD, LIONEL A.
1946. New southern record for Atlantic halibut. Copeia, No. 2, pp. 100–101.

WALLACE, DANA, and JOHN GLUDE.
1952. Plague of green crabs. Maine Coast Fisherman, vol. 6, No. 7, p. 1. February.

WILLETT, H. C.
1950. Temperature trends of the past century. Centenary Proceedings Royal Meteorological Soc., pp. 195–206. London.

WOOD, WILLIAM.
1634. New Englands prospect by T. Cotes. 83 pp. London. Reprinted for E. M. Boynton, 1898. 103 pp. Boston.

WORLEY, LEONARD G.
1933. Development of the egg of the mackerel at different constant temperatures. Jour. General Physiology, vol. 16 No. 5, pp. 841–857. May.

APPENDIX

Monthly mean water temperatures listed in table 1 are based on the daily records of surface temperatures taken at 8 a. m., 12 noon, and 4 p. m. from 1905 to 1949 by the Branch of Fish Culture, of the U. S. Fish and Wildlife Service, at Boothbay Harbor, Maine. Similar records (table 2) were kept by the Branch of Fish Culture at Woods Hole for the period 1881 to 1942. The data for the period 1944 to 1952 were provided by the Woods Hole Oceanographic Institution.

APPENDIX TABLE 1.—*Monthly mean water temperatures, Boothbay Harbor, Maine, 1949 to 1905*

[Temperature in °F.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
1949	38.4	36.0	37.0	42.9	50.9	57.3	63.5	------	------	------	------	------	------
1948	34.6	32.4	34.8	40.5	47.5	53.6	60.5	61.2	56.9	48.0	47.6	42.5	46.7
1947	36.5	35.6	36.5	41.1	46.7	54.0	63.2	63.4	60.5	55.9	48.6	40.0	48.5
1946	33.5	33.7	37.5	40.4	46.5	53.6	60.3	60.4	58.8	52.5	47.7	41.3	47.2
1945	36.5	33.6	35.8	43.5	47.6	53.5	59.8	61.7	58.3	51.0	45.7	37.1	47.0
1944	34.1	34.0	34.0	38.6	48.2	52.9	60.8	60.5	58.7	51.0	45.8	39.2	46.5
1943	32.8	32.9	33.6	37.0	46.1	53.0	55.5	59.9	54.7	51.7	46.7	40.1	45.3
1942	34.6	32.0	33.9	39.8	49.8	56.3	60.1	60.0	57.3	52.8	45.0	37.4	46.6
1941	36.2	33.2	35.5	41.7	48.3	53.2	60.6	57.0	52.1	50.4	44.8	39.5	46.0
1940	31.4	29.1	30.0	36.2	47.9	51.9	59.5	58.9	56.3	49.2	45.0	39.7	44.6
1939	34.1	32.0	32.0	34.6	44.4	49.8	57.1	60.0	54.7	48.0	40.9	33.7	43.4
1938	34.4	31.7	32.3	37.5	43.8	56.0	59.6	60.2	54.3	49.8	43.8	37.3	45.1
1937	36.0	36.0	37.5	41.3	48.7	56.6	61.5	64.2	57.9	51.1	45.0	41.7	48.1
1936	33.7	31.3	37.4	40.7	46.0	53.1	60.5	61.6	57.3	48.0	39.3	36.0	45.4
1935	32.0	32.0	34.8	41.1	47.0	56.5	62.4	62.3	57.4	50.9	45.2	37.9	46.6
1934	31.8	30.0	31.9	41.1	50.2	56.6	61.5	60.0	59.1	46.9	41.3	36.2	45.6
1933	38.0	38.0	38.2	41.6	50.3	57.1	61.6	62.1	55.8	48.3	42.8	35.5	47.4
1932	36.2	36.0	35.9	40.2	45.7	54.1	58.7	62.5	56.9	50.5	46.5	38.9	46.8
1931	38.0	36.5	38.7	43.5	48.1	59.6	64.2	60.4	58.0	50.1	45.2	38.3	48.4
1930	32.3	31.2	33.1	39.5	47.2	57.7	62.6	60.9	57.2	53.7	45.5	37.8	46.6
1929	34.5	33.1	33.7	37.7	46.1	58.8	57.9	58.7	55.5	49.0	42.6	32.7	45.0
1928	36.0	33.0	34.9	39.1	46.6	55.0	63.1	64.6	57.4	51.7	43.8	38.0	46.9
1927	33.4	32.5	34.5	38.6	47.1	55.7	60.9	60.4	56.8	51.1	44.6	38.7	46.2
1926	32.7	29.8	32.2	36.1	45.0	54.0	61.2	61.4	56.3	50.3	43.5	35.6	44.8
1925	29.6	31.5	35.5	40.6	48.0	55.5	61.4	61.2	56.1	46.8	41.5	36.8	45.4
1924	34.3	30.9	34.5	39.2	46.9	54.6	61.5	61.1	56.9	50.4	43.8	35.8	45.8
1923	30.1	29.8	30.5	38.5	49.0	55.4	59.6	58.5	57.8	50.0	44.3	40.4	45.3
1922	31.8	31.0	34.9	41.6	49.4	58.1	63.9	62.4	59.0	49.4	41.6	33.4	46.4
1921	35.4	33.2	36.7	43.1	50.7	57.1	63.4	60.7	59.3	51.4	42.7	37.2	47.6
1920	29.9	29.4	35.6	39.7	49.7	55.5	61.6	64.1	57.0	53.5	43.8	39.8	46.6
1919	34.5	34.5	36.8	41.6	48.5	58.3	62.8	60.5	57.3	50.4	44.1	36.8	47.2
1918	28.1	29.5	33.0	38.8	49.0	54.0	62.3	62.0	56.6	49.8	44.3	37.5	45.4
1917	33.0	29.9	31.9	36.6	40.6	51.3	59.8	62.6	53.9	48.0	40.3	31.9	43.3
1916	33.0	31.3	30.8	38.3	45.0	52.9	59.4	59.4	54.6	47.3	41.3	35.4	44.1
1915	31.4	30.7	33.1	39.9	45.3	54.4	60.1	58.8	57.2	47.7	41.8	36.3	44.7
1914	34.1	29.9	31.9	37.1	46.0	53.0	58.4	59.8	56.4	50.4	42.1	34.6	43.6
1913	36.6	33.4	35.7	40.7	46.3	54.0	61.7	61.3	56.9	53.4	47.5	41.8	47.4
1912	31.7	30.4	33.2	38.9	47.1	54.1	61.6	62.0	57.3	50.7	44.8	38.9	45.9
1911	34.9	31.5	34.3	40.0	49.1	55.8	64.8	61.2	56.4	50.1	44.0	39.5	46.8
1910	34.6	33.5	37.2	45.3	50.0	57.3	64.0	63.1	59.4	50.9	46.7	36.4	48.2
1909	33.7	32.3	35.5	40.7	47.8	58.1	61.2	62.6	59.0	53.4	45.3	38.5	47.3
1908	36.2	32.4	34.8	40.1	50.0	56.3	62.4	62.9	58.9	53.1	44.1	37.2	47.4
1907	32.2	29.0	32.2	37.4	42.9	51.5	57.7	59.7	57.3	48.4	43.1	39.0	44.2
1906	34.9	31.4	31.3	37.7	44.9	51.7	58.5	62.1	55.7	49.0	42.3	35.5	44.6
1905	------	------	32.7	38.0	44.2	52.7	59.4	60.1	54.3	47.9	41.4	35.8	------
Average, 1948–1905	33.9	32.3	34.4	39.7	47.3	54.9	60.9	61.2	57.0	50.4	44.4	37.5	45.0

APPENDIX TABLE 2.—*Monthly mean water temperatures, Woods Hole, Mass., 1952 to 1881*

[Temperature in °F.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
1952	36.1	35.0	36.4	45.2	54.0	65.0							
1951	37.1	34.9	38.4	46.7	56.0	65.0	70.6	71.7	70.2	61.4	50.4	41.3	53.6
1950	39.6	36.2	34.0	42.3	50.1	62.0	69.7	71.3	66.2	59.5	52.9	42.9	52.2
1949	37.7	36.7			55.4	65.5	71.6	72.5	67.9	61.4	52.0	41.9	
1948	30.0	30.5	35.2	44.6	52.2	60.6	69.1	71.3	68.0	58.3	50.4	43.8	51.2
1947	35.8	34.0	36.2	43.5	57.9	58.8	71.7	72.4	69.6	60.9	49.4	38.4	52.4
1946	32.9	31.9	39.0	45.3	53.0	61.9	68.4	68.6	66.3	61.1	53.6	42.9	52.1
1945	32.4	30.6	38.0	48.0	54.5	63.1	70.7	70.6	68.6	59.1	50.5	37.8	52.0
1944				42.1	59.2	63.1	70.0	71.8	68.2	59.2	48.0	38.1	
1943													
1942	33.3												
1941	33.6	30.6	32.3	41.9	52.5	61.1	68.1	69.4	67.0	60.3	51.2	41.8	50.8
1940	29.7	30.0	33.4	40.3	51.1	59.1	65.7	67.9	66.4	57.0	47.9	39.2	49.0
1939	33.3	31.4	34.1	40.6	48.9	59.8	66.1	70.6	65.2	57.4	44.8	36.8	48.2
1938	35.8	36.2	37.7	45.0	51.9	60.4	66.9	70.1	64.4	57.2	50.8	39.6	51.3
1937	39.9	37.4	37.7	43.5	52.9	62.5	68.2	72.2	66.5	56.6	49.2	44.6	52.6
1936	31.2	29.5	37.6	45.2	55.1	63.0	68.2	70.7	67.2	60.2	49.4	39.7	51.4
1935	30.8	28.6	33.6	39.9	49.9	59.6	67.4	68.3	63.5	56.3	50.1	36.5	47.0
1934	32.7	29.8	32.5	42.9	52.8	62.4	69.9	69.9	67.8	58.3	47.9	39.0	50.5
1933	39.3	35.7	35.9	43.2	53.8	62.4	67.5	70.2	67.7	60.8	47.3	38.0	51.8
1932	41.1	35.9		43.6	53.1	62.1	69.6	72.2	67.5	60.9	50.5	41.0	
1931													
1914	33.9	31.1	32.0	42.0	51.8	62.4	66.4	68.7	67.2	60.5	49.1	39.1	50.4
1913	39.2	34.1	38.1	45.5	52.9	62.0	69.6	71.7	66.8	60.2	51.2	42.7	52.8
1912	31.6	30.1	34.0	42.3	51.8	65.0	69.4	69.5	66.9	60.1	51.5	41.5	51.1
1911	34.7	31.3	33.7	41.3	52.9	62.5	71.0	71.1	66.3	57.8	49.1	41.5	51.1
1910	31.5	32.0	37.8	46.9	55.3	62.6	70.4	71.0	66 9	60.4	48.0	36.7	51.6
1909													
1908	35.7	30.4	35.9	41.3	52.4	61.9	71.0	69.3	62.7	57.2	46.6	40.2	50.4
1907													
1906	33.0	34.4	35.0	42.2	53.2	62.8	68.9	70.9	68.1	60.0	48.4	36.2	51.1
1905	30.7	29.0	32.6	42.4	52.0	61.5	70.3	69.9	66.3	59.4	48.1	39.8	50.2
1904	29.3	29.0	33.1	40.9	53.3	62.2	69.4	65.8	67.0	57.7	46.5	34.4	49.1
1903	32.7	32.0	39.1	45.7	54.5	61.0	67.6	68.0	66.6	57.3	47.8	36.5	50.7
1902	31.5	29.1	36.2	45.7	54.0	62.0	66.3	69.1	67.3	60.7	52.0	38.8	51.1
1901	33.2	29.6	33.4	41.2	51.2	61.2	69.6	69.9	68.7	62.2	47.8	36.8	50.4
1900	34.6	31.2	33.8	40.9	52.7	61.7	68.6	70.9	68.8	60.1	50.7	39.8	51.1
1899	33.4	30.8	34.5	41.6	51.9	63.2	69.6	69.4	66.0	57.8	49.4	41.8	50.8
1898	36.1	34.0	39.0	43.7	49.7	60.5	68.2	70.8	68.2	59.6	49.9	37.1	51.4
1897	32.0	31.6	35.4	43.0	49.7	60.0	69.6	70.3	67.6	59.4	49.9	41.9	50.9
1896	32.9	31.7	32.4	40.7	53.3	63.4	65.7	70.9	66.7	58.2	53.1	41.2	50.8
1895	34.0	29.6		42.0	53.4	63.4		69.9	67.6	59.5	49.5	39.7	
1894	35.0	32.7	37.6	42.7	53.6	62.0	70.4	69.4	67.2	59.6	48.1	39.2	51.5
1893	29.6	29.8	30.7	40.9	51.0	61.2	69.6	73.3	67.4	60.4	52.4	40.8	50.6
1892	36.8	31.9	33.3	42.5	51.1	62.1	69.9	71.8	67.1	58.8	50.6	37.3	51.1
1891	33.1	34.8	35.7	44.3	52.3	61.1	66.9	68.6	69.1	57.6	47.4	42.0	51.1
1890	40.2	36.4	36.4		53.3	62.0	69.4	71.1	68.0	59.0	48.0	36.7	
1889	36.6	32.2	34.7	42.7	55.7	65.4	68.7	70.7	67.2	57.0	49.8	44.4	52.1
1888	31.1	30.4	33.1	41.0	50.2	62.7	66.6	68.9	64.3	54.3	48.6	39.1	49.2
1887	32.6	33.2	34.7	40.0	52.6	62.0	70.6	72.0	66.5	58.9	48.2	40.3	51.0
1886	32.2	30.9	32.2	42.6	55.7	62.5	68.7	69.1	68.1	60.3	51.0	38.0	51.0
1885	34.6	29.8	31.8	40.3	50.1	61.3	71.4	71.8	65.9	55.6	51.4	39.7	50.6
1884	32.4	34.5	35.3	42.8	55.1								
1883		31.2	32.3	41.4	52.5	64.9	71.3	69.9	65.1	55.9	47.7	37.1	
1882	34.5	33.1	37.5	43.3	49.8	61.6					48.0		
1881		30.9		41.0	53.8					59.0	50.5		
Average, 1952–1881	34.10	32.15	35.07	42.83	52.88	62.15	69.01	70.33	67.01	58.97	45.92	39.69	