RESTRICTED

International Commission for the Northwest Atlantic Fisheries

Serial No. 3897
(D.c.1)

ICNAF Res.Doc. 76/VI/85

ANNUAL MEETING - JUNE 1976

Spring and autumn bottom-water temperatures in the Gulf of Maine and Georges Bank, 1968-1975[1]

by

Clarence W. Davis
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts USA 02543

Introduction

This paper summarizes variations in bottom-water temperatures in the Gulf of Maine-Georges Bank area during spring and autumn, 1968-1975. Unusually high temperatures were observed in 1973 and 1974 during several cruises in the Gulf of Maine-Georges Bank area. These observations coincided with recent changes in the distribution and/or timing of spawning of certain fish and shellfish. Notable changes during this period included: extended distribution of green crabs, bluefish, and menhaden along the coast of Maine; mackerel overwintering in ICNAF Subdiv. 5Zw northeast of their usual grounds; delayed inshore movement of silver hake; delayed spawning and change in availability of the inshore stock of sea herring in the Gulf of Maine (Anderson, 1975; V. Anthony, personal communication). According to several authors, as cited by Colton and Stoddard (1973), the distribution of benthic organisms in continental shelf waters in temperature latitudes is controlled largely by seasonal temperature conditions. Further, Colton (1968a) attributed a delay in the timing of maximum haddock spawning on Georges Bank and vernal augmentation of the Gulf of Maine stock of *Calanus finmarchicus* to decreasing temperatures.

The question was raised whether there had been a significant upward trend in average temperatures or simply a couple of anomalous years since 1968. Although bottom temperatures alone represent only a partial picture of the temperature structure of the region, they are sufficient to show major changes and are particularly relevant for the distribution of demersal species. The remainder of the temperature profile, from surface to near bottom, is not included in this study. Also salinity profiles are excluded from the study since subsurface data were not routinely obtained on these surveys. For these reasons, specific identification of subsurface water masses is not possible; however, it is known that the major source of subsurface inflow into the Gulf of Maine is relatively warm slope water through the Northeast Channel (Bigelow, 1927; Colton, 1968b). Therefore, major changes in the average bottom-water temperature in the Gulf should be preceded by changes in the volume and temperature of water entering the Gulf via the Northeast Channel.

Georges Bank water is derived largely from the Gulf but is also sporadically influenced, especially on the surface, by intrusions of slope water along the southern boundary (Bumpus, 1975). Since the Bank is usually well mixed by tidal and wind forces throughout most of the year, subsurface temperatures there are influenced to a large degree by the deeper boundary waters.

Recent papers by Colton and Stoddard (1973), Colton (1968b), and Schopf (1967) have summarized the distribution of bottom-water temperatures from 1955 to 1967 in the Gulf of Maine and contiguous waters. A contemporary paper by

[1] Presented as Working Paper 76/IV/112 at Environmental Working Group meeting, Szczecin, Poland, April 1976.

Karaulovsky and Sigaev (1976) summarizes similar data for 1962-1972 and provides an intermediate comparison between the earlier papers and this present study which covers the years 1968-1975. These earlier studies are not exactly comparable with the present study because of the variability of the data bases and different analytical methods. Nevertheless comparisons should be useful for broad-term generalizations.

It should be emphasized that this is a preliminary study which does not include even all of the available temperature data which would help adjust for annual variations in seasonal temperature cycles. However, the analyses are adequate for first approximation to annual changes in spring and autumn temperatures for the Gulf of Maine and Georges Bank.

Data and Methods

Bottom temperature data are based on mechanical or expendable bathythermograph observations obtained during spring and autumn groundfish surveys conducted by the National Marine Fisheries Service, Woods Hole, Massachusetts, and described by Grosslein (1974). Approximately 100 observations were made in the Gulf of Maine and 60 observations on Georges Bank during each cruise; most observations were made in 100-360 m depths in the Gulf but only those waters within the 100-meter isobath on Georges are considered in this report because of the high temperature variability beyond this depth caused by sporadic excursions of warm slope water onto the southern perimeter of the Bank. This localized phenomenon would mask the primary object of this analysis, i.e. to show the general temperature conditions and overall trend on the Bank itself.

Timing of the collection of temperature data is shown in Figure 1. The effects of irregular seasonal sampling over the eight-year period must be considered but the effects of these sampling variations are difficult to determine, especially for shoal areas like Georges Bank. For the Gulf of Maine, the autumn cruises nearly all overlap and the spring cruises mostly occurred when the bottom-water temperatures remain virtually stable and isolated from surface effects (Bigelow, 1927; Colton and Stoddard, 1973). The timing of cruises on Georges Bank was fairly consistent in the autumn, but the spring cruises have two rather distinct groupings - March dates for 1969-1972 and April dates for the four remaining years. No clear relationship between timing and mean temperature is evident in these latter cruises; for example, two of the April or late cruises had values the same as the eight-year mean and two of the March or early cruise means (1971-1972) were greater than the mean of the time series. The data presented by Colton and Stoddard (1973) show that average bottom-water temperatures on Georges Bank between 1940-1966 were slightly lower during March than in April; thus the late cruise mean temperatures may be biased slightly upward because of their timing. Considering the objective to portray the general temperature trends over an extensive area, it is assumed that the timing of the cruises was not critical to the estimation of major temperature trends.

Both the Gulf of Maine and Georges Bank were analyzed in their entirety and by subareas of 1° longitude. Subareas in the Gulf are identified by the Roman numerals I-V and Georges Bank subareas are termed Western, Central, and Eastern Georges Bank (Figure 2). Analysis by 1° segments of longitude was chosen because this represents rather distinct physiographic regions of the Gulf and Georges Bank (Table 1) and also was a convenient method of establishing segment boundaries to show possible progressive temperature differences and trends in various parts of the study area, i.e. western, central, and eastern parts of the Gulf and Georges Bank.

Table 1. Subarea characteristic(s) of the Gulf of Maine and Georges Bank

Subarea		Characteristic(s)
Gulf of Maine:	I	Coastal, <200 m, Jeffreys Ledge & Stellwagen Bank
	II	Western Basin, some banks and ledges
	III	Intermediate between II & IV
	IV	Eastern Basin, mostly >200 meters
	V	Coastal W. Nova Scotia, Entrance Northeast Channel
Georges Bank:	Western	Cultivator Shoal, adjacent Great South Channel
	Central	Georges Shoal, no adjacent channels
	Eastern	Mostly >60 meters, adjacent Northeast Channel

F 3

Contoured isotherms at 1° C intervals were overlaid on grid charts and the number of 5x5 minute units counted to determine the percentage area represented by each temperature class interval of 2° C. An index of the mean seasonal bottom temperature was calculated by multiplying the midpoint of each class interval by the percentage area within that interval and dividing the total by 100.

Results

Gulf of Maine - Spring

Spring bottom-water temperatures in the Gulf of Maine show a general warming trend since 1968 reaching a peak in 1973-1974, with only slight annual decreases (-0.1° C) in 1972 and 1975 (Figure 3). The largest annual increase (0.8° C) occurred in 1970 and accounted for over 50 percent of the total eight-year range of 1.4° C (5.2°-6.6°). The spring mean of 6.1° C was about 1° C colder than in 1955-56 but 1° C warmer than in 1965-66 as reported by Schopf (1967) and the 1962-72 long-term mean reported by Karaulovsky and Sigaev (1976). Individual years from 1968-1972 corresponded with data of the latter authors to within $\pm 0.2^{\circ}$ C. The highest mean of 1974 corresponds with the highest positive sea surface temperature anomaly between 1970-74 in the Gulf (J. L. Chamberlin, personal communication).

Figure 4 illustrates the changes in percentage of temperature class intervals (TCI's) for the entire Gulf. The general warming trend is characterized by a rather progressive decrease in water $<4^{\circ}$ C with a corresponding increase in water $>8^{\circ}$ C (solid bars in histogram). Although some years had the same or nearly the same mean temperature, the TCI's were usually of quite different magnitude. For example, during the spring cruises of 1970-72, the means varied by only 0.1° C but the coldest and warmest TCI's varied by factors of about 2 and 13, respectively. The 6°-8° TCI dominated in all years while the 4°-6° TCI remained the most consistent during the study period.

Figure 5 summarizes the annual mean spring temperatures for the Gulf by subareas of one degree longitude. Subareas I and IV had the lowest and highest values respectively in each of the years investigated as expected since I has the most shoal water and nearly all of IV is greater than 200 m. The relative shoalness of I is also reflected in the large temperature variability between years, especially the increases between 1969-70 ($+1.5^{\circ}$ C) and 1973-74 ($+1.0^{\circ}$ C), and the decreases between 1970-71 (-0.6° C) and 1971-72 (-0.7° C). A temperature increase was noted between years in all subareas from 1968-70 and 1972-73 but no year produced a decrease in every subarea. The eight-year means and yearly anomalies are summarized in Table 2 and show that all subareas had negative values in 1968-69 and positive values in 1974-75 but a mixture of values in the intervening years.

Comparison of the Gulf by subarea again shows how years of similar mean temperatures can have vastly different TCI's (Figure 6). In subarea I the means were all 5° C in 1970, 1974 and 1975 but the TCI's in 1970 were about 20 percent each 2°-4° and 6°-8° and 60 percent 4°-6°, while 1974 and 1975 were both nearly 100 percent 4°-6°. Conversely, a deep stable subarea like IV had very similar TCI percentages when the spring means were similar and clearly shows the decrease of coldest and increase of warmest TCI's as the warming trend progressed.

Gulf of Maine - Autumn

Autumn bottom water temperatures in the entire Gulf of Maine increased steadily from 1968-74 and decreased quite abruptly in 1975 (Figure 3). The total seven-year increase was 1.3° C (7.3°-8.6° C) while the single decrease was 0.6° C. The eight-year mean of 7.9° C was 0.9° C warmer than observed by Karaulovsky and Sigaev (1976) for the years 1962-72, and about 2° C warmer than the seasonal mean indicated for this area by Schopf (1967).

Temperature class intervals in the Gulf showed a consistent change annually even though the mean temperatures varied only slightly between several years (Figure 4). Generally, water $<6^{\circ}$ C in colder years was "replaced" by $>10^{\circ}$ C and dominance of the 6°-8° TCI shifted to the 8°-10° TCI to account for the warming trend.

Temperatures fluctuated widely between years and generally did not show a consistent pattern between subareas. However, the easternmost subarea (V) was usually the warmest and subarea II the coldest, and in 1975 all subareas decreased (Figure 7). The largest fluctuations occurred in the coastal subareas I and V which had annual differences as much as 1.5°-1.8° C. Although subarea I is the smallest of the Gulf divisions, its exceptionally large negative anomaly of 1.6° C (Table 2) accounted for most of the 1975 decline in mean bottom water temperature for the entire Gulf (Figure 3). Subarea II, which comprises most of the Western Basin of the Gulf of Maine, had the lowest mean bottom-water temperature (7.3° C), whereas subarea V, influenced by its large area of shoal water and the inflow through the Northeast Channel, had the highest mean (9.1° C).

The subarea TCI's are shown in Figure 8 and unlike the histogram for the entire Gulf indicate that similar mean temperatures usually had similar TCI percentages. Best examples of this relationship occurred in 1969 between subareas I and V; in 1972 between IV and V; and in 1973 among I, II, and III. The relatively large amounts of 4°-6° C water in subareas II and III in 1968 and in subarea I in 1975 were chiefly responsible for the lowest annual mean and single annual decrease. The absence of this TCI in 1974 coincided with the highest mean temperatures observed for the entire Gulf of Maine but not necessarily for the individual subareas.

Table 2. Eight-year means and yearly anomalies for subareas of the Gulf of Maine.

					SPRING				
Subarea	$\bar{x}$	1968	1969	1970	1971	1972	1973	1974	1975
I	4.2	-1.5	- .7	+ .8	+ .2	- .5	- .2	+ .8	+ .8
II	5.9	-1.0	- .8	+ .6	+ .3	- .1	+ .1	+ .3	+ .4
III	6.2	-1.1	- .5	+ .5	+ .3	- .1	+ .2	+ .3	+ .3
IV	7.0	- .7	- .5	- .1	- .2	+ .4	+ .6	+ .7	+ .2
V	6.0	-1.0	-1.0	- .3	0	0	+ .8	+ .5	+ .5

					AUTUMN				
Subarea	$\bar{x}$	1968	1969	1970	1971	1972	1973	1974	1975
I	8.1	+ .3	+ .2	+1.2	0	+ .3	- .3	- .1	-1.6
II	7.3	-1.2	- .5	0	+1.1	+ .1	+ .6	+ .1	- .2
III	7.5	-1.2	- .4	- .3	+ .1	+ .2	+ .2	+ .8	+ .5
IV	8.2	- .4	- .9	-1.0	- .5	+ .6	+ .4	+1.1	+ .5
V	9.1	- .2	- .7	-1.3	- .6	- .3	+ .9	+1.7	- .1

Georges Bank - Spring

Spring bottom-water temperatures on Georges Bank are characterized by a low in 1971 of 4° C followed by rather large annual increases to a peak of 6.5° C in 1974, and then a sharp decline of 1.1° C in 1975 (Figure 9). The eight-year mean of 5.2° C is 1° C lower than reported by Karaulovsky and Sigaev (1976) for 1962-72 but their coverage included waters >100 m. Schopf (1967) calculated a mean bottom-water temperature of approximately 4.8° C for Georges Bank during this season in the period 1955-56 and 1965-66.

Georges Bank is usually dominated by the 4°-6° TCI in the spring which in 1969 accounted for 90 percent of the area within the 100-m isobath (Figure 10). The coldest (1971) and warmest (1974) years are marked by a displacement of this TCI with 2°-4° and 6°-8° C water, respectively. Since the Bank waters are well mixed, these changes in TCI percentages reflect broad-scale habitat differences in 1971 and 1974 from average conditions.

Unlike the Gulf of Maine, year-to-year changes in spring temperatures were similar in all the subareas of Georges Bank, which again points out the homogeneity of these shoal waters (Figure 11). Central Georges was usually the coldest of the three subareas and reached a minimum of 3.6° C in 1971. Western and Eastern Georges had very similar mean temperatures except in 1968 when the latter subarea had an anomaly of -1.7° C (Table 3).

Table 3. Mean bottom-water temperatures and anomalies by subareas of Georges Bank, spring and autumn, 1968-1975.

					SPRING				
Subarea	$\bar{x}$	1968	1969	1970	1971	1972	1973	1974	1975
Western	5.3	- .7	- .1	- .3	-1.1	0	+ .9	+1.4	+ .2
Central	5.1	0	+ .1	-1.0	-1.5	+ .1	+ .7	+1.4	+ .4
Eastern	5.2	-1.7	0	- .4	-1.0	0	+1.0	+1.2	+ .6

					AUTUMN				
Subarea	$\bar{x}$	1968	1969	1970	1971	1972	1973	1974	1975
Western	12.9	0	-1.8	-1.1	+1.0	+ .4	+ .6	+1.3	- .3
Central	12.9	- .4	-1.2	- .7	+ .3	- .2	+1.2	+1.1	- .1
Eastern	10.3	- .2	-1.6	-1.3	- .3	0	+1.5	+1.5	+ .4

Subarea TCI's for both spring and autumn are shown in Figure 12. It is interesting to note that the quite warm years of 1973 and 1975 were substantially influenced by water >8° C in all three subareas but that the warmest year, 1968, had none of this water. The rather low mean for the entire Bank in 1968 was mainly the result of a 2°-4° TCI of 75 percent in the Eastern subarea.

<u>Georges Bank - Autumn</u>

Mean bottom-water temperatures on Georges Bank in the autumn increased from a low of 10.6° C to a high of 13.4° C in 1973 (Figure 13). The largest annual variations were -1.5° C (1974-75), -1.1° C (1974-75), +1.3° C (1970-71), and +1.2° C (1972-73). The eight-year mean of 12.1° C was recorded in both 1968 and 1975; this value was about 1° C warmer than that reported by Karaulovsky and Sigaev for 1962-72.

The two coldest years, 1969 and 1970, are characterized by relatively large amounts of water <10° C and small amounts >14° C, while the two warmest years, 1973 and 1974, had no water less than 8° C (Figure 10). Years of similar mean temperatures did not necessarily have similar TCI percentages; 1973 and 1974 were alike but 1968 and 1975 were quite different.

Figure 14 and Table 3 summarize the mean temperatures and variations for the three subareas of the Bank. Especially notable are the consistently low temperatures on Eastern Georges during all years of the study. The warmest part of the Bank alternated nearly every year between the Western and Central subareas and each had the same eight-year mean (12.9° C). Despite the large annual fluctuations, each subarea was in phase with the general trend depicted for the entire Bank.

The influence of the Eastern subarea on autumn mean temperatures for the whole of Georges Bank is evident in the TCI distributions shown in Figure 12. Relatively large amounts of 6°-8° C water and small amounts of 14°-16° C water in the eastern subarea are prevalent in cold and warm years respectively. The modal TCI percentages are consistently lower by one interval than those in the western and central subareas.

Discussion

Annual fluctuations in spring and autumn bottom-water temperatures in the Gulf of Maine and Georges Bank are obviously related to the volume of unusually cold or warm water which denotes change in composition of these waters. Bigelow (1927) and Colton (1968b) concluded that it is the volume and composition of offshore waters entering the Gulf of Maine via the Northeast Channel that principally determines these variations, at least in the deeper basins of the Gulf. Although salinity observations were not determined in this study, it can be reasonably assumed that slope water entering the Gulf through the Northeast Channel was mainly responsible for the general temperature trend observed in much of the Gulf and ultimately affected changes in Georges Bank. Examination of the plotted isotherms (Figures 15, 16), especially for the spring cruises, clearly supports this assumption. R. Schlitz (personal communication) suspects, from the above examination, that the high spring temperatures observed in 1972-1974 were either the result of a repeated inflow through the Northeast Channel each year, as indicated by the 8° isotherm (Figure 15), or that a single major pulse occurred in 1972, perhaps followed by lesser intrusions, and this warm water persisted in the deep basins until natural decay resulted in the observed 1975 decline in mean bottom temperature. Another hypothesis is that a similar sequence was initiated in the autumn of 1971 and that the warm spring conditions were the result of "over-wintering" slope water. Regardless of the hypothesis it seems clear that anomalous conditions occurred commencing in the autumn of 1971 and spring of 1972 and persisted through 1974. In order to understand the dynamics of such changes it will be necessary to carry out continuous monitoring of temperature, salinity, and currents in the very important Northeast Channel and contiguous waters. As stated by Bigelow (1927) this channel is the most striking feature of the Gulf of Maine affecting the hydrography of the region. Also, an examination of available data on the volume and temperature of adjacent slope waters in the past decade may provide a better understanding of the observed conditions in the Gulf of Maine and on Georges Bank during this period.

The trend of increasing temperatures since 1968 was much smoother in the Gulf of Maine than on Georges Bank when each area is analyzed as an entire unit (Figures 3 and 9), but on Georges Bank the subareas are much more similar within a given year (Figures 5 and 10). This is to be expected as the entire waters of Georges are often well mixed by tides and winds as indicated by the homogeneity of TCI's in years of very comparable mean temperatures such as in the spring 1969 and 1972 (Figure 12). This phenomenon was not observable in the autumn because Eastern Georges was consistently two or more degrees colder than the rest of the Bank. This can partially be explained by the fact that Eastern Georges contains the least amount of shoals of the three subareas and the effect of the indraft through the Northeast Channel would tend to cool Eastern Georges in the autumn (Colton, 1968b).

With respect to biological changes it is perhaps more important to note the fluctuations in volumes of certain temperature intervals rather than variations in temperature means or extremes. For example, the TCI's might be considered estimates of suitable habitat area for any given species providing its temperature tolerances or preferences are known; if spawning and survival of species "X" on Georges Bank is most successful in 6°-8° C water, then 1974 might be expected to result in a better year-class than the other seven years of presented data as no other year had large quantities of this water in this area (Figure 12). A close examination of such relationships with real species in the entire water column appears warranted as a follow-up to this report. It is perhaps unlikely that a simple linear relationship between year-class success and temperature will be found for any species; however, temperature trends of the magnitude shown in this paper undoubtedly influence certain biological phenomena in significant ways, e.g. changes in time of spawning of sea herring and haddock and distributional patterns of mackerel and silver hake. A more complete understanding of the net effects of temperature on spawning, hatching success, growth, predation, etc., is required, but nevertheless other gross effects such as those stated might be evident if available biological data for the last decade is closely scrutinized. Certainly there would be significant value of such correlation analyses of time series data, especially after we have better measures of the dynamics involved with temperature variations in the Gulf of Maine and on Georges Bank.

References

Anderson, E. D. 1975. The effects of a combined assessment for mackerel in ICNAF Subareas 3, 4, and 5 and Statistical Area 6. ICNAF Res. Doc. 75/14: 14 p.

Bigelow, H. B. 1927. Physical oceanography of the Gulf of Maine. Bull. U.S. Bur. Fish., 40(2): 511-1027.

Bumpus, D. F. 1975. Review of the physical oceanography of Georges Bank. ICNAF Res. Doc. 75/107: 32 p.

Colton, J. B., Jr. 1968a. A comparison of current and long-term temperatures of continental shelf waters, Nova Scotia to Long Island. Res. Bull. Int. Comm. Northw. Atlant. Fish. No. 5: 110-129.

Colton, J. B., Jr. 1968b. Recent trends in subsurface temperatures in the Gulf of Maine and contiguous waters. J. Fish. Res. Bd. Can., 25(11): 2427-2437.

Colton, J. B., Jr., and R. R. Stoddard. 1973. Bottom-water temperatures on the continental shelf, Nova Scotia to New Jersey. NOAA Tech. Rep. NMFS Circ. 376: 55 p.

Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Mass., USA. ICNAF Res. Doc. 74/96: 27 p.

Karaulovsky, V. P., and I. K. Sigaev. 1976. Long-term variations in heat content of the waters on the Northwest Atlantic Shelf. ICNAF Res. Doc. 76/VI/2: 9 p.

Schopf, T. J. M. 1967. Bottom-water temperatures on the continental shelf off New England. U.S. Geol. Surv. Prof. Paper 575-D: D192-D197.

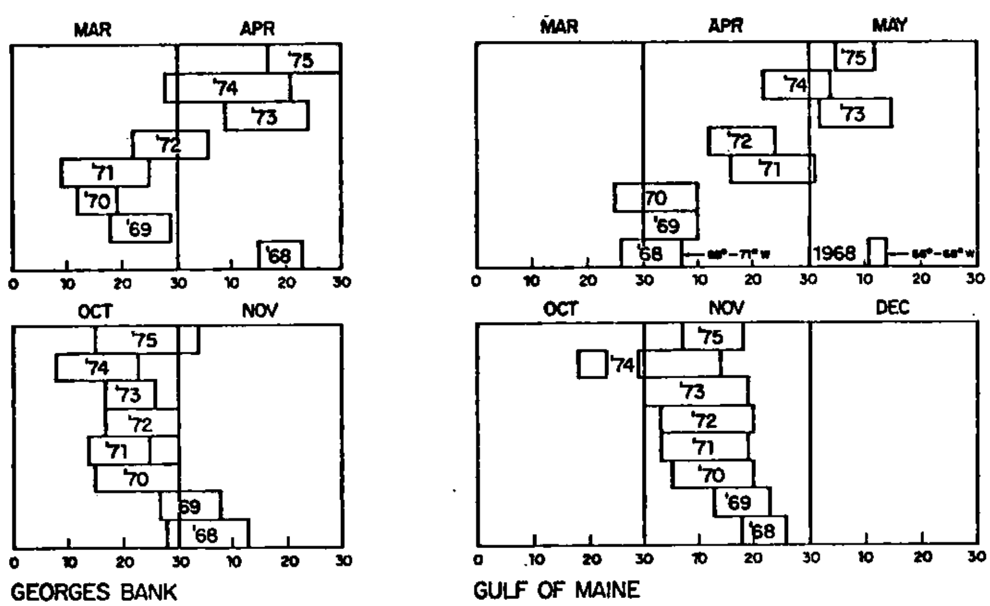

Figure 1. Timing of the collection of temperature data in the Gulf of Maine and Georges Bank, 1968-1975.

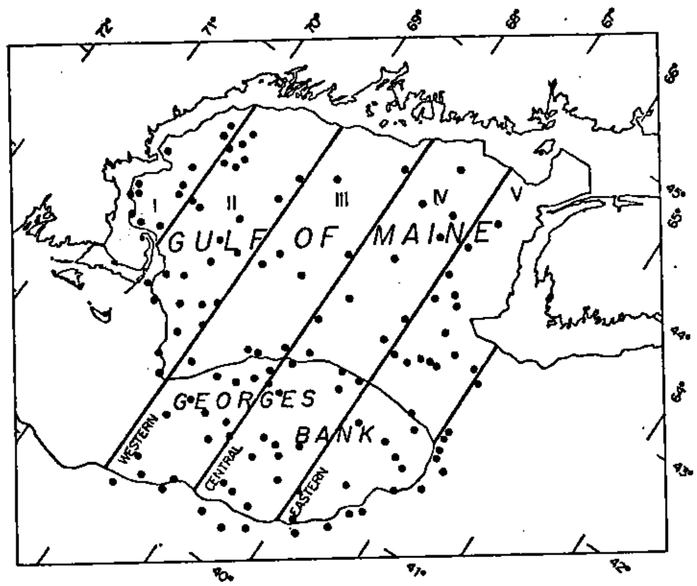

Figure 2. Gulf of Maine-Georges Bank and subarea boundaries used in data analysis (solid circles represent typical distribution of BT stations).

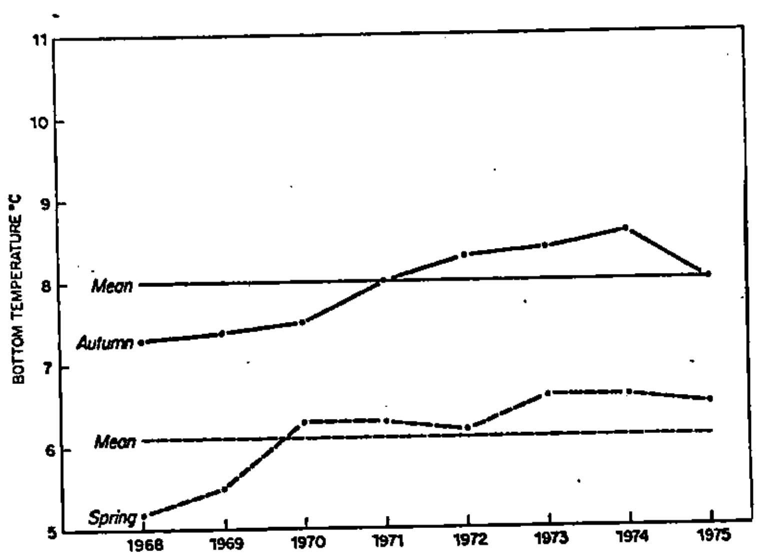

Figure 3. Spring and autumn mean bottom-water temperatures in the Gulf of Maine, 1968-1975.

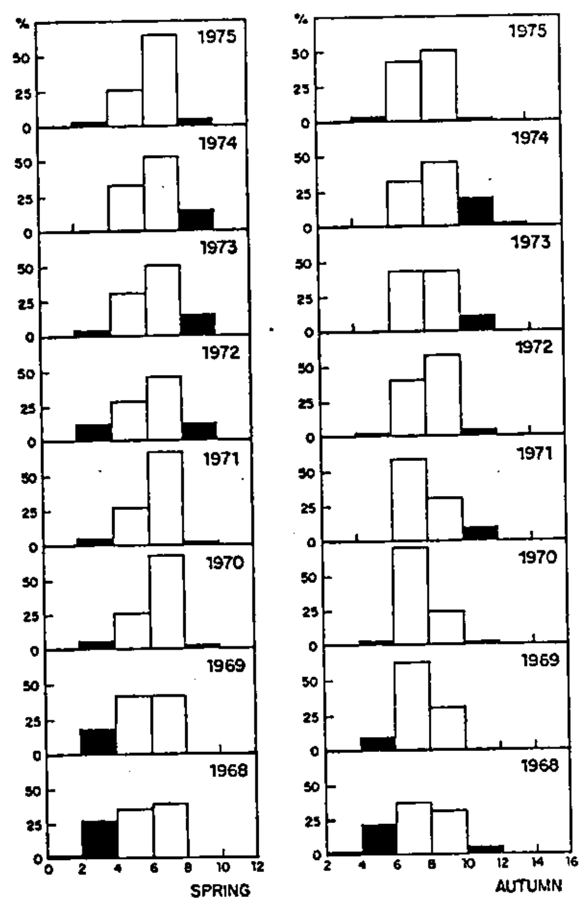

Figure 4. Percentages of temperature class intervals (TCI's) in the Gulf of Maine, spring and autumn 1968-1975.

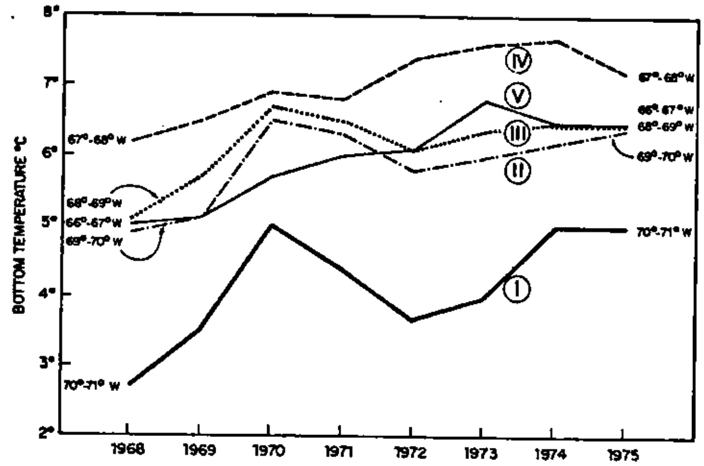

Figure 5. Mean bottom-water temperatures in the Gulf of Maine by Subareas I-V, spring 1968-1975.

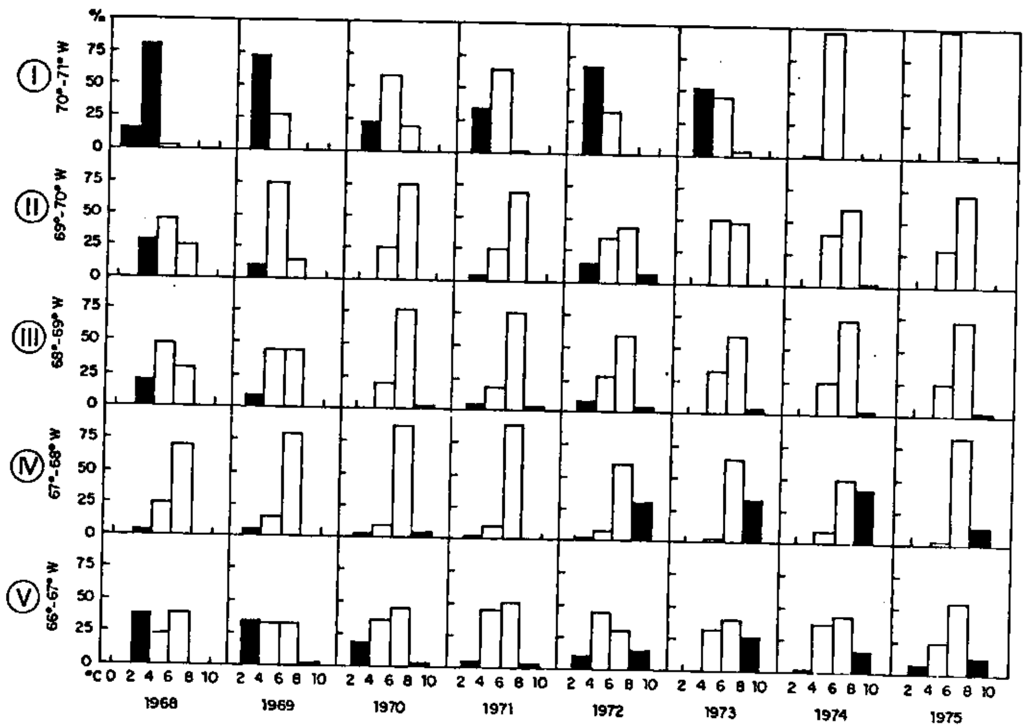

Figure 6. Percentages of temperature class intervals (TCI's) in the Gulf of Maine by Subareas I-V, spring 1968-1975.

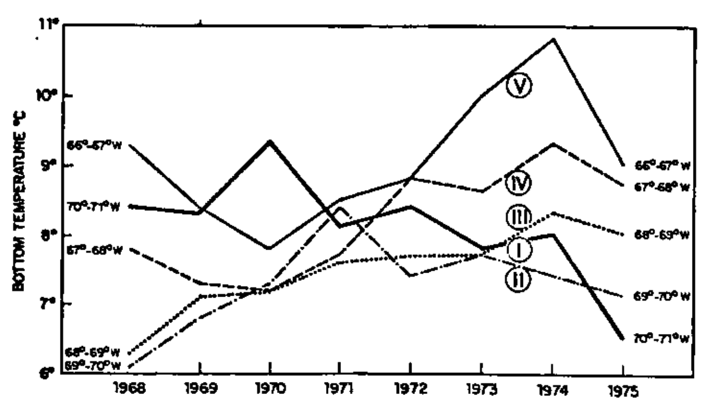

Figure 7. Mean bottom-water temperatures in the Gulf of Maine by Subareas I-V, autumn 1968-1975.

F 10

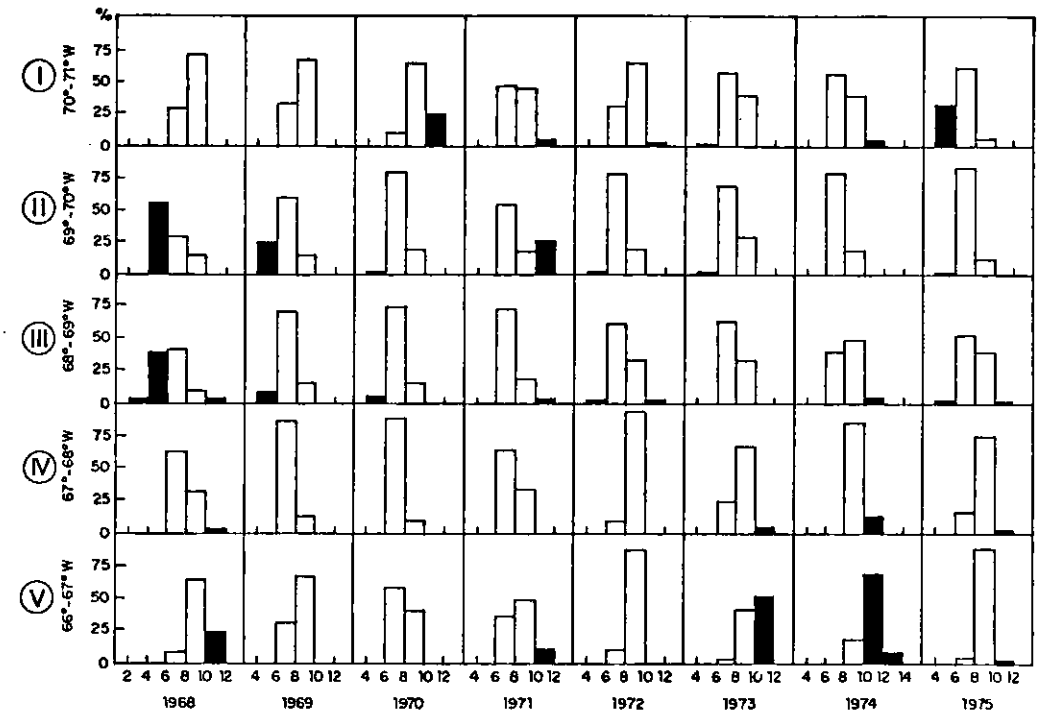

Figure 8. Percentages of temperature class intervals (TCI's) in the Gulf of Maine by subareas, autumn 1968-1975.

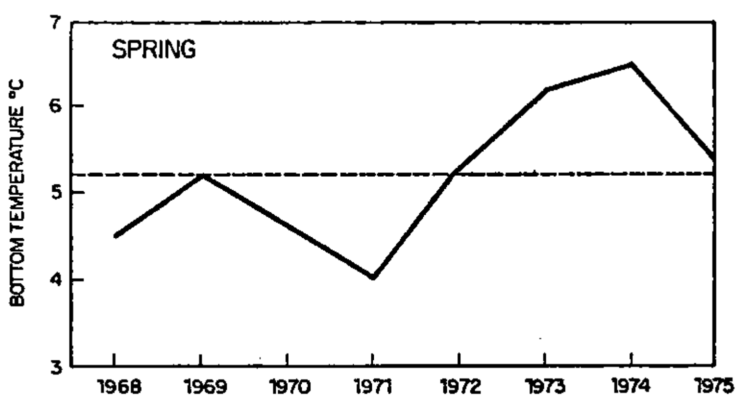

Figure 9. Mean bottom-water temperatures on Georges Bank, spring 1968-1975.

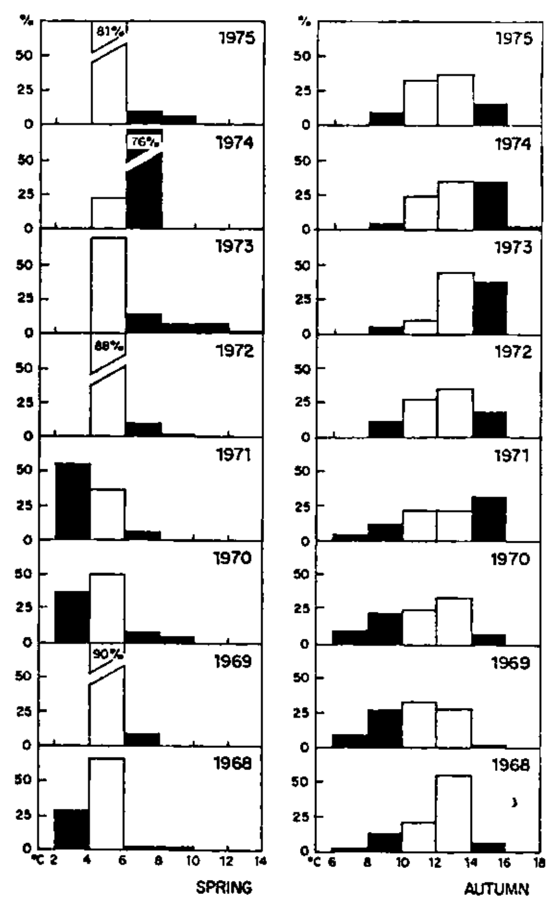

Figure 10. Percentages of temperature class intervals (TCI's) on Georges Bank, spring and autumn 1968-1975.

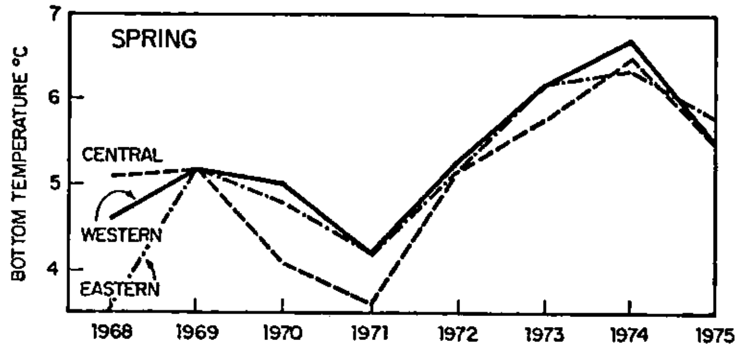

Figure 11. Mean bottom-water temperatures on Georges Bank by subareas, spring 1968-1975.

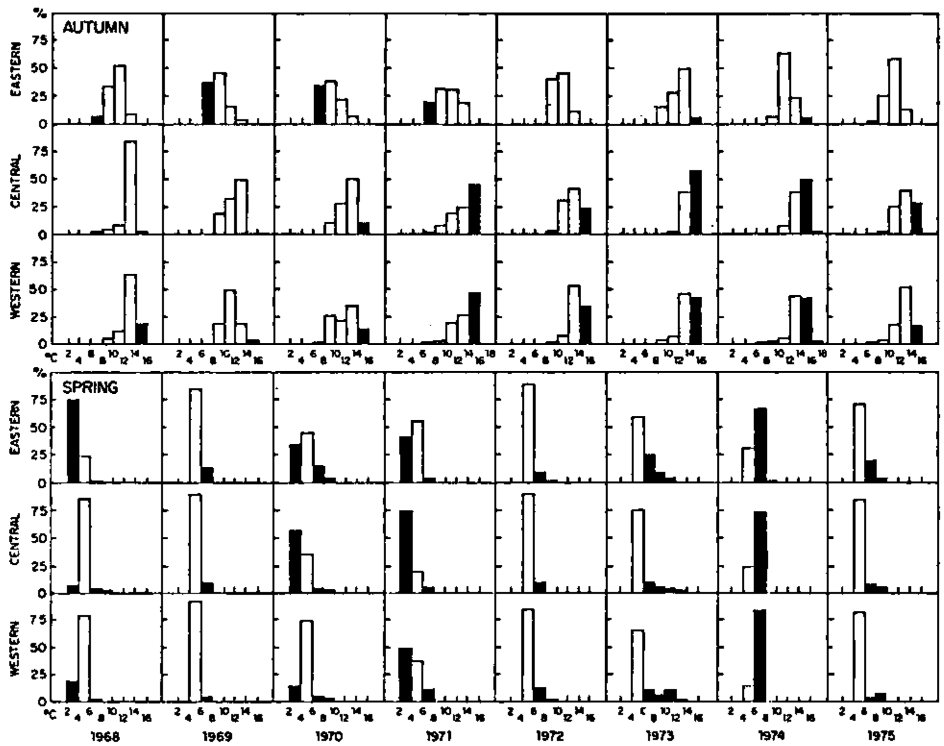

Figure 12. Percentages of temperature class intervals (TCI's) on Georges Bank by subareas, spring and autumn 1968-1975.

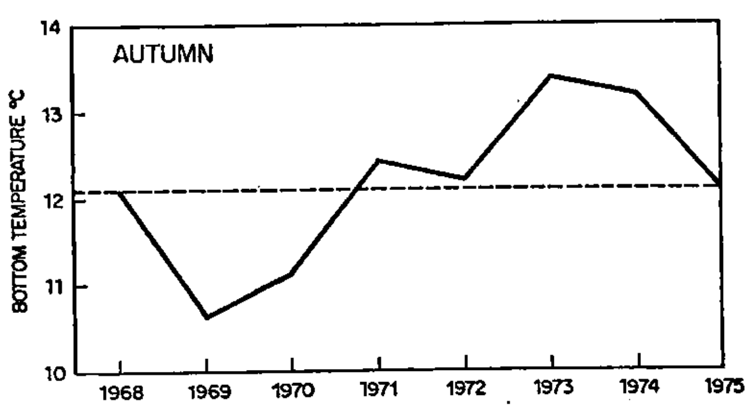

Figure 13. Mean bottom-water temperatures on Georges Bank, autumn 1968-1975.

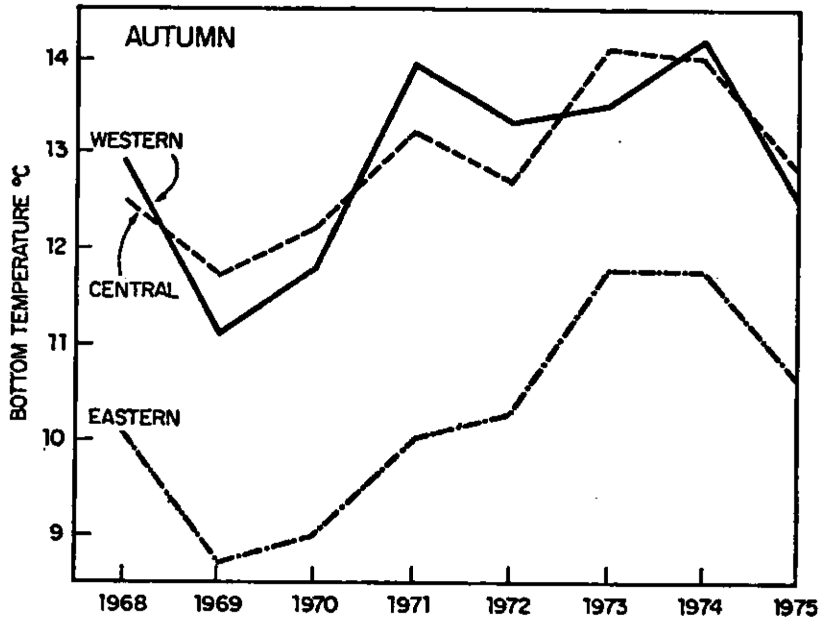

Figure 14. Mean bottom-water temperatures on Georges Bank by subareas, autumn 1968-1975.

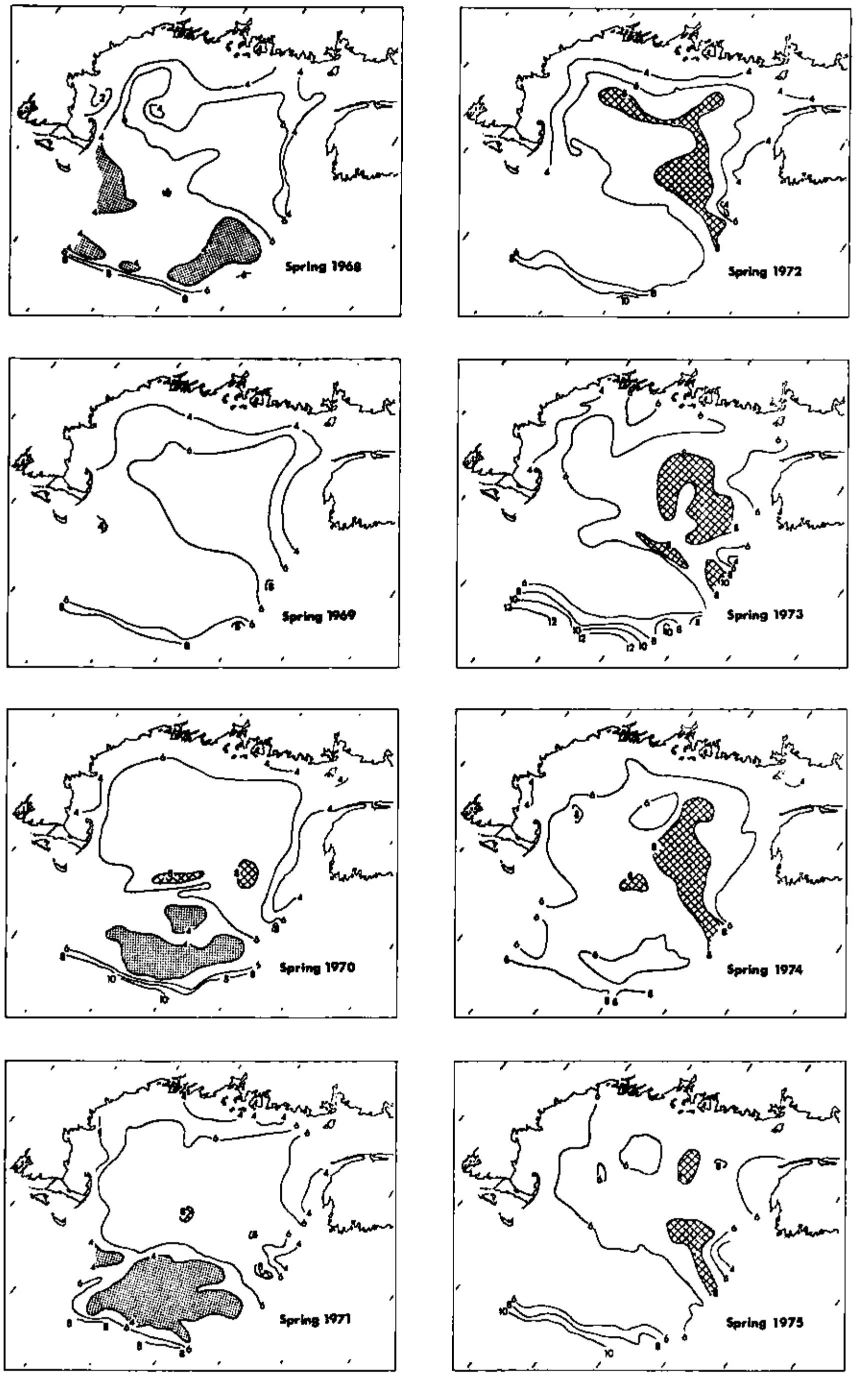

Figure 16. Distribution of autumn bottom-water temperatures, 1968-1975. (Georges Bank dotted area = temp. >14^{0} C; Gulf of Maine grid area = temp. >8^{0} C).

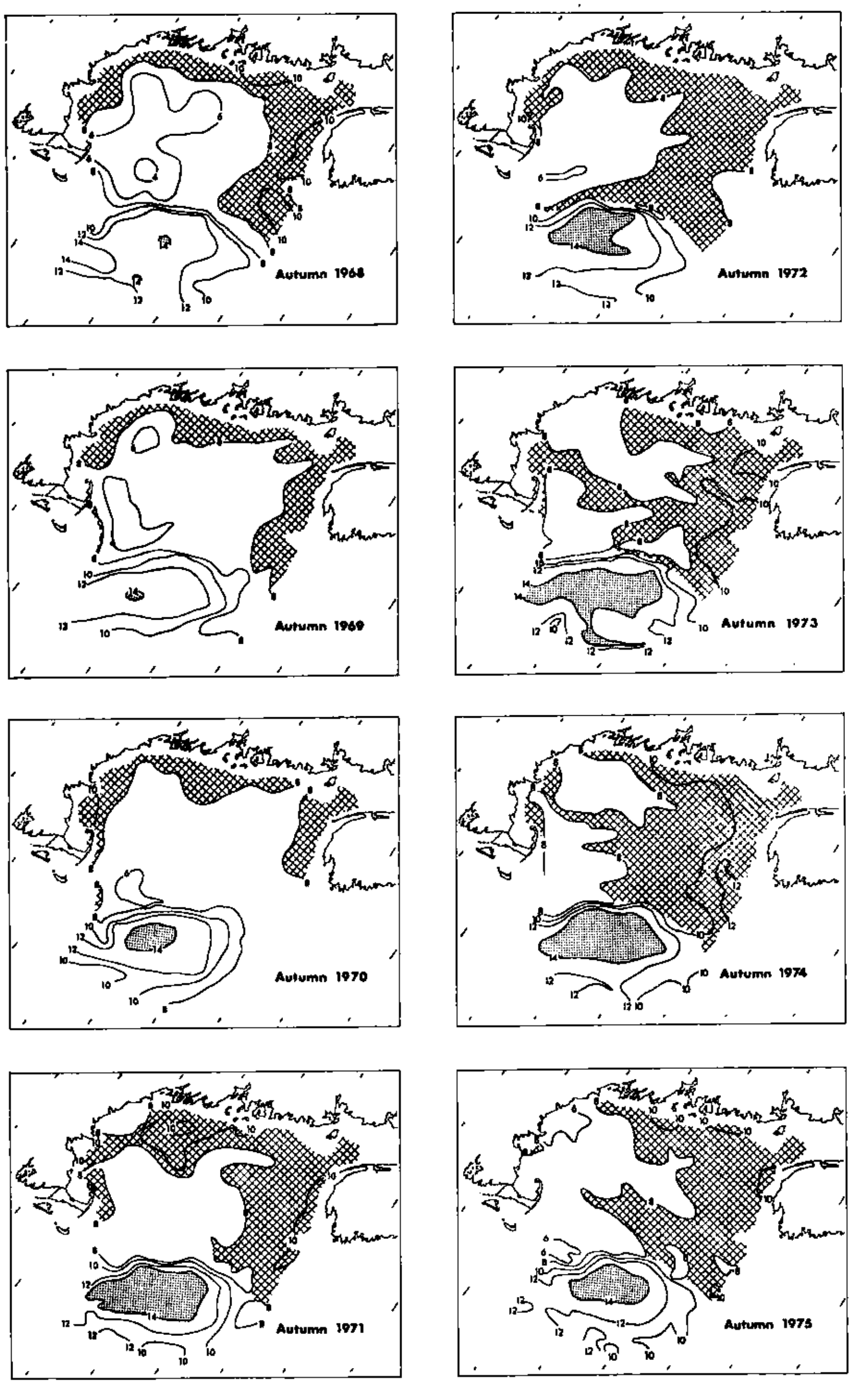

Figure 15. Distribution of spring bottom-water temperatures, 1968-1975. (Georges Bank dotted area = temp. <4^{0} C; Gulf of Maine grid area = temp. >8^{0} C).