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Oceanographic Conditions in Subareas 5 and 6 During 1970-79

by

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Introduction

This report presents an overview of the hydrographic conditions in North Atlantic Fisheries Organization (NAFO) subareas 5 and 6 during the 1970-1979 decade. The data analyzed are from the continental shelf areas between Cape Hatteras and Nova Scotia, including the Gulf of Maine, and are primarily sea surface and near bottom temperature measurements. The purpose of this report is to provide both a description of the hydrographic changes within the decade and continuity with previous studies of earlier decades. The emphasis is on multiyear changes or trends and not on individual or short-lived events. A noteworthy example of the latter is the extreme anoxia conditions that developed in the Middle Atlantic Bight in the summer of 1976 (see Swanson and Sindermann, 1979).

The oceanographic and atmospheric conditions and trends over the western North Atlantic Ocean during earlier decades have been discussed by many authors (e.g., Rodewald, 1972; Dickson and Lamb, 1972; Cushing and Dickson, 1976). In general, mid-latitude sea surface temperatures warmed to a maximum in the early 1950's and decreased through the middle to late 1960's. A return to increasing temperatures at the end of the 1960's decade was suggested in many cases. Associated with these temperature changes (and their probable indirect cause) was a surface atmospheric pressure anomaly pattern during the cooling period (1956-1965) that had a high value over Greenland and a low over the mid-latitude North Atlantic Ocean (Dickson and Lamb, 1972). The resultant anomaly wind circulation

SYMPOSIUM ON ENVIRONMENTAL CONDITIONS 1970-79

would bring cold Arctic air to lower latitudes along the east coasts of the United States and southern Canada.

Coastal Sea Surface Temperature

The longest available time series of oceanographic observations are sea surface temperatures recorded at coastal stations. These allow the conditions during the most recent decade to be put into perspective with conditions during the earlier part of the century. The yearly average sea surface temperature at Boothbay Harbor, Maine (Welch, 1981) and Woods Hole, Massachusetts, are shown in Figure 1. Both series clearly show the warming during the 1940's and early 1950's and the subsequent cooling through the 1960's. Both also show a return to warmer values in the 1970's. The magnitude of change was larger at Boothbay Harbor, but both series show similarity on the nature of even the year to year variations. Comparison with the earlier part of the century at Boothbay Harbor indicates that earlier decades which ranged in average from 7.7-8.0°C were all cooler than the three most recent decades (1950-1959: 9.7°C; 1960-1969: 8.2°C; 1970-1979: 8.8°C).

Sea Surface Temperature Anomalies

Monthly averaged sea surface temperature anomaly data for large areas of the western North Atlantic Ocean are reported in one degree latitude-longitude squares by the Pacific Environmental Group of the National Marine Fisheries Service (e.g., McLain, 1976). The data originate from ship reports received by the U.S. Navy and anomalies are calculated for each square and month relative to a 1948-1967 mean. This reference period includes both the peak warming of the 1950's and cooling of the 1960's. For analysis here four regions have been chosen - the Gulf of Maine, Georges Bank, the Middle Atlantic Bight (MAB), and NAFO subarea 6E (Figure 2). The last is included to provide an offshore, deep ocean series to compare with the nearshore or continental shelf changes. The monthly average surface temperature anomaly, for the four regions through the 1970 decade are shown in Figure 3. Due to both the quality and the irregular reporting of the original data, a high noise level might be expected in these time series. The large anomalies, however, tend to be present for a number of months, representing seasonal variations, and are also simultaneously evident in more than one area. The magnitude of variation is largest in the MAB and smallest in area 6E. This offshore reduction is reasonable since any anomaly in air temperature, originating over the continent and influencing the ocean surface, would be moderated by the ocean before reaching the offshore area.

The major trend of the decade in the MAB was from large periodic negative anomalies in the first years to a warming at mid-decade and a return to negative anomalies in the later years. The same tendency exists, although with lesser amplitude, in the Georges Bank and 6E series. In the Gulf of Maine little trend is found through the decade. The large anomalies in the first few years (1970-1972) extended across the three coastal regions and were characterized by negative values in winter and positive values in summer. The warming was greatest in the Gulf of Maine and the cooling was greatest in the MAB. The warming in mid-decade (1974-1976) noted above was largely the result of the winters having positive temperature anomalies. The largest cooling events during these years were in the spring and summer in the Gulf of Maine and on Georges Bank. The cooling in later years (1977-1978) showed a return to dominant wintertime negative anomalies.

To consider the decade as a whole, the anomaly values were averaged by season (Table I; winter is January-March, spring is April-June, summer is July-September, and fall is October-December). Only the Gulf of Maine showed a positive anomaly for the decade relative to the 20-year reference period. Seasonally the largest negative values were centered in the winter (two in winter and one each in spring and fall), while the most positive contributions were centered in the summer (two in summer and one each in spring and fall). The summer warming tendency was dominant in the Gulf of Maine and the winter cooling dominated in the other three regions.

Bottom Temperature Trends

Bottom water temperature values are available since the 1960's for the coastal areas identified above. These data were obtained as part of the groundfish survey cruises carried out each spring (March-April) and fall (October-November) by the National Marine Fisheries Service. The fall data begin in 1963 and the spring data in 1968. Davis (1978 and 1979) calculated area averaged bottom temperature values in both seasons for the Gulf of Maine, Georges Bank and the northern and southern MAB. Hudson

Canyon separated the latter two areas. The same procedures (see Davis,1978) have been used to extend these series through 1979 (Figure 4).

In the Gulf of Maine a minimum occurred in the fall bottom temperature during the mid-1960's. This was followed by a sharp rise near the end of the decade and a continued gradual increase through 1974. A subsequent decrease then began, although interrupted by a peak temperature in 1976. The spring data mirrored this pattern closely. Spring values for 1965 and 1966 derived from two other data sets (Colton, et al., 1967) suggest that the marked cooling in the fall curves also occurred in the spring (the circles in Figure 4). Georges Bank showed a similar warming from the 1960's through 1974 followed by a decreasing temperature trend. For both the northern and southern MAB the spring curves had similar trends although the peaking in temperature in the mid-1970's was more exaggerated. The fall values in the MAB leveled off or reached a peak in 1971-1972, two years earlier than in either the Gulf of Maine or Georges Bank. The sharp decrease in the southern MAB in the fall of 1970 is due, at least in part, to the timing of the fall cruise about a month before other years and before the annual maximum temperature is usually obtained. Davis (1979) estimated an upward adjustment of 2.2°C for this timing difference.

The changes in temperature indicated in Figure 4 are substantial and are over the entire coastal area under consideration. The range in extreme values is over 3°C in the Gulf of Maine, over 4°C on Georges Bank, and over 5°C in the southern MAB. Comparison of the fall temperature distributions for the Gulf of Maine and Georges Bank in the fall of 1967 and 1974 emphasizes this point (Figure 5, from Davis, 1978). The gulf in 1967 had only small coastal areas where the temperature was above 8° and Georges Bank was generally between 8 and 10°C with no values above 12°C. In 1974 the entire eastern Gulf of Maine was above 8°C with some areas above 10°C. The 8°C contour extended over about half of the western gulf as well. Georges Bank was generally above 14°C.

Variations in Gulf of Maine Bottom Water

The surface and bottom temperature trends are similar in both the MAB and on Georges Bank, but not in the Gulf of Maine. Unlike the shallow continental shelf areas the bottom water in the gulf is derived by advection of Slope Water from over the continental slope into the gulf through

Northeast Channel. This inflow occurs generally below 75 m depth (Ramp, et al., 1980). As a result changes in the character of the bottom water indicated in Figure 4 may be due to changes in the character and rate of the Slope Water inflow to the gulf and not solely to heating, cooling, and mixing processes at the surface. Colton (1968) concluded that changes in the temperature in the gulf between 1955-1960 and 1961-1965 were due to changes in the character of the entering Slope Water from a Warm Slope Water to a colder Labrador Slope Water. Wright (1979) attributed unusually high salinity water on Georges Bank in February 1977 to a large influx of Slope Water into the eastern gulf in the spring of 1976.

To investigate the origin of the observed temperature changes the amount of heating and cooling of the Gulf of Maine bottom water between successive seasons is considered from Figure 4. Any warming from spring to fall must derive from advection of heat (i.e., inflow of Slope Water) since the near surface thermocline and mid-depth temperature minimum layer that developed in the spring isolate the bottom waters from downward exchange of heat. Cooling between fall and spring is more complicated, being a balance of heat loss through vertical mixing induced by surface cooling and of heat gain by the Slope Water inflow. The two curves for the Gulf of Maine in Figure 4 are closely parallel, indicating that the warming from spring to fall is about the same each year. Differences do occur as in 1968, 1977, and 1979 when the warming was larger than in other years and in 1970 and 1975 when it was somewhat smaller. The major changes in the trend of the curves, however, are first seen in the spring values - that is due to differences in the amount of cooling from one fall to the following spring. The cooling over the winters of 1967-1968 and 1975-1976 was smaller than normal, while that over the winter of 1976-1977 was considerably larger than in other years.

Variations in the character and rate of Slope Water inflow should result in changes in not only the temperatures of the bottom water, but in its salinity as well. To investigate this, temperature and salinity values at or near 200 m depth obtained on fall cruises were averaged to yield characteristic water types for the western and eastern Gulf of Maine in different years. The 68° W meridian was used to divide the gulf. The fall season was chosen since it would be farthest removed in time from the complicating effect of water property alteration through surface cooling induced convection. The data used are listed in Table II and the results are plotted in Figure 6. For each year the western gulf (cross-hatched symbol in Figure 6) has the lower salinity and cooler water type. The initial indication is that the salinity values do vary considerably in different years. The temperature-salinity characteristics of Warm Slope Water and Labrador Slope Water (Gatien, 1975) and a line indicating their mixing products are included in Figure 6. If the inflowing Slope Water is assumed to mix uniformly and progressively with a resident water as it spreads across the Gulf of Maine, a line through the western and eastern water types would pass through the characteristics of the original Slope Water. The lines so defined for the different years do intersect different Slope Water characteristics. The colder years (1964 and 1965) point to a nearly pure Labrador Slope Water while the warmest years of 1974 and 1976 point to a higher percentage of Warm Slope Water input; 1978 is intermediate between these extremes. The mixing assumption made above is overly simplistic since the residence time of water in the Gulf of Maine is 1-2 years and therefore the western gulf has likely been exposed to the effects of winter cooling. Still the consistency of the implications - cold years with cold Slope Water, warm years with warmer Slope Water - supports the concept that variations in the Gulf of Maine bottom water are due, at least in part, to changes in the character of the inflowing Slope Water.

Another interesting aspect of Figure 6 is the distance from the eastern Gulf of Maine water type to the original Slope Water values. In 1976 the eastern gulf was nearly pure Slope Water, while in 1964 and 1965 it was far removed from the Slope Water characteristics. This greater distance in 1964 and 1965 is indicative of greater isolation from the source Slope Water and may be due to increased residence time in the gulf resulting from a reduced rate of Slope Water inflow. The 1976 value on the other hand implies a greater volume of inflow, as suggested by Wright (1979), and would account for the peak in bottom water temperature observed that year (Figure 4).

Discussion

The variations in the sea surface temperature anomalies in Figure 4 are likely related to variations in local air temperature over the same period. Comparison with the air temperature anomaly data presented by Ingham (1981) indicates that the two variables are similar in their major characteristics. The frequency and magnitude of negative anomalies decreases toward the mid-decade, while the positive anomalies increase. The later years in both series are dominated by the extremely cold winters.

The warming through the early 1970's in both air and sea surface temperatures is likely related to the large-scale atmospheric pressure patterns. Cushing and Dickson (1976) show that the pressure change between the late 1960's and early 1970's was marked by a low over Greenland and a high over the mid-latitude North Atlantic Ocean. The resulting anomaly winds would bring lower latitude, warmer air to the coastal areas of the northwest U.S. and southeast Canada. This pattern is inverse to that observed during the earlier cooling period of 1945-1965 (Dickson and Lamb, 1972).

A latitude dependence is evident in both the sea surface and air temperature anomaly patterns, particularly in the extreme winters of 1977, 1978, and 1979. The magnitude of cooling was greatest to the south in the MAB and considerably smaller or absent in the Gulf of Maine.

Summary

The oceanographic conditions along the northeast coast of the U.S. during the 1970 decade were characterized by the continuation of a warming trend that began in the late 1960's. The warming peaked in the middle of the decade and was followed by decrease in the average temperature. This pattern was observed in both sea surface and bottom temperature measurements. The trends were not strictly a coastal phenomenon being present in subarea 6E, although at a reduced magnitude.

The similarity of the surface and bottom temperature series in the MAB and on Georges Bank is expected due to the shallowness of the water in these areas and the top to bottom mixing that occurs. In general, these series appear to reflect the influence of local atmospheric conditions. The situation in the Gulf of Maine is more complicated since the surface and bottom waters are more isolated from each other. The data in Figures 4 and 6 suggest that the strength of local atmospheric cooling, the character of the Slope Water entering the gulf through Northeast Channel and even the rate of Slope Water inflow may all be important at different times in determining the conditions observed at depth in the Gulf of Maine.

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Table I. Decade average sea surface temperature anomaly (°C).

Region	Decade	Winter	Spring	Summer	Fall
Gulf of Maine	0.22	-0.05	0.17	0.38	0.38
Georges Bank	-0.27	-0.28	-0.42	-0.24	-0.15
Middle Atlantic Bight	-0.27	-0.65	-0.33	-0.10	-0.33
6E	-0.18	-0.10	-0.04	-0.18	-0.40

Table II. Gulf of Maine data used in Figure 6.

Year	Month	Ship	Comments
1965	September	ALBATROSS IV	200 m values
1966	September	ALBATROSS IV	
1974	September	PROGNOZ	near bottom values
1974	October	WIECZNO	
1976	December	RESEARCHER	100 m values; no data
1976	December	ALBATROSS IV	from Jordon Basin
1978	August	BELOGORSK	200 m values
1978	October	BELOGORSK	

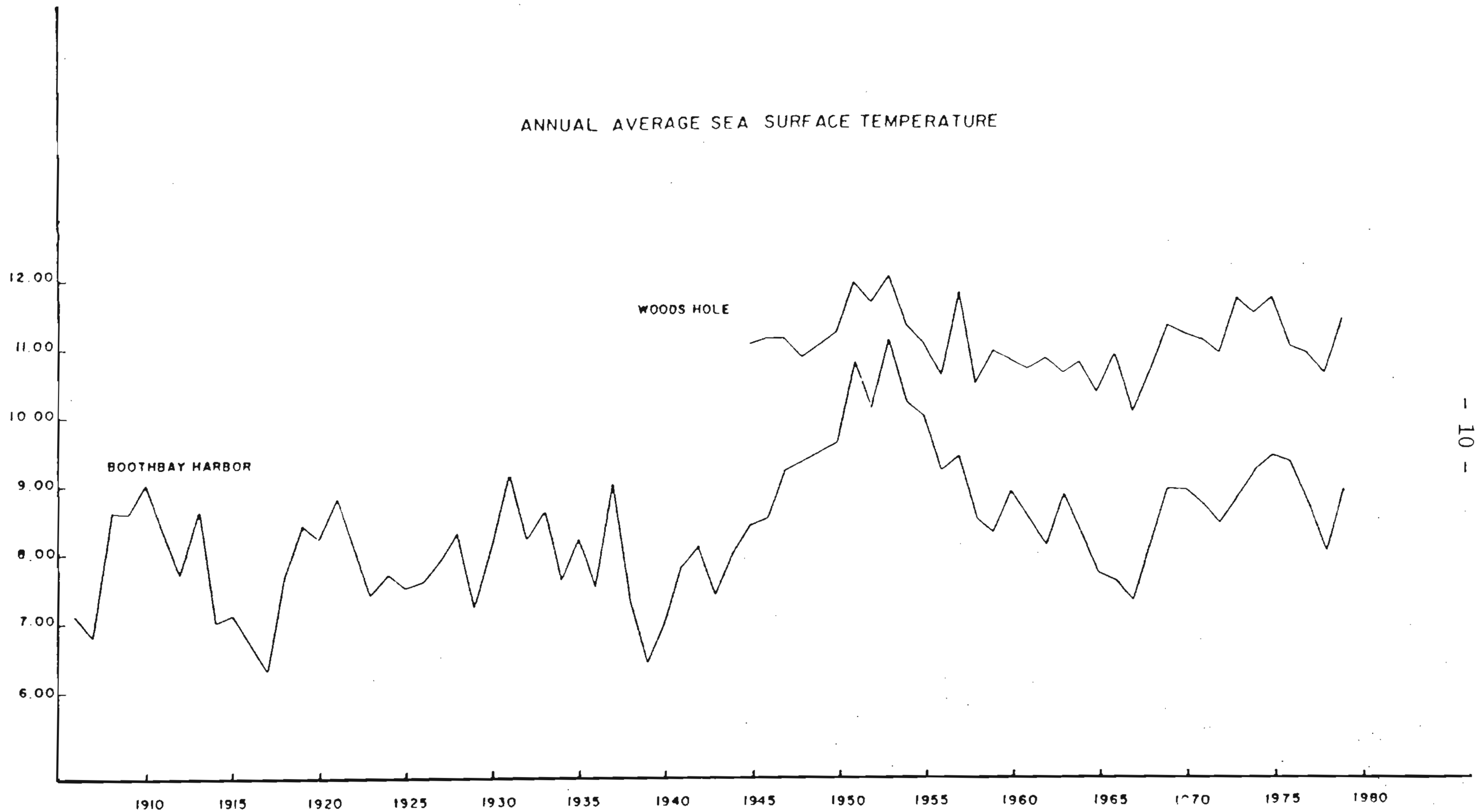

Figure 1. Annual average sea surface temperature (^{o}C) at Boothbay Harbor, Maine and Woods Hole, Massachusetts.

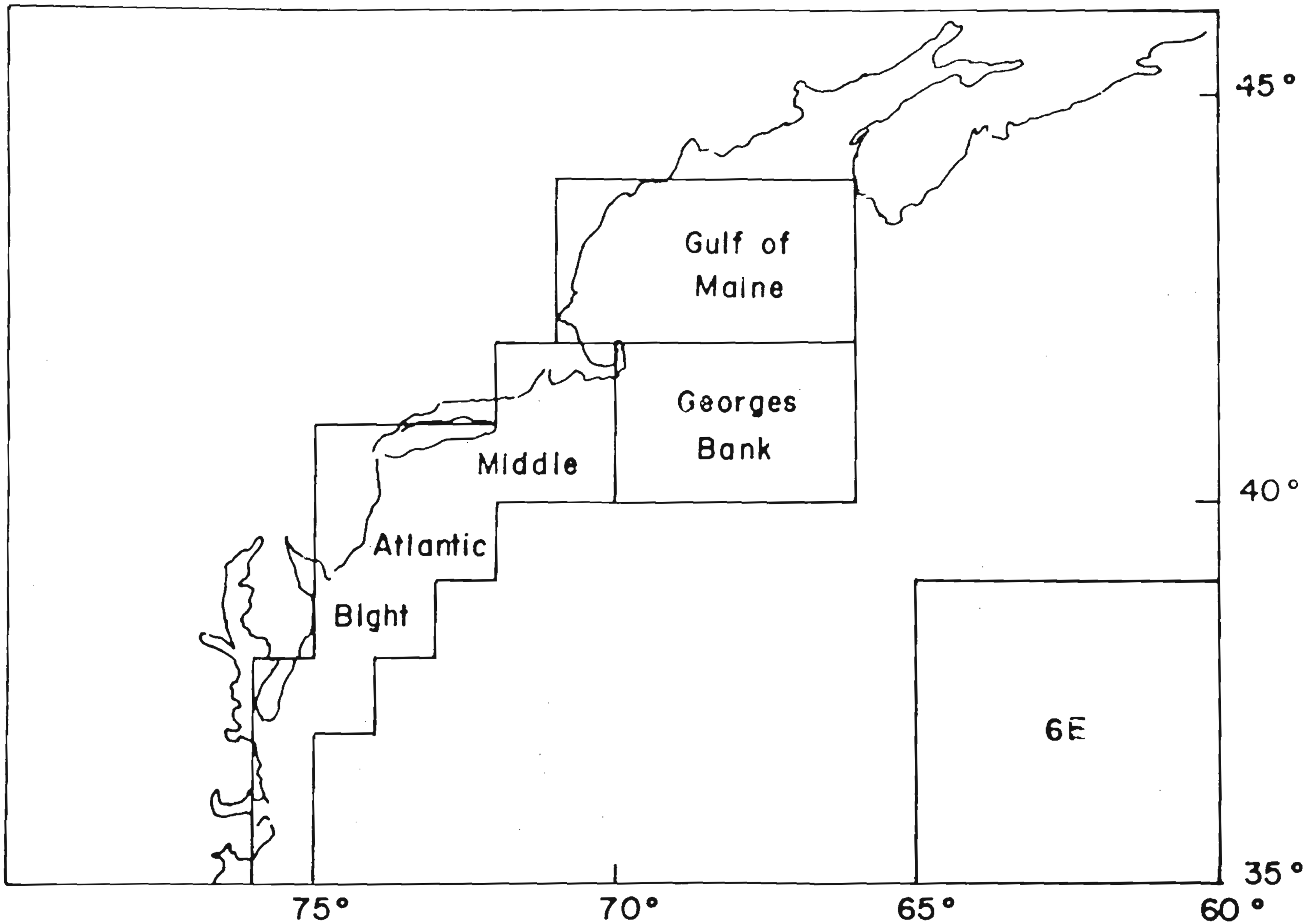

Figure 2. Areas used for averaging sea surface temperature data.

MONTHLY SEA SURFACE TEMPERATURE ANOMALIES (°C)

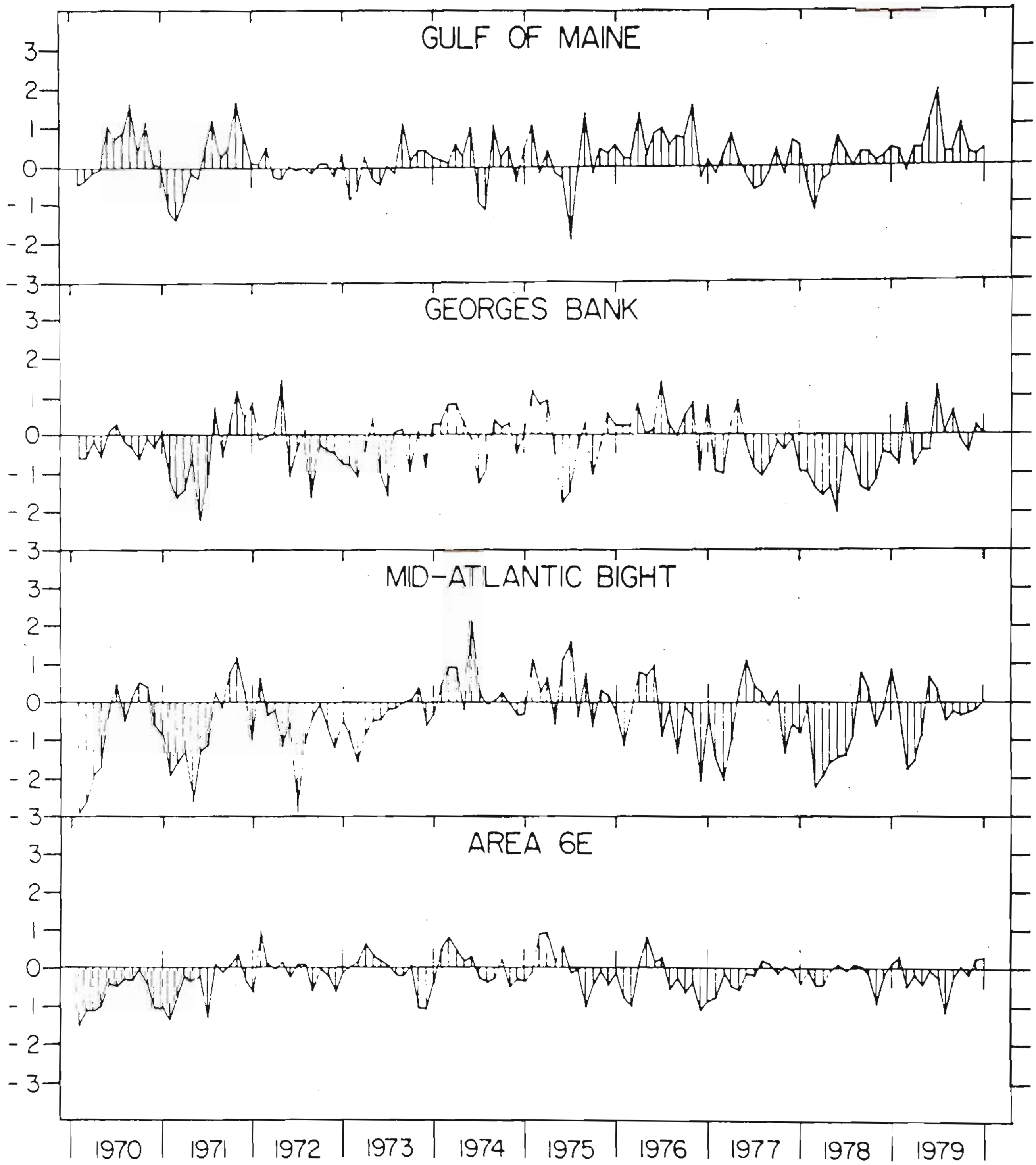

Figure 3. Monthly average sea surface temperature anomaly (°C) for four regions in Figure 2. Reference period is 1948-1967.

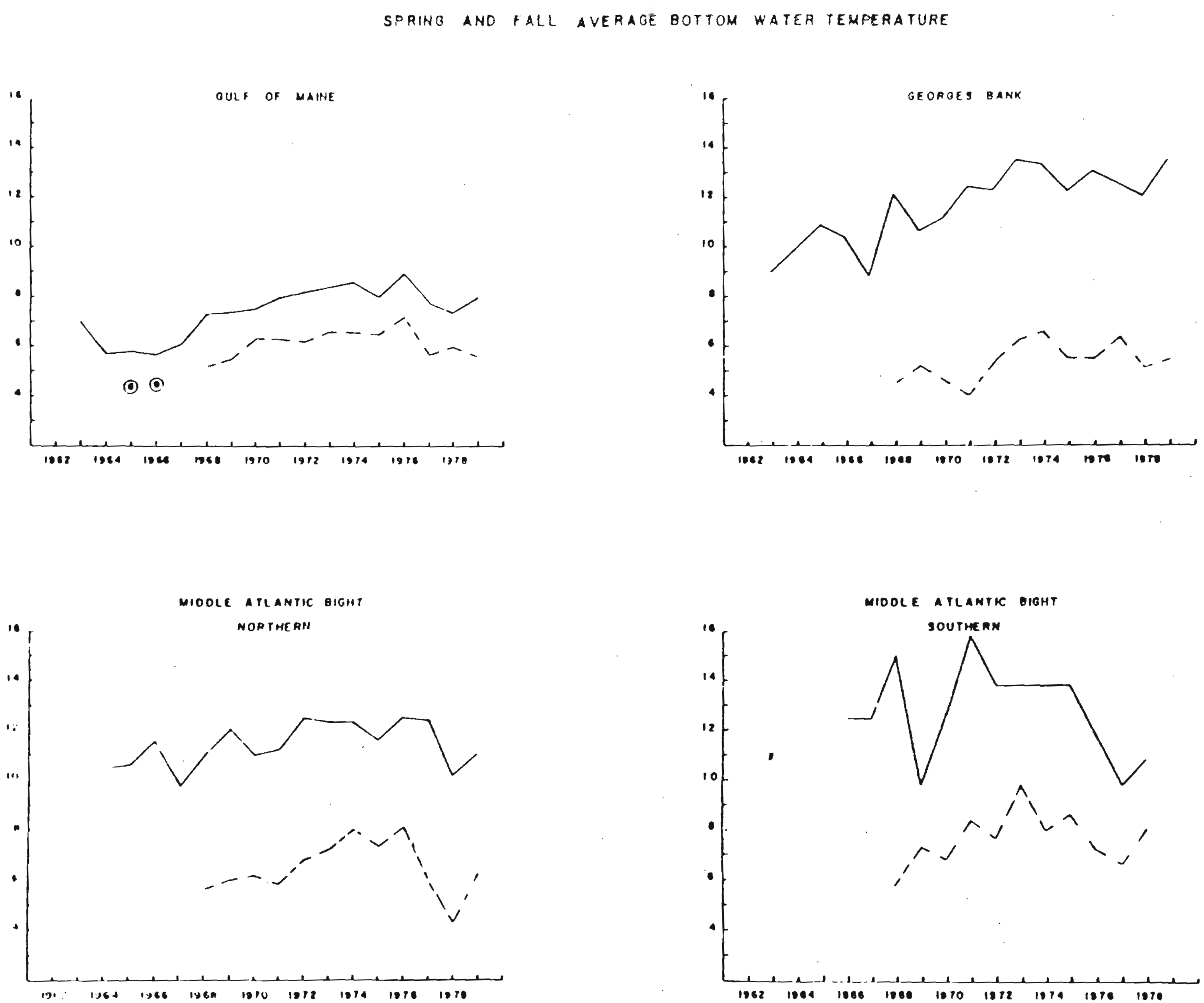

Figure 4. Spring (---) and Fall (——) average bottom-water temperature from NMFS groundfish survey cruises. Circles (⊙) indicate values from other sources.

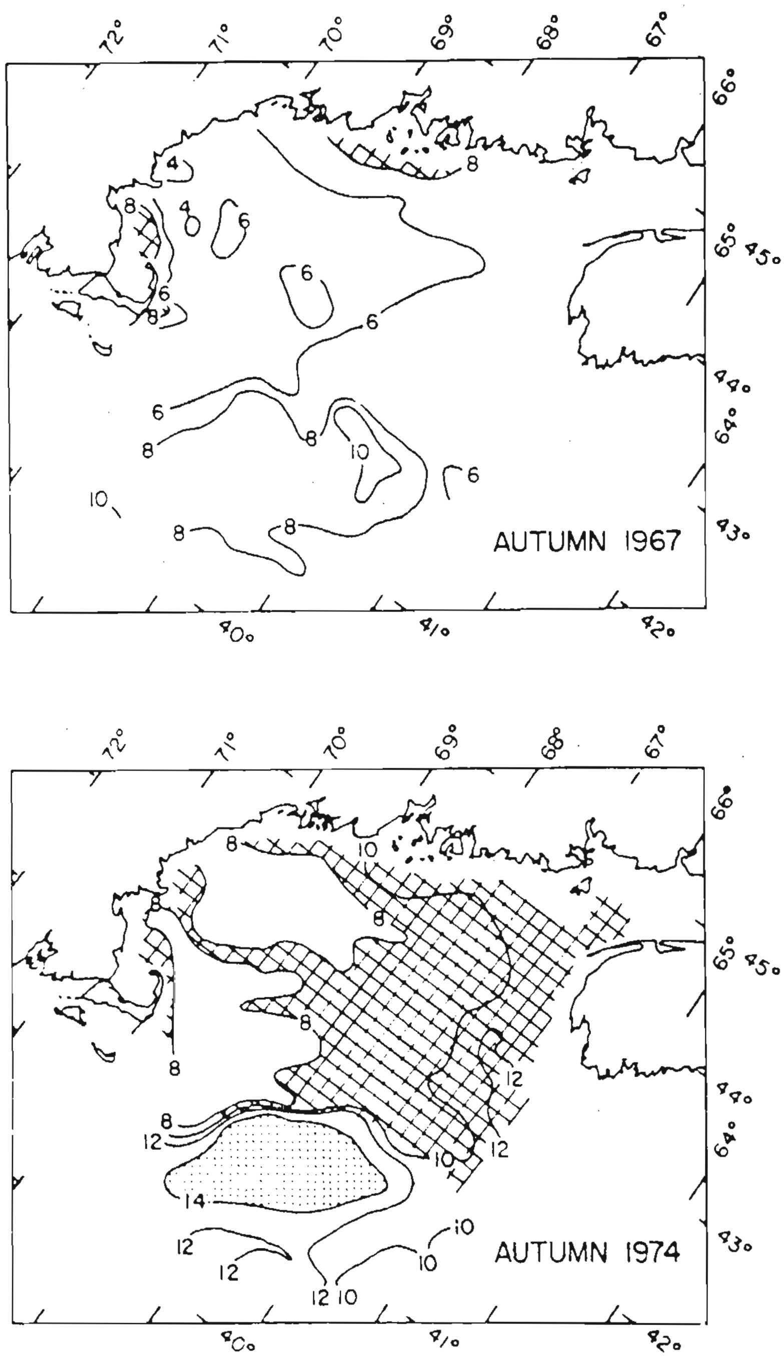

Figure 5. Distribution of fall bottom-water temperature in 1967 and 1974. Dotted areas represent Georges Bank temperatures greater than 14°C; cross hatched areas represent Gulf of Maine temperatures greater than 8°C.

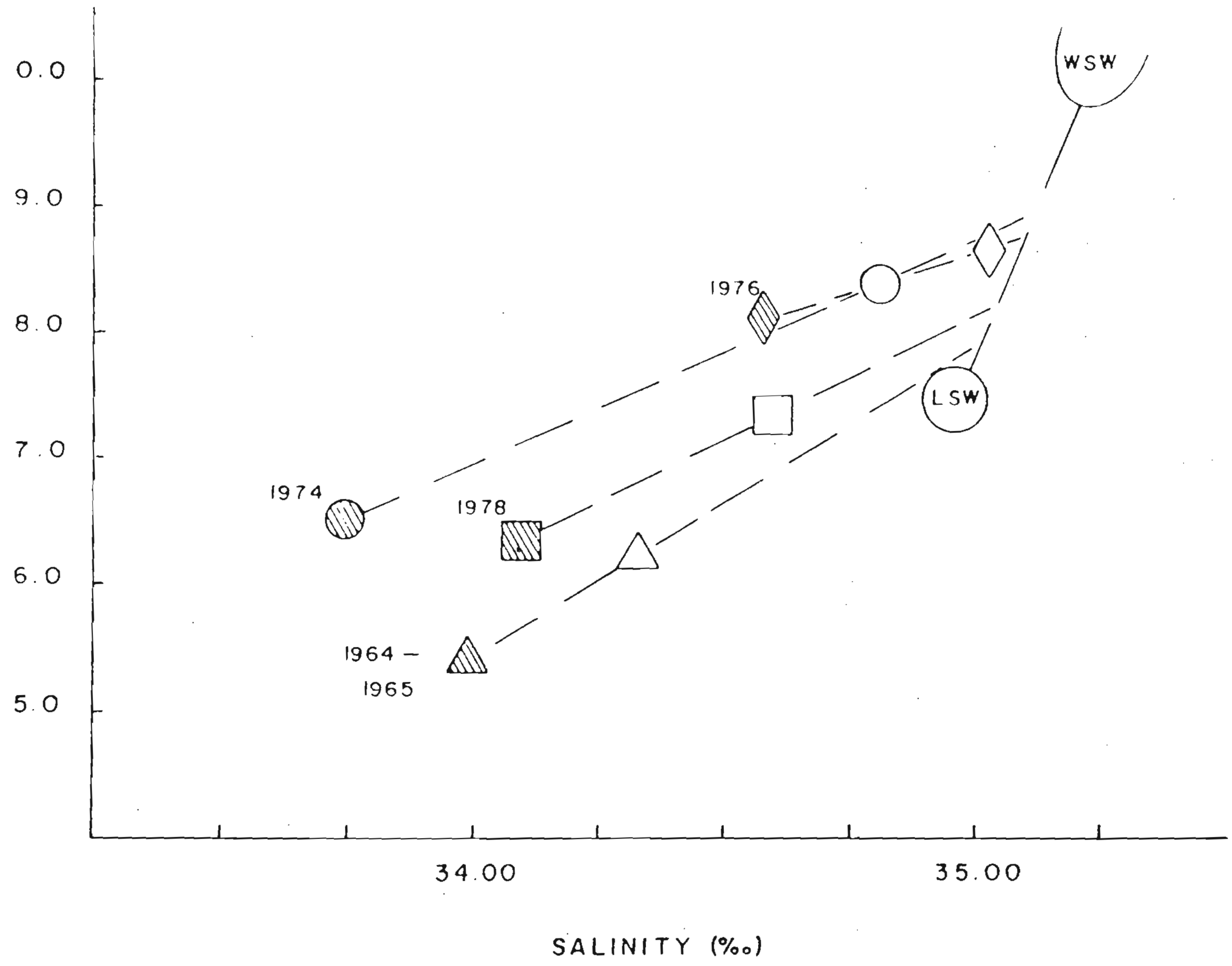

Figure 6. Temperature-salinity characteristics at or near 200 m in the western (shaded symbols) and eastern (open symbols) Gulf of Maine in the fall of the years indicated. Data used are listed in Table II.