Spring and fall sea-surface temperature and salinity on the northeastern continental shelf; Cape Hatteras to Cape Sable, 1972-1977

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Charts by S. R. Nickerson

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Abstract

Twenty-four charts drawn from the National Marine Fisheries Service (NMFS) bottom trawl survey data depict spring and fall sea-surface temperatures and salinity conditions on the northeastern United States continental shelf, Cape Hatteras to Cape Sable, for the years 1972 through 1977. The general temperature and salinity distribution are described, including regions of maxima, minima, and sharp gradients. Areas of river runoff, Scotian Shelf inflow, and Slope Water intrusions are noted, along with localized effects from such events. Spring flow from the Scotian Shelf into the Gulf of Maine and southwesterly across the Northeast Channel to the Northeast Peak and the Shelf-Slope Front appear common characteristics. Shelf-edge and Slope Water intrusions occur in both the Middle Atlantic Bight and Gulf of Maine during the study period. Other than these patterns, the distribution and range of both temperature and salinity appear similar to the original findings when the area was first intensively studied a half century earlier.

Introduction

The temperature and salinity of the northeastern continental shelf were first discussed fully in the volumes of Bigelow (1927, 1933) and Bigelow and Sears (1935), in which the general oceanographic features were presented by month and season. These findings were based on widely spaced data obtained over several years. Following these studies, the temperature data base developed much more rapidly than that for salinity, with atlases of long-term temperature means drawn by Walford and Wickland (1968) for the waters from the Florida Keys to Cape Cod, and Colton and Stoddard (1972) for the waters from Cape Cod to Nova Scotia. No comparable mean salinity charts have been produced. The most useful charts existing are those of Emery and Uchupi (1972) showing surface salinity in the Northwest Atlantic Ocean for February and August. Fuglister (1954) and Worthington (1977) have also prepared charts for ocean-wide salinity distribution in the North Atlantic Ocean at 200-m and 30-m depth, with no regard for season. The next comprehensive data set after Bigelow's was collected by the Bureau of Commercial Fisheries (BCF), now NMFS, in a series of eight cruises between December 1964 and September 1966 covering the shelf from Cape Sable west to 72°30'W (Colton et al. 1968). This report included sea-surface temperature and salinity charts as well as vertical sections showing distribution of properties.

In 1963, the BCF initiated the annual bottom trawl survey to aid in assessing the size of fishery stocks. The continental shelf from Cape Hatteras to Cape Sable was sampled each fall until 1968, when a spring series of surveys was added. Water-column temperature has been measured routinely since

[1]This publication is a special issue based upon data gathered in conjunction with the NMFS NEFC semiannual bottom trawl survey.

the beginning, with bottom temperatures published as a part of the Fishermen's Report[2] and discussed by Davis (1976). Sea-surface salinity data have been collected since 1972. This report presents the sea-surface temperature and salinity data gathered since 1972 and notes the significant features and events encountered during the six years. It is planned to issue a new set of charts each year as the data become available.

Methods

Data were collected by expendable bathythermograph (XBT) casts, surface thermometer readings, and surface water samples taken at each bottom trawl survey station during the period listed in Table 1. Stations were selected by stratified random method (Grosslein 1969) to achieve statistically valid coverage for the purpose of groundfish assessment. Positions were determined at sea by electronic navigation (LORAN A and C) and bathymetric soundings, with each position accurate to and plotted to the nearest mile. Sampling covered the continental shelf in a southwest to northeast direction, in three consecutive legs (Figure 1): I, Cape Hatteras-Cape Cod (70°W); II, Cape Cod-Georges Bank; and III, Gulf of Maine-Browns Bank. Stations were taken between 15 and 200 fathoms for Legs I and II, and between 30 and 200 fathoms for Leg III, with the exception of 1977. In 1977, surveys were taken inshore to 5 fathoms for Legs I and II and 20 fathoms for Leg III. Cruise tracks for each leg were circulated with the corresponding Fishermen's Report. Additional stations were taken in Cape Cod and Massachusetts Bays as a part of the NMFS BIOME program. These observations were made from smaller vessels and when in the proper time frame were included for more complete coverage.

Temperature

Temperature data were collected by a Sippican[3] Model R-603C XBT system, which provides continuous vertical profiling of temperature against depth, with an accuracy of ±0.2° C and ±0.2% depth. Each record was corrected for recorder error and compared to surface thermometer readings. Data were read and plotted to 0.1° C and contoured every 1.0° C. A complete file of XBT data is available through the NOAA National Oceanographic Data Center (NODC).

Because the surveys required approximately two months during the seasons of most rapid warming and cooling and followed a standard south to north direction, there are inherent inadequacies in the portrayal of the sea-surface temperature field. In the spring, vernal warming tended to diminish the real geographic differences, while fall cooling exaggerated such differences. In either case, the resulting plot cannot be considered synoptic in the sense that it represents a snapshot of the sea-surface temperature field at a moment in time. However, all stations in each leg were completed within about two weeks, providing internal consistency within each leg. Furthermore, because a standard direction was used, each leg was accomplished in approximately the same time frame each year, so that annual variations were not masked by seasonal trends. Davis (1976) has carefully looked into this problem with respect to bottom temperatures. Contouring across leg junctions sometimes proved to be a second problem area, as delays of a week or more often occurred. In a few cases, contours were smoothed by ignoring or eliminating data points, i.e., fall 1973, where a redundant set of observations was removed. In the case of the junction between Legs II and III, the northern edge of Georges Bank, the sharpness of the gradients may be partially attributed to such delays. A similar situation also existed in the spring of 1975 and 1976 in Cape Cod and Massachusetts Bays, where irregular BIOME observations during a period of rapid warming made contouring difficult. In such cases, these temperatures were simply omitted and only sea-surface salinity values were used.

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[2]Fishermen's Report. Seasonal circular discussing catch results, cruise tracks, and bottom temperatures from each bottom trawl survey leg. Produced and circulated by the NOAA NMFS NEFC Resource Surveys Investigation.

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Salinity

A sea-surface water sample was collected at each station, stored on board, and processed ashore with an inductive salinometer. Several different instruments were used, with each standardized to known conductivity standards at the beginning, middle, and end of the run, giving results accurate to $\pm 0.01^{o}/oo$. Data were plotted to $0.1^{o}/oo$, and contoured every $0.5^{o}/oo$. The contouring problems mentioned with temperature were not apparent with salinity because of its slow rate of change. Therefore, the salinity charts can be considered synoptic in their entirety.

Description and Discussion

The continental shelf east of Cape Hatteras can be considered both geographically and oceanographically as two major subdivisions: the Middle Atlantic Bight to the southwest and the Gulf of Maine-Georges Bank region to the northeast, separated by Cape Cod and the Nantucket Shoals. Some of the principal differences are:

1. Topography. The Middle Atlantic Bight is characterized by a gently sloping sea floor to the shelf edge, while the Gulf of Maine is noted for "its labyrinthine coastline, its deep basins interrupted by ridges and swells enclosed by offshore banks, Browns and Georges, which are intersected by the Northeast and Great South Channel." (Bumpus 1973).

2. Freshwater runoff. Most of the great rivers of the eastern United States drain into the Middle Atlantic Bight and its mean stream flow (about 5,000 m^3/sec [Bue 1970]) is about three times the flow into the Gulf of Maine.

3. Oceanography. The Gulf of Maine is open to inflow from the Scotian shelf to the east and the Slope Water regime to the south. The Middle Atlantic Bight has no significant exchange with the shelf waters to the southwest, but is influenced by westerly flowing water from the Gulf of Maine and along the shelf-slope front. Both areas have direct exchange with the Slope Water regime, but the Middle Atlantic Bight also contacts Gulf Stream and oceanic waters because of the shoring of warm core rings and the end of the Slope Water regime at Cape Hatteras.

4. Tides. Tidal currents and mixing are much stronger in the Gulf of Maine-Georges Bank region than on the Middle Atlantic Bight.

Among the general observations, a "coastal" structure usually exists for both regions with temperature and salinity increasing to seaward. This structure is complicated by relatively sharp gradients at areas where known water masses meet and/or geographical barriers exist. These areas include: the shelf-slope front from Cape Hatteras northeastward to 66°W, the Scotian shelf break east of the Gulf of Maine, the northern edge of Georges Bank, and the Nantucket Shoals-Great South Channel area (70°W). The range of temperature and salinity and the horizontal structure of each are similar to the observations of Bigelow and Colton, indicating no marked change in sea-surface characteristics during the last half-century. There is also no clear evidence of long-term surface temperature or salinity trends in these six years of observations, but many short-term and local events are noted.

Temperature

Temperature plots show both seasonal and geographical trends, with temperatures warmer to the south and cooler to the north and warmer in the fall than in the spring. Geographically, a latitudinal gradient characterizes all sections, with isotherms running mostly parallel in the spring, changing to east-west alignment by the fall, a pattern similar to the mean temperature charts of Schroeder (1966) and Colton and Stoddard (1972). This gradient appears more defined in the fall, primarily due to the sampling methods.

There is no such gradient for salinity. Temperatures appear consistent with the mean monthly temperatures of Colton and Stoddard (1972) and Walford and Wickland (1968). The Middle Atlantic Bight generally ranges from 3° to 17° C during spring, with isotherms paralleling the coast and temperatures increasing to seaward. The structure is generally 3-5° C in coastal waters, 5-10° C for the shelf, and greater than 10° C offshore. The fall structure differs in that temperatures are warmer, 15-26° C, and isotherms transect the shelf. A latitudinal gradient of 5-7° C occurs each fall, with a sharp gradient (centered around 15° C) at Nantucket Shoals and increasing temperatures southwesterly to Cape Hatteras (20° C). A second gradient persists offshore, with waters warmer than 20° C indicative of the Slope Water regime.

The Gulf of Maine-Georges Bank region is consistently cooler than the Middle Atlantic Bight, as is to be expected. Spring temperatures range from 2 to 14° C with waters less than 4° C on the Scotian shelf and in the Bay of Fundy, 4-8° C over the Gulf of Maine and Georges Bank, and greater than 8° C offshore. Temperature gradients exist along the 100-m isobath at the Scotian shelf break and along the shelf-slope front. Waters inside the Gulf of Maine and across Georges Bank are generally horizontally homogeneous, with no apparent gradients. Autumn conditions are seasonally warmer, having a different gradient structure. Temperatures range from 7° to 22° C, with waters 8-12° C on the Scotian shelf and in the Gulf of Maine, 12-16° C on Georges Bank, and greater than 16° C over the Slope Water regime. A significant difference between spring and fall structure is the 3-6° C gradient across the northern edge of Georges Bank, separating the cooler Gulf of Maine waters from the warmer shallow waters on the bank. The eastern gradient, along the Scotian shelf break, is not evident in these sections as homogeneous conditions extend to the west from the shelf. A gradient continues to exist across the Northeast Channel. To the west, a fall gradient develops at Nantucket Shoals (centered around 15° C), separating the cooler Gulf of Maine waters from the Middle Atlantic Bight. This gradient generally spans 4° C. The shelf-slope front continues to form a southern boundary.

Salinity

Sea-surface salinity does not show the same strong seasonal effects as temperature. The freshwater runoff reaches its peak in spring and is reflected in extreme low values (less than 30°/oo) but only in localized nearshore areas. The higher runoff into the Middle Atlantic Bight has no visible effect outside the coastal zone. In the mid-shelf region of the Atlantic Bight, spring values tend to be more saline than fall, the same being true for Georges Bank, while the Gulf of Maine is generally fresher. A "coastal" salinity structure generally characterizes the Middle Atlantic Bight for both spring and fall, with gradual increase in values from the shore seaward. The isohalines appear evenly spaced, with the only significant gradient being along the shelf-slope front. This gradient steepens at Cape Hatteras, where shelf and slope water regions end and coastal waters come in direct contact with the Gulf Stream. Values range from less than 30°/oo in coastal areas to greater than 36°/oo in either the Gulf Stream or where rings contact the shelf, with shelf waters generally being 32-35°/oo.

In the Middle Atlantic Bight, Wright and Parker (1976) distinguished between coastal waters (less than 33.5°/oo), shelf-edge waters (33.5-35°/oo), and slope water (greater than 35°/oo), a distinction that applies equally well to the Gulf of Maine-Georges Bank region. The distribution of these waters over the continental shelf varies with different seasons and as conditions change from year to year. Examples of this are spring 1974 and 1975, where shelf-edge values exist inshore to the 50-m isobath. By the following season such conditions have dissipated, with higher values in the vicinity of the 100-m curve.

The Gulf of Maine-Georges Bank area differs from the Middle Atlantic Bight's "coastal" salinity structure by having large homogeneous areas bounded by sharp gradients: an eastern gradient at the Scotian shelf break, with waters greater than 32.5°/oo in the Gulf of Maine and less than 32.5°/oo on the Scotian shelf; and a southern gradient at the shelf-slope front. Inside the Gulf of Maine and across Georges Bank, salinities generally range from 32.5-33.5°/oo. The structure within this region appears to be dependent on inflow from the bordering water regimes.

Inflow from the Scotian shelf and Slope Water regimes appears to be the dominant factor in varying conditions in the Gulf of Maine-Georges Bank region. During each spring, relatively cold fresh tongues extend from the Scotian shelf into the northern Gulf of Maine, influencing the southwestern coast of Nova Scotia, north to the Bay of Fundy. The six years of sections also indicate a southwesterly flow from Browns Bank across the Northeast Channel and onto the Northeast Peak of Georges Bank and the shelf-slope front. Monthly monitoring of the Northeast Channel by the NMFS NEFC, USCG, and ICNAF vessels since 1975 (data unpublished) shows that the shelf-slope front existed inside the Northeast Channel (below 100 m) during each month, with a significant gradient above 100 m. Above this gradient, waters characteristic of the Scotian shelf are common. These data help to substantiate the existence of a southwesterly flow across the Northeast Channel and that such a flow can mask the surface expression of the shelf-slope front east of 66°W.

Two intrusions from the shelf-slope front into the Gulf of Maine were observed at the Northeast Channel during fall 1974 and 1976. These intrusions reverse the normal salinity structure, bringing waters greater than 33°/oo to the northern Gulf of Maine and less than 33°/oo over the southwestern Gulf of Maine and Georges Bank. This structure appears to have moved by the following spring, bringing more saline conditions onto Georges Bank and the Great South Channel.

The effects and roles of the Scotian shelf and shelf-edge waters interacting in the Gulf of Maine are important to consider. Sutcliffe et al. (1976) noted the movement of Scotian shelf waters into the Gulf of Maine and suggested a possible mechanism might be forcing by the St. Lawrence River outflow. His findings lacked sufficient evidence, in the proper time frame for the Gulf of Maine, to substantiate the theory. The fresh tongues observed by NEFC at the Scotian shelf break occur at the proper time and provide additional evidence for this theory. The importance of these fresh inflows appears to be in the interaction with intruded shelf-edge waters. In four of the six falls sampled, shelf-edge water occurred in the northern Gulf of Maine. This water appears to move south by the following spring, apparently forced out by the annual inflow. If this is indeed the case, then two significant points can be made. One is that the interaction between these two masses is important for maintaining the more saline conditions found in the Gulf of Maine than on the shelf to the northeast. The second point is that the intrusion of this water onto Georges Bank may have a significant effect on the biology of the bank. Fournier (1977) noted that the shelf-edge waters off Nova Scotia are richer in nutrients than either the surrounding shelf or slope waters. If this water is moved onto Georges Bank during the spring, as charts appear to indicate, then the higher nutrient levels should be available for the annual spring phyto- and zooplankton blooms.

The only other significant events are the differences between seasons and years for the shelf-slope front location and the localized effects of warm core rings. The shelf-slope front occupies a different position in each section as described by Wright (1976) and Ingham (1976), but appears to remain between the 1,000-m and 100-m isobaths. This structure is modified in several sections by intrusion of warm core rings. Such rings, which bring waters greater than 36°/oo inside the sampling area, appear primarily between 70° and 71°W and in the southern Middle Atlantic Bight south of 40°N. Little activity appears east of 70°W, while some structure associated with ring edges exists between 71° and 73°W. These ring edges modify the shelf-slope structure, causing steepened gradients surrounded by open areas where shelf waters appear to be entrained offshore. All effects from rings appear short-term and have dissipated by the following sampling period. The occurrence, distribution, and size of these rings could not be determined from the project's data distribution. Bisagni (1976) has looked into this situation during 1974 and 1975 in the Middle Atlantic Bight and notes the usual occurrence of three rings per year, with an average residence time of 22 days per ring.

Summary

In summary, the 24 charts showed basically a "coastal" structure for both temperature and salinity, with gradients at geographical boundaries and fronts between different water regimes. Spring temperature conditions were expectedly

cooler than fall, with a latitudinal gradient evident for both seasons. No significant difference in the salinity structure appeared regularly between seasons.

The shelf-slope front formed a temperature and salinity gradient at the continental shelf break from Cape Hatteras northeast to 66°W. Along this area, localized effects from frontal movement and warm core ring activity were observed.

Temperature and salinity gradients existed at the Scotian shelf break, separating the colder fresher Scotian shelf waters from the Gulf of Maine and Georges Bank. Inflow across this break appeared a standard spring characteristic, affecting the waters in the northern Gulf of Maine, on the northeast peak of Georges Bank, and in the shelf-slope front area. This inflow provided a mechanism for refreshening and maintaining the 32.5-33.5^{o}/oo salinity level in the Gulf of Maine-Georges Bank region. Intrusions of shelf-edge and slope water occurred at the Northeast Channel during fall 1974 and 1976, which brought waters greater than 33.5^{o}/oo into the Gulf of Maine. Similar conditions were observed in fall 1973 and 1977, but the high-salinity cells could not be clearly traced to the shelf edge. This more saline water appeared to have moved south onto Georges Bank by the following sampling period.

Acknowledgment

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Table 1. Dates of groundfish cruises and legs occupied by the NMFS between 1972 and 1978.

Cruise	Date	Vessel	Leg
72-02	08 Mar-14 Mar	ALBATROSS IV	1
	22 Mar-07 Apr		1 & 2
	12 Apr-24 Apr		3
72-08	27 Sep-10 Oct	ALBATROSS IV	1
	17 Oct-30 Oct		2
	03 Nov-20 Nov		3
73-03	16 Mar-30 Mar	DELAWARE II	1
	20 Mar-30 Mar	ALBATROSS IV	1a
	09 Apr-25 Apr		2
	03 May-15 May		3
73-08	26 Sep-11 Oct	ALBATROSS IV	1
	18 Oct-26 Oct		2
	30 Oct-20 Nov		3
74-04	12 Mar-22 Mar	ALBATROSS IV	1
	28 Mar-11 Apr		1a & 2
	16 Apr-04 May		3
74-11	23 Sep-04 Oct	ALBATROSS IV	1
	08 Oct-27 Oct		2
	30 Oct-14 Nov		3
75-03	14 Mar-18 Mar	ALBATROSS IV	1
	20 Mar-29 Mar		1a
	17 Apr-30 Apr		2
	05 May-12 May		3
75-08	15-Oct-07 Nov	DELAWARE II	1
75-12	07 Oct-23 Oct	ALBATROSS IV	2
	07 Nov-18 Nov		3
76-05	04 Mar-24 Mar	DELAWARE II	1
76-02	25 Mar-09 Apr	ALBATROSS IV	2
	13 Apr-05 May		3
76-09	28 Sep-17 Oct	ALBATROSS IV	1
	20 Oct-05 Nov		2
	09 Nov-23 Nov		3
77-03	19 Mar-08 Apr	DELAWARE II	1
77-02	13 Apr-27 Apr	ALBATROSS IV	2
	30 Apr-14 May		3
77-12	26 Sep-14 Oct	DELAWARE II	1
	15 Oct-05 Dec		2 & 3

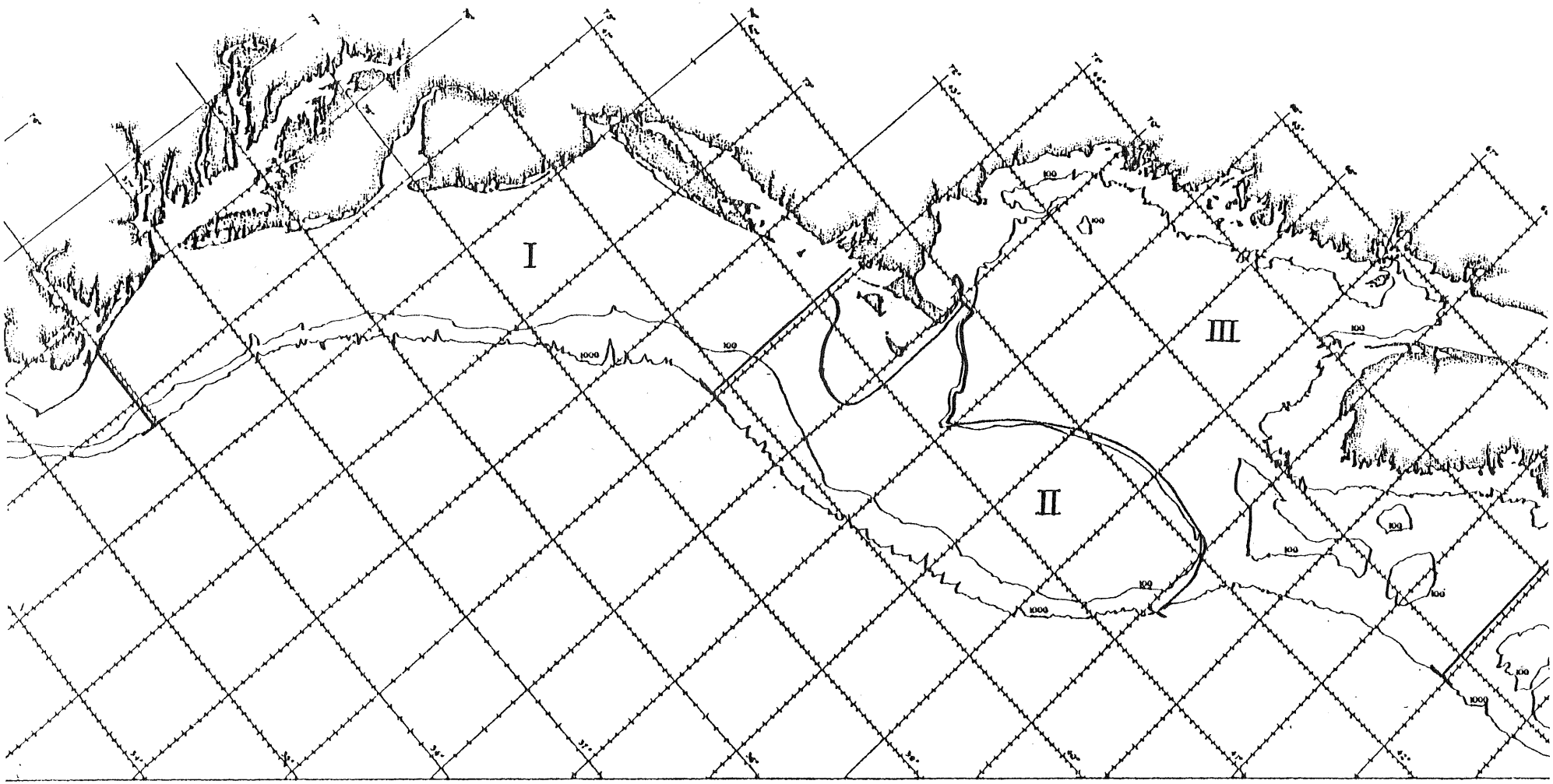
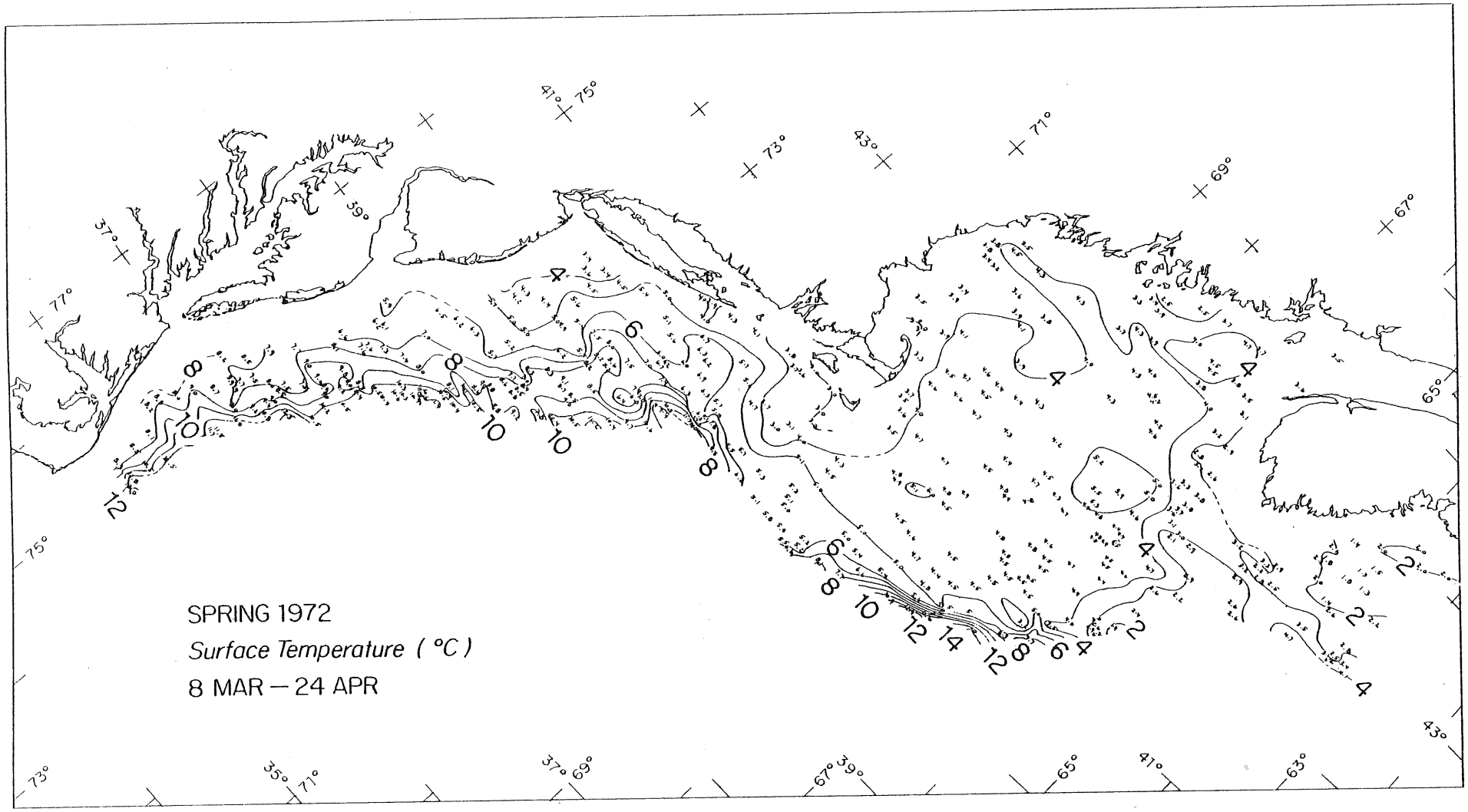
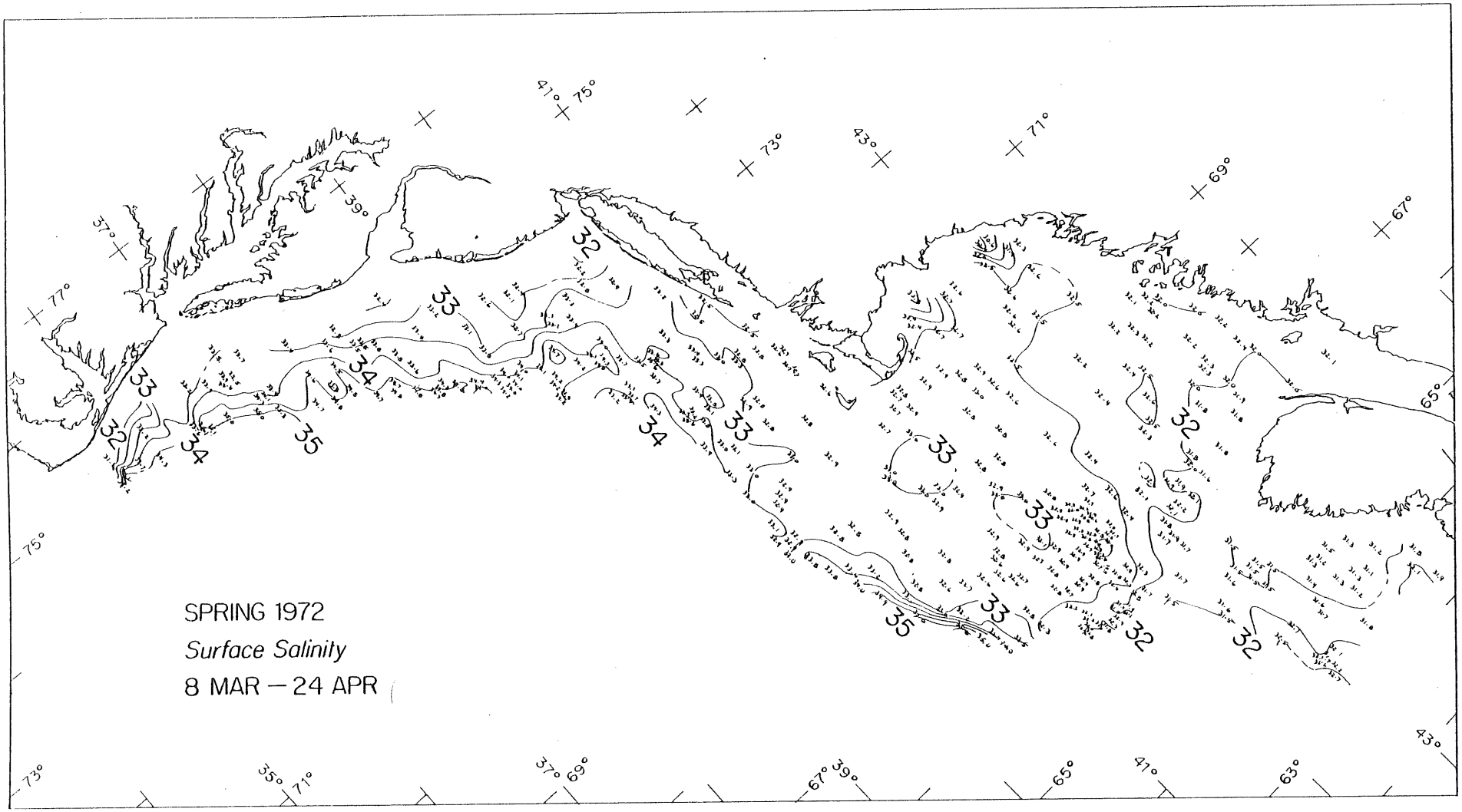
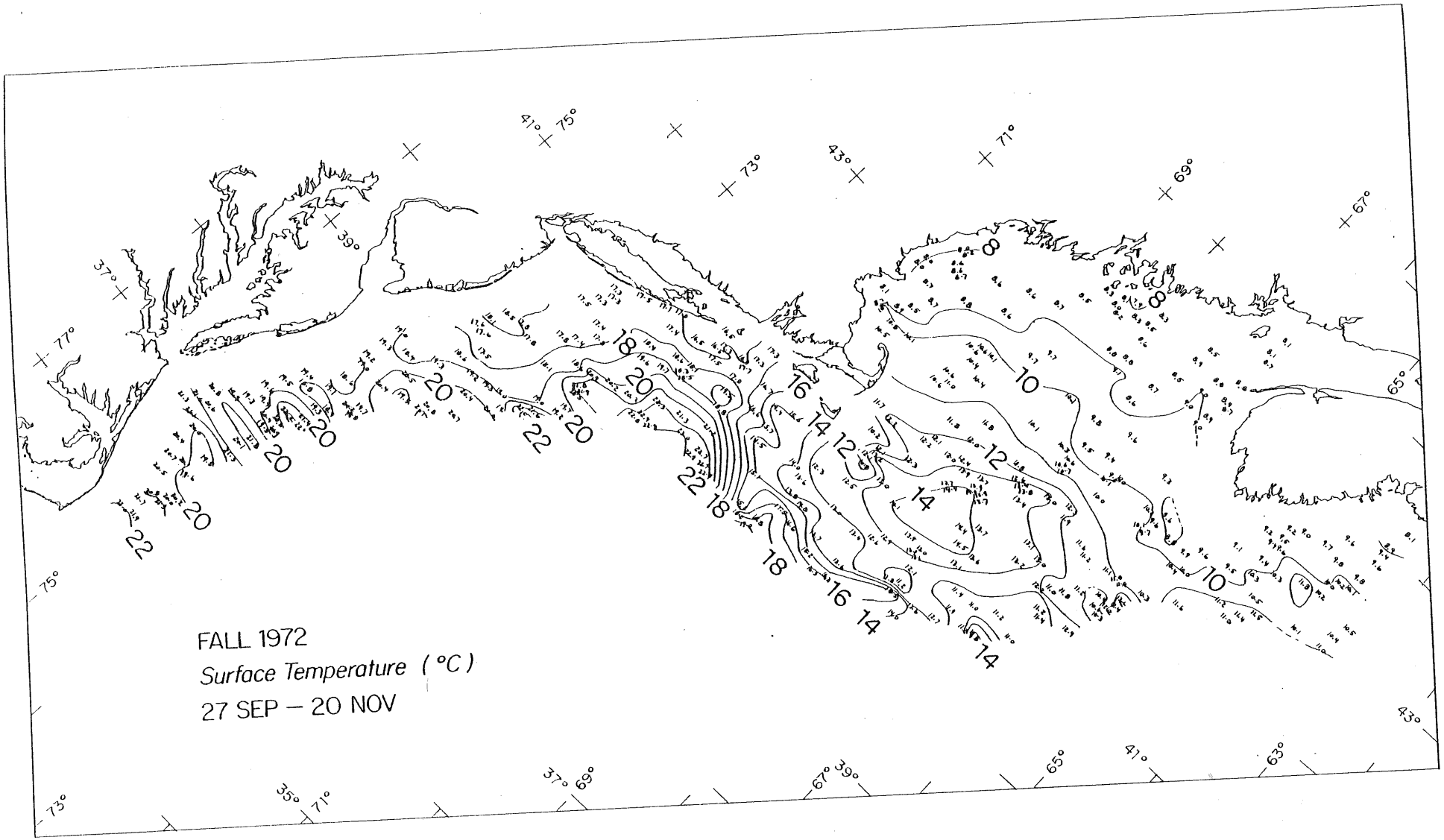
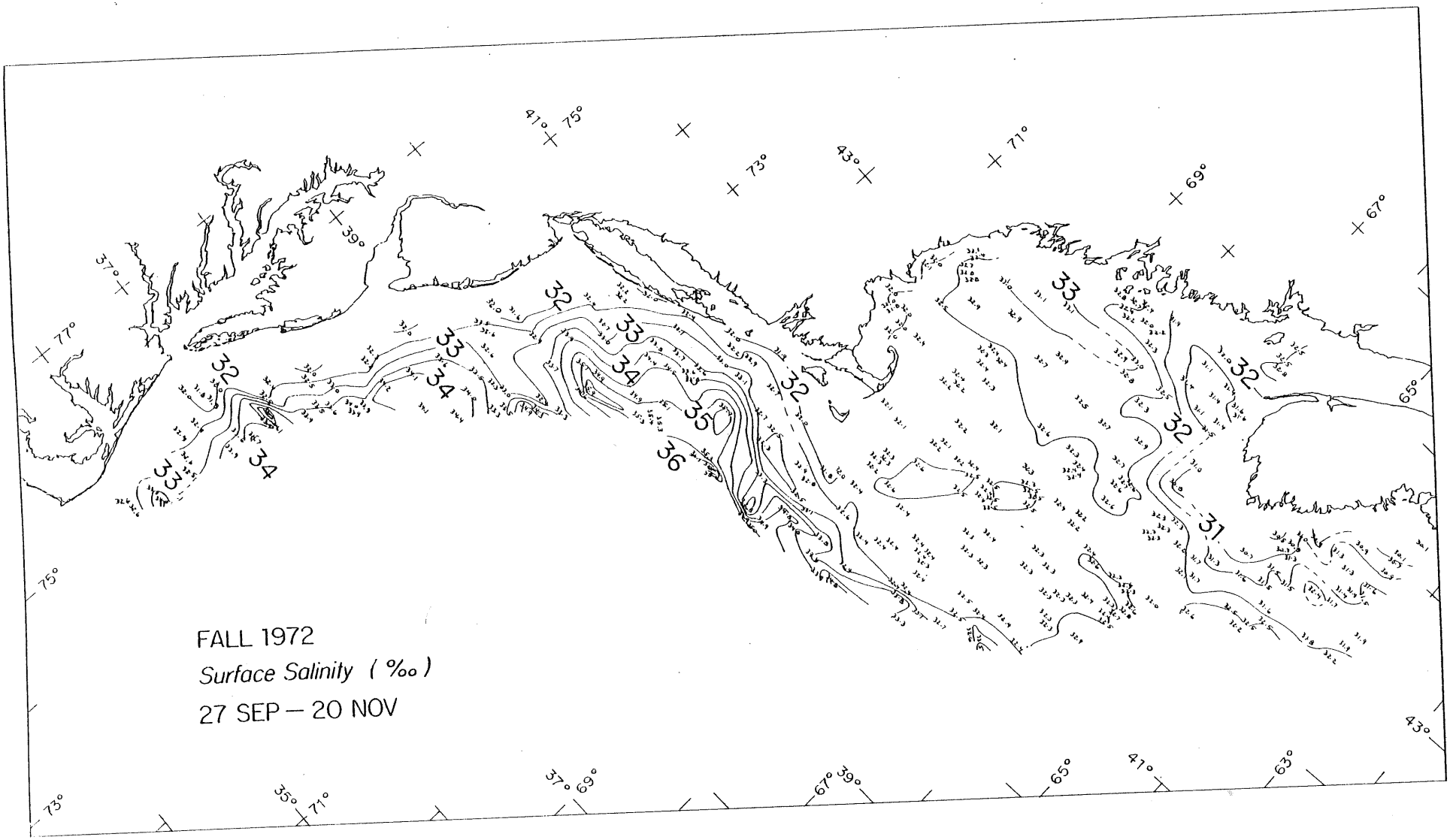


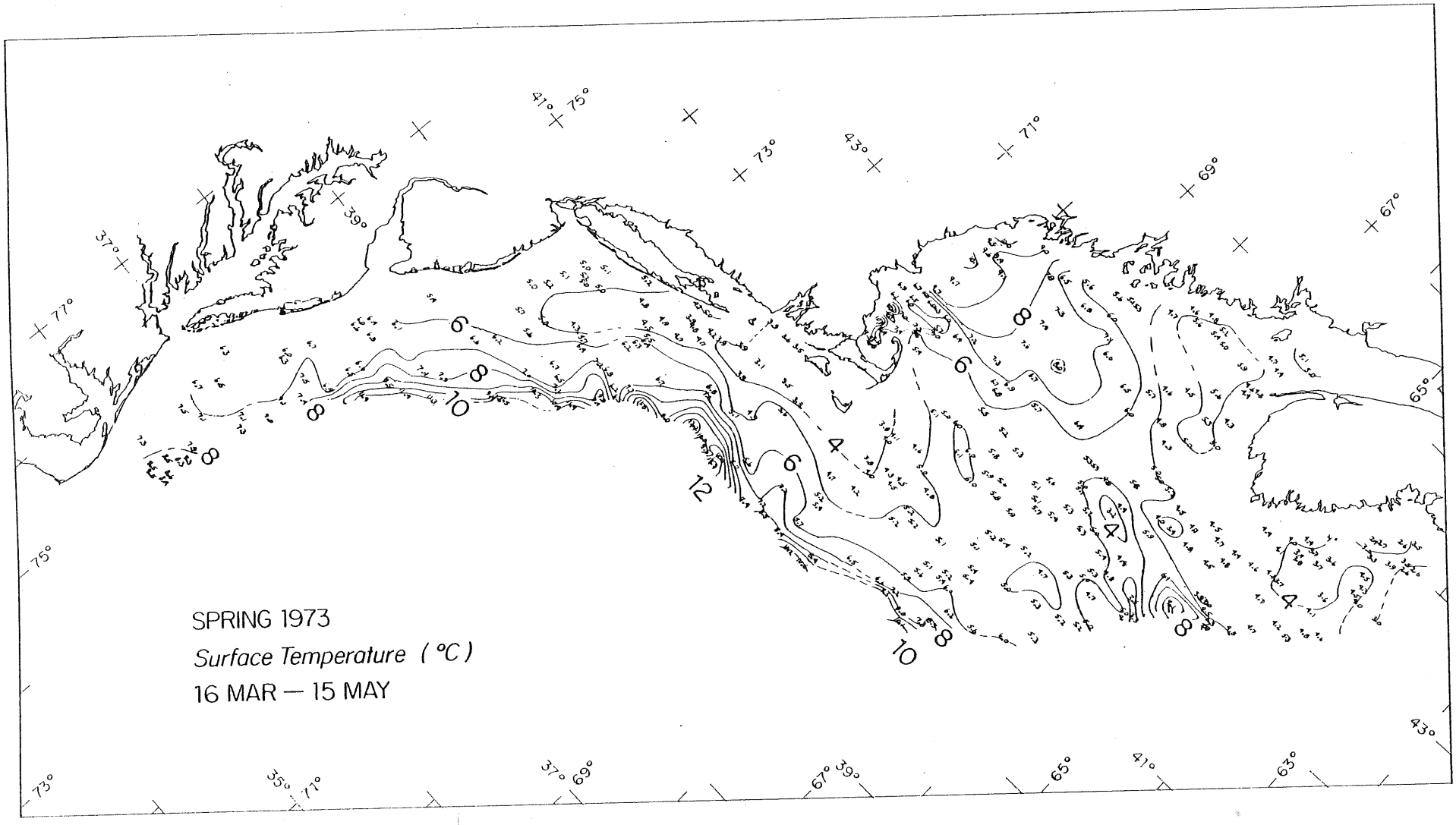
Figure 1. Location of survey area for the NMFS Groundfish Survey, with area of each leg indicated.

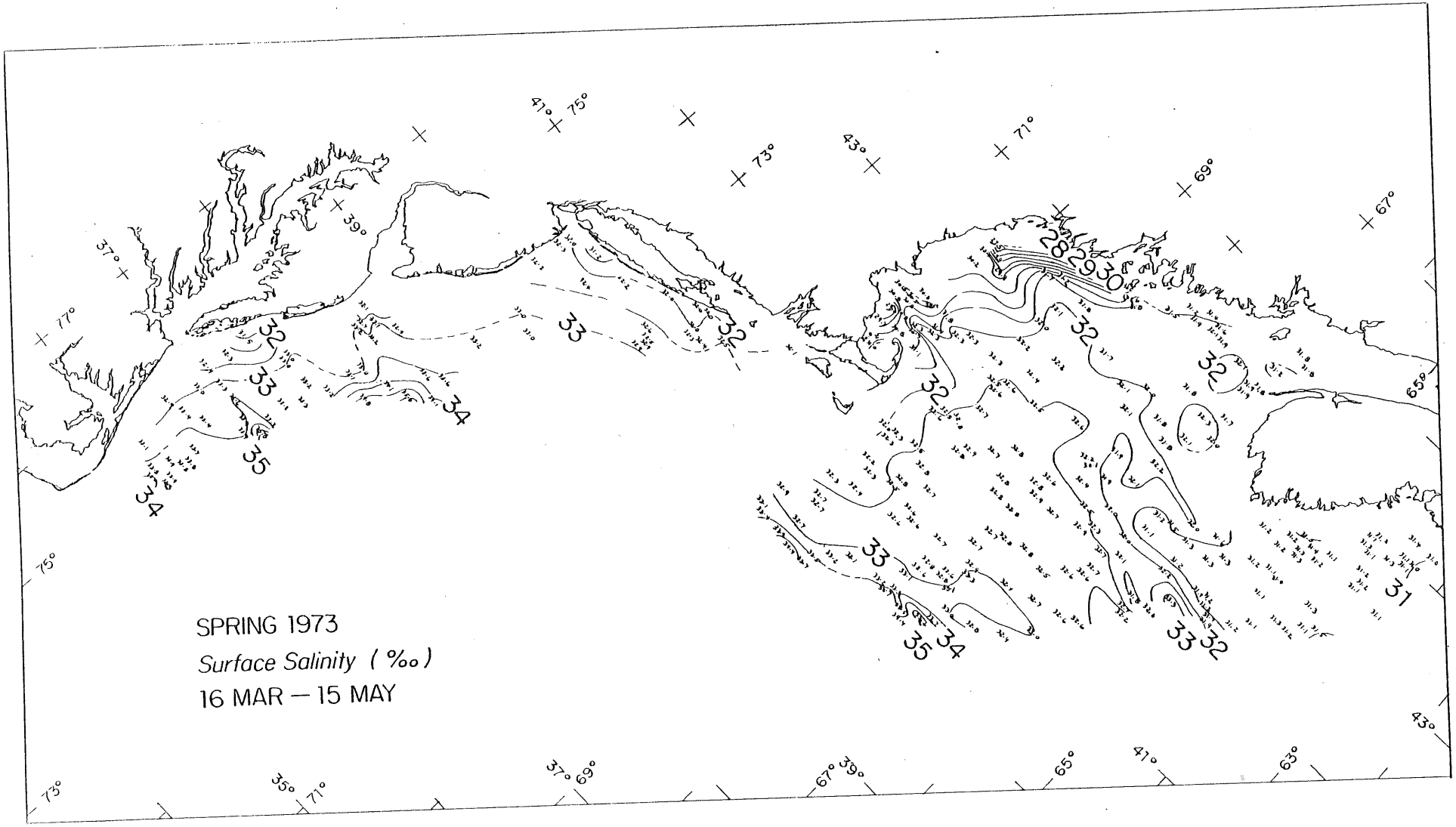

SPRING 1972
Surface Temperature (°C)
8 MAR — 24 APR

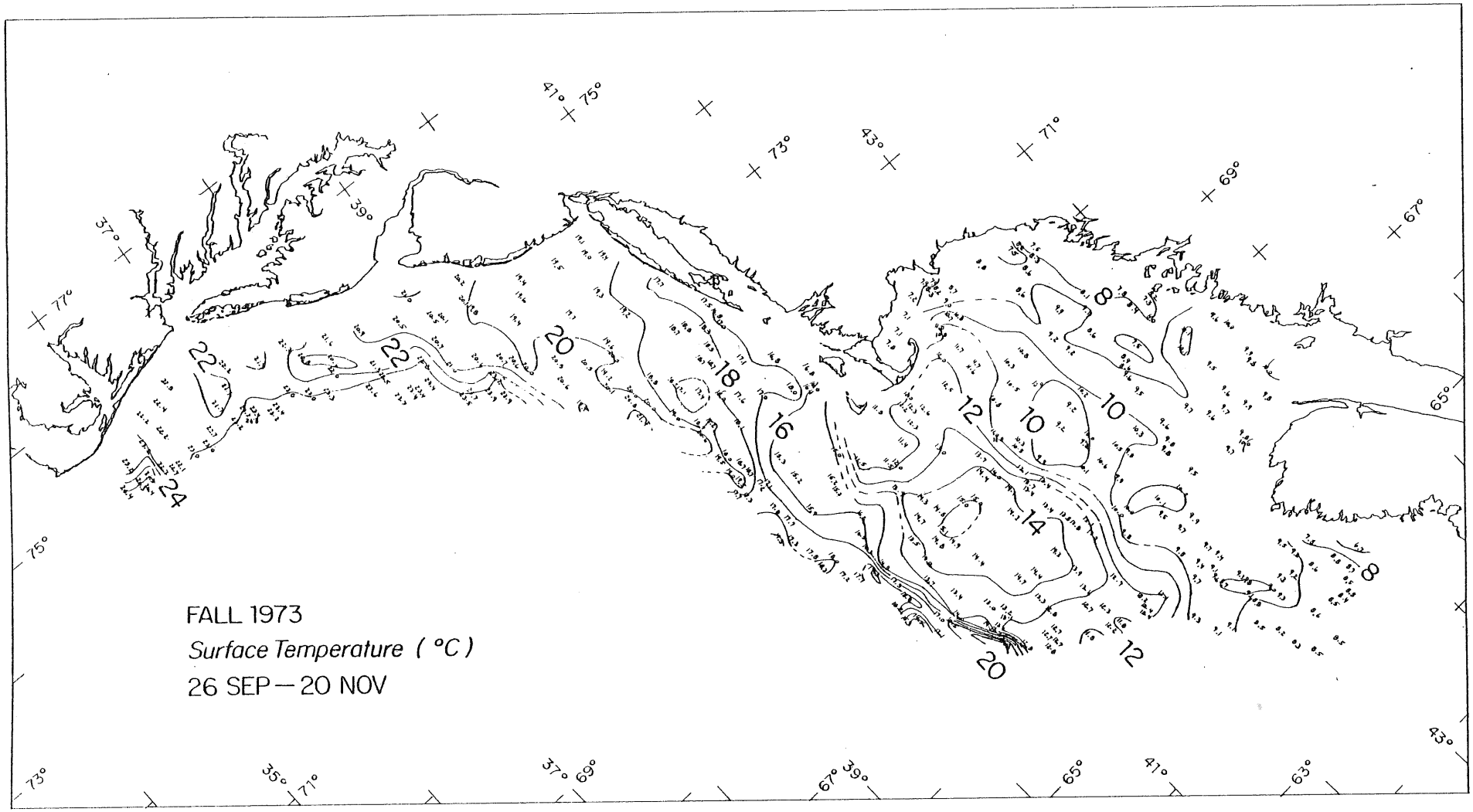

SPRING 1972
Surface Salinity
8 MAR — 24 APR
41°
75°
73°
43°
71°
69°
67°
39°
37°
77°
65°
75°
73°
35°
71°
37°
69°
67°
39°
65°
41°
63°
43°
32
33
34
35


FALL 1972
Surface Temperature (°C)
27 SEP – 20 NOV


FALL 1972
Surface Salinity (‰)
27 SEP – 20 NOV
32
33
34
35
36
31
77°
75°
73°
71°
69°
67°
65°
63°
43°
41°
39°
37°
35°


SPRING 1973
Surface Temperature (°C)
16 MAR — 15 MAY


SPRING 1973
Surface Salinity (‰)
16 MAR — 15 MAY


FALL 1973
Surface Temperature (°C)
26 SEP — 20 NOV
24
22
20
18
16
14
12
10
8
41°
75°
73°
43°
71°
69°
67°
39°
37°
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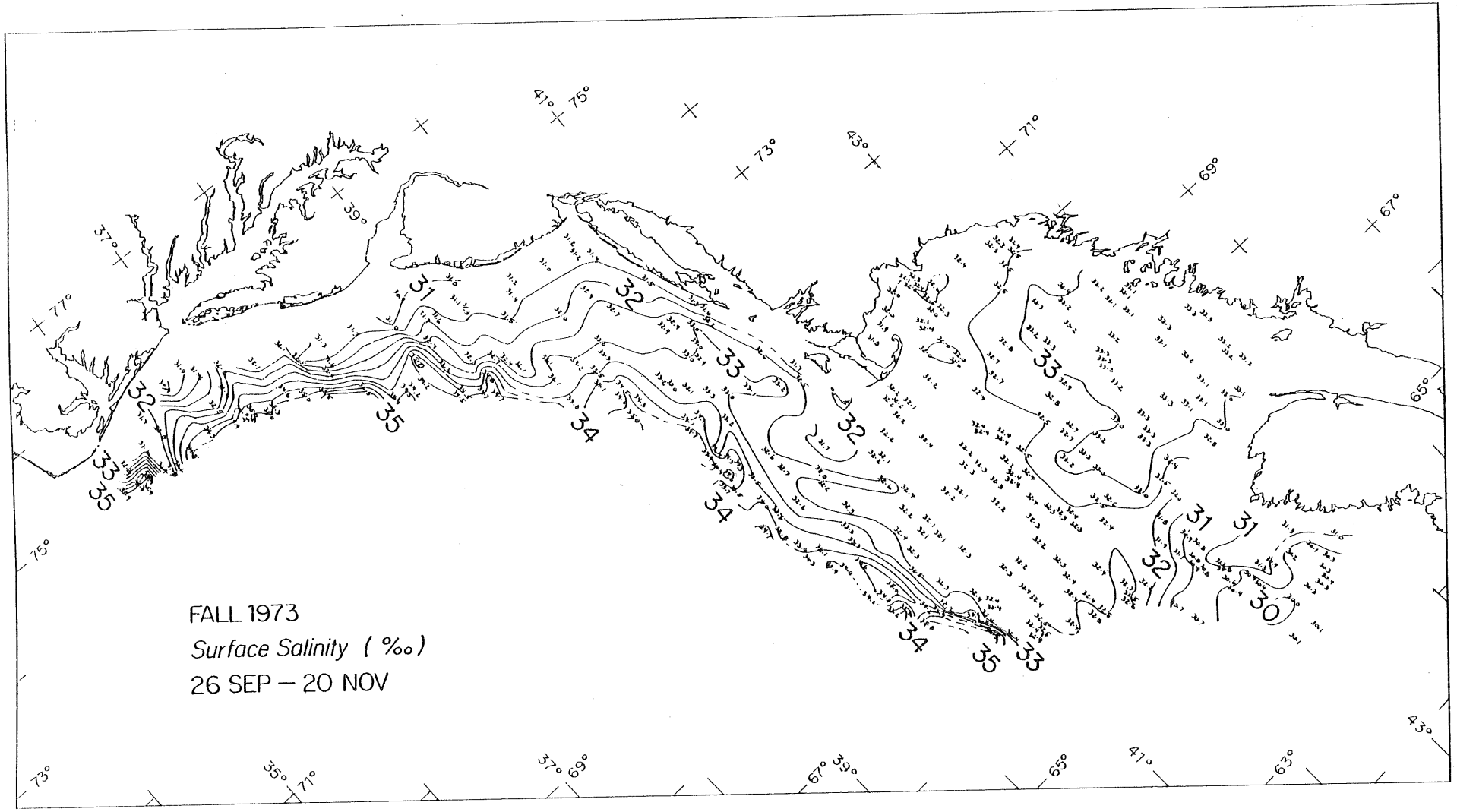
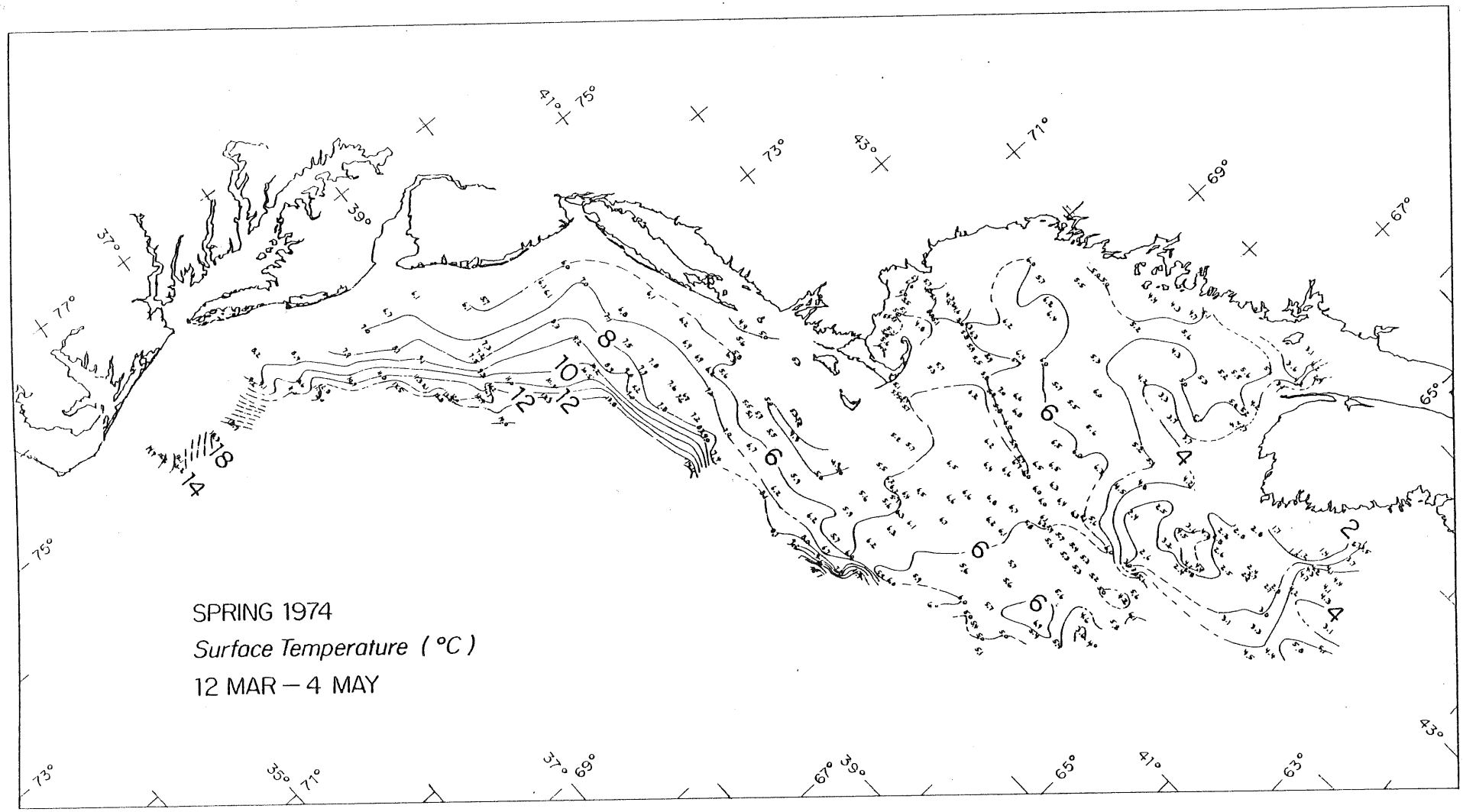
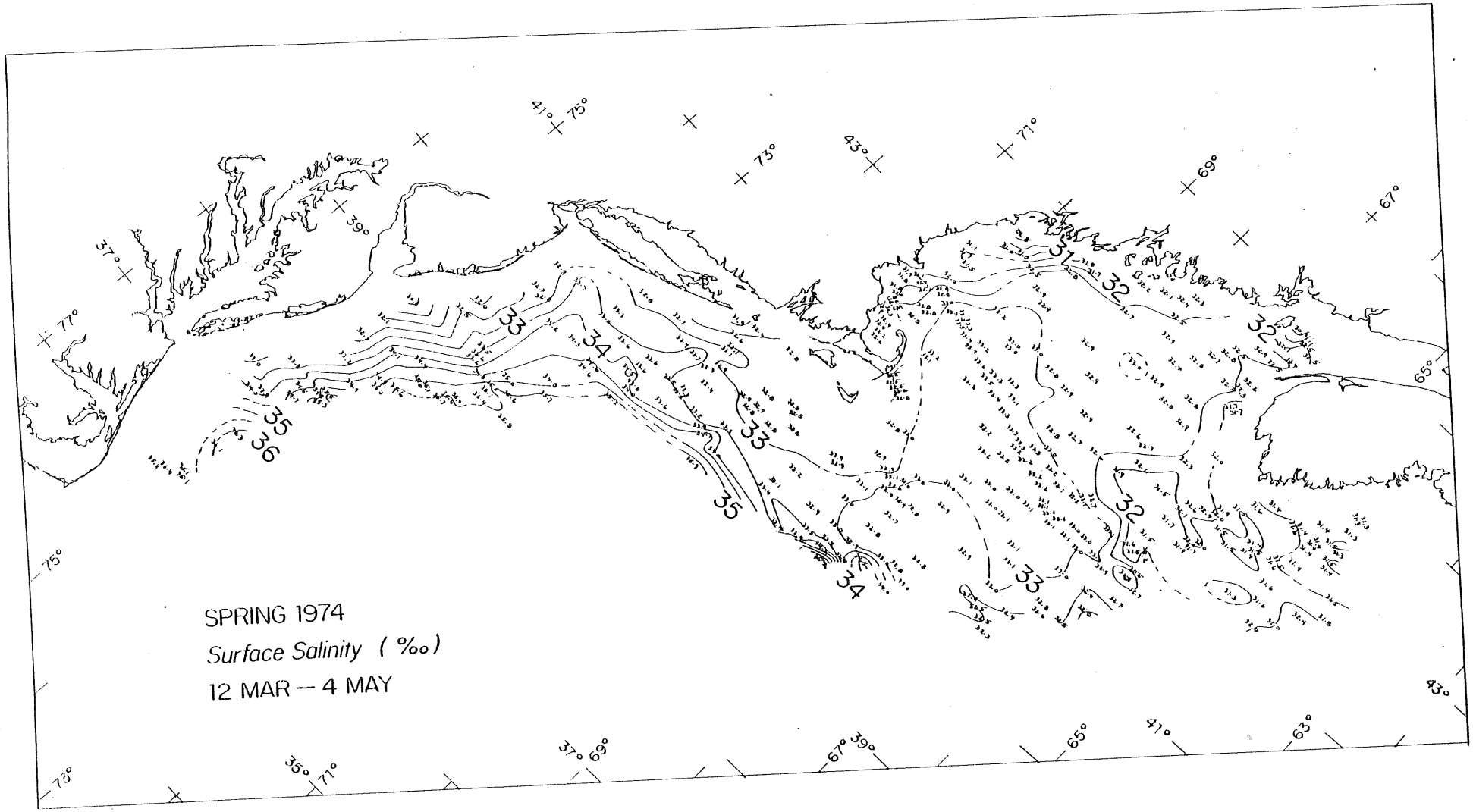
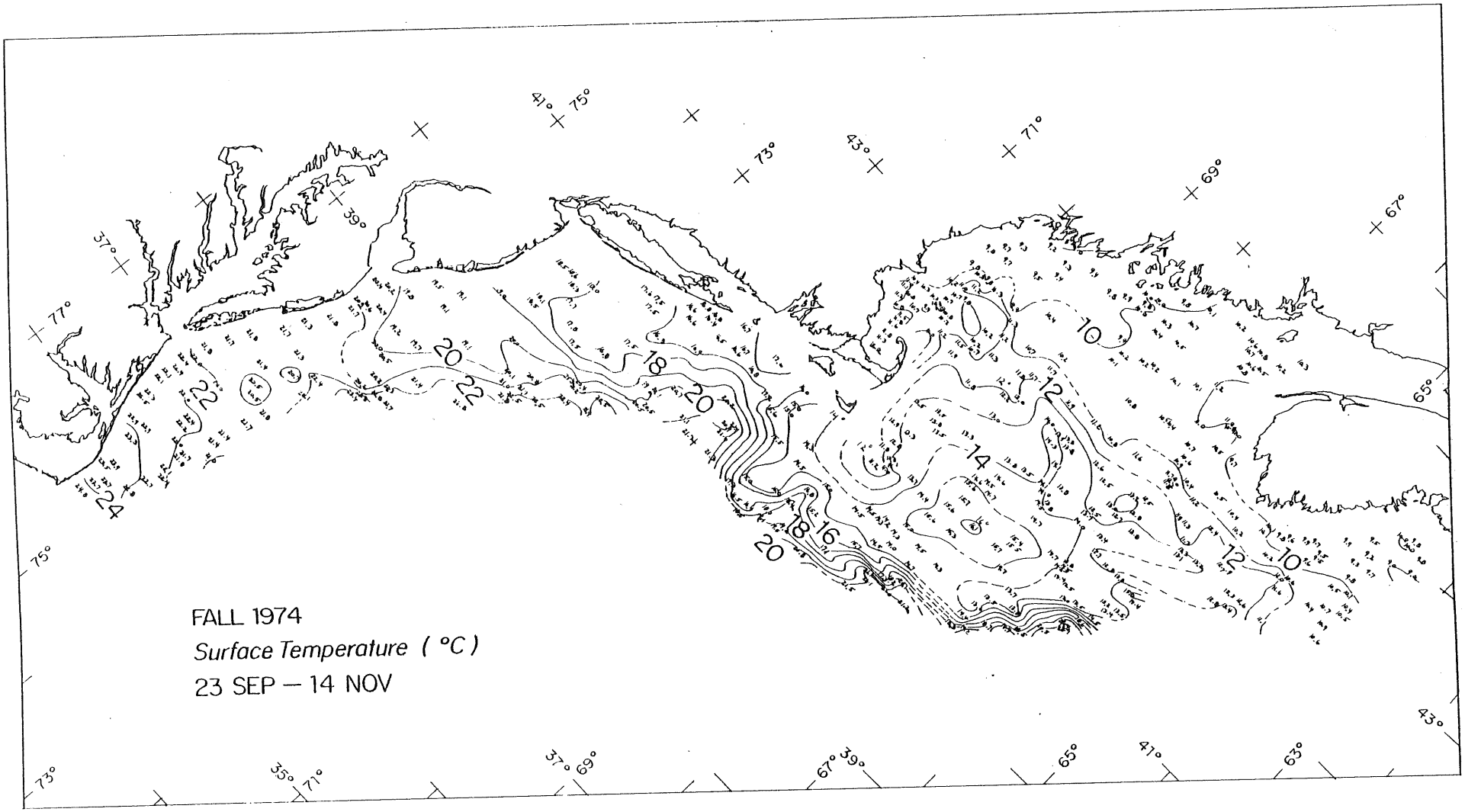
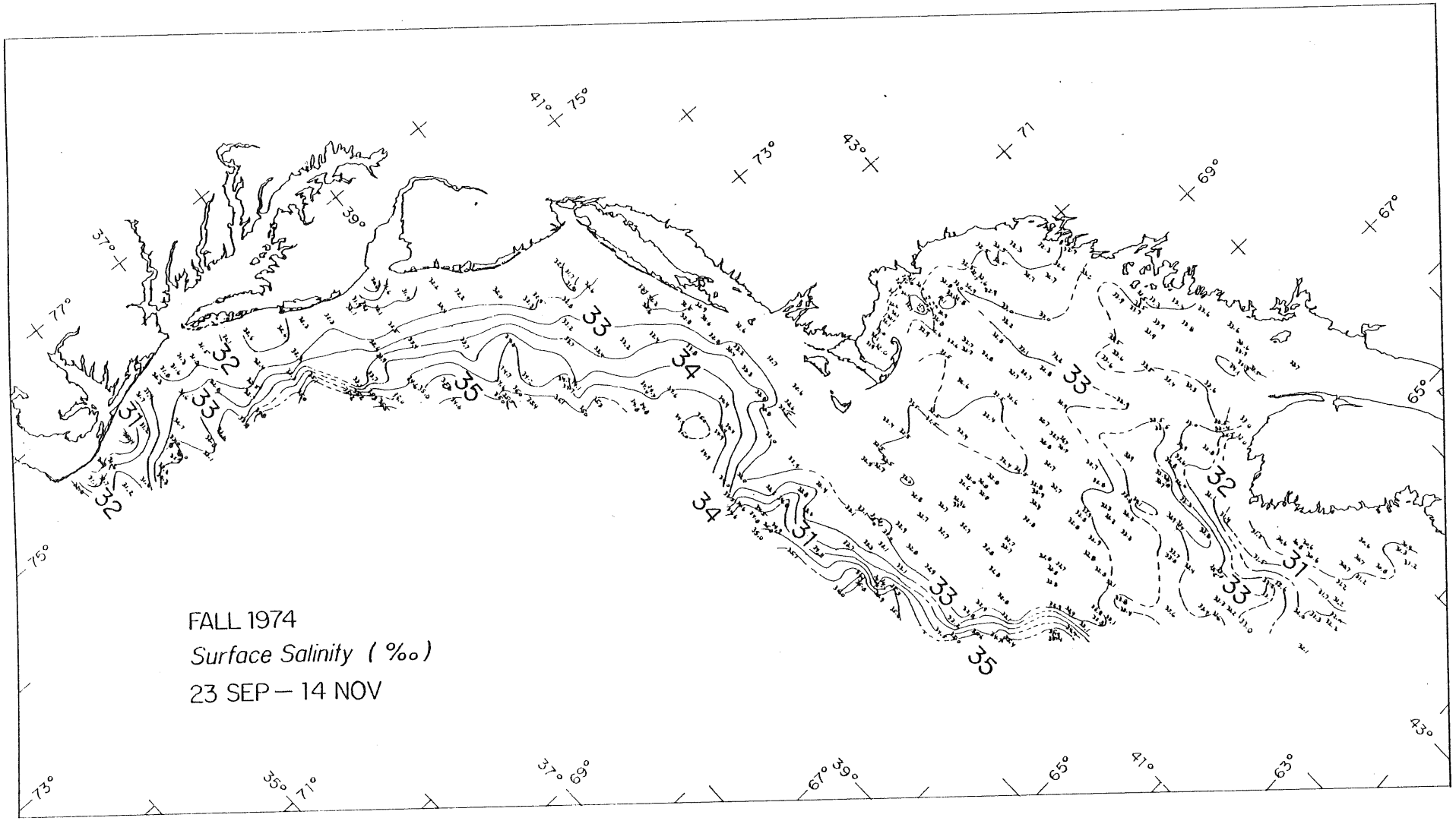
39°
65°
41°
63°
43°

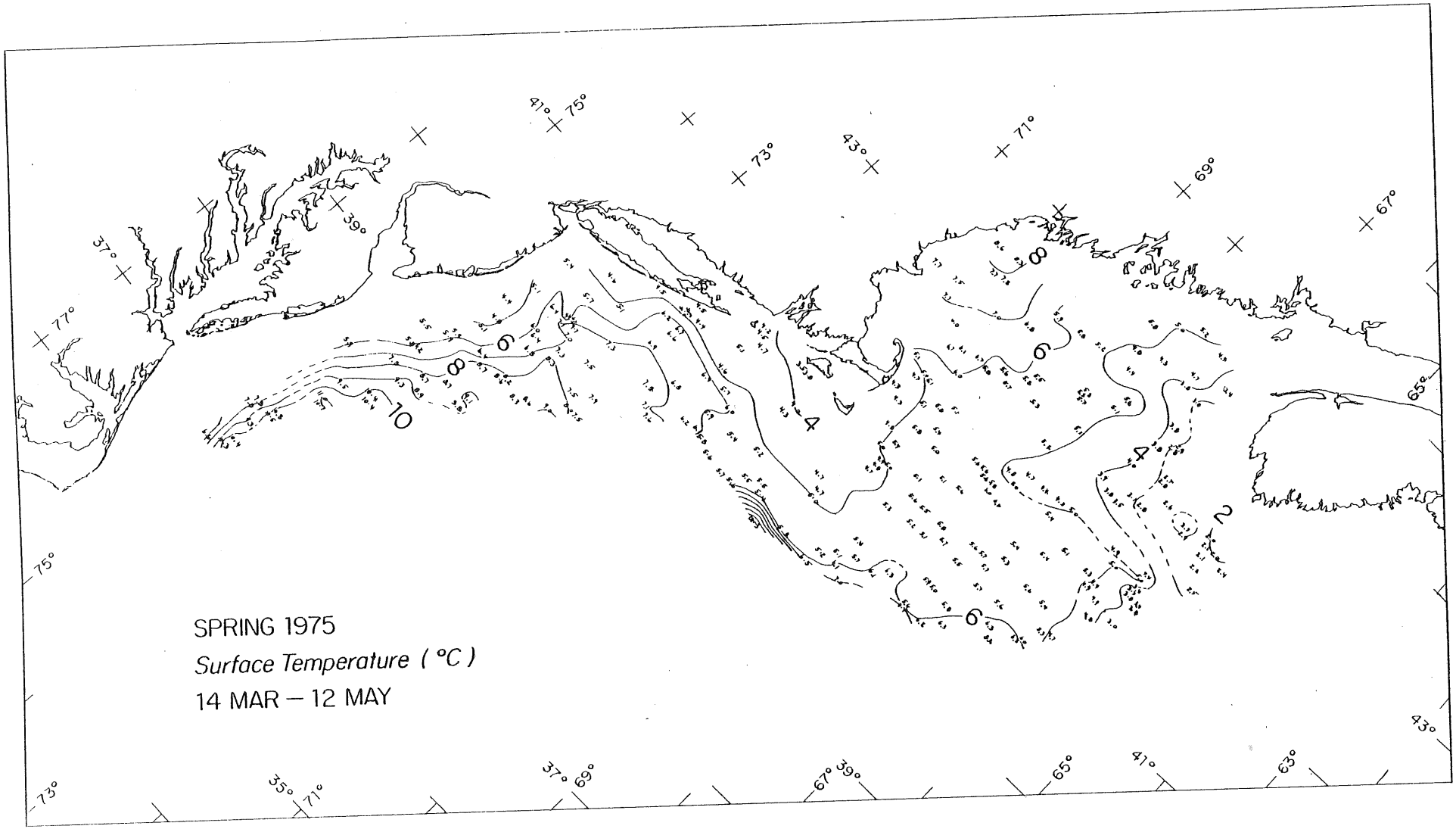

FALL 1973
Surface Salinity (‰)
26 SEP – 20 NOV

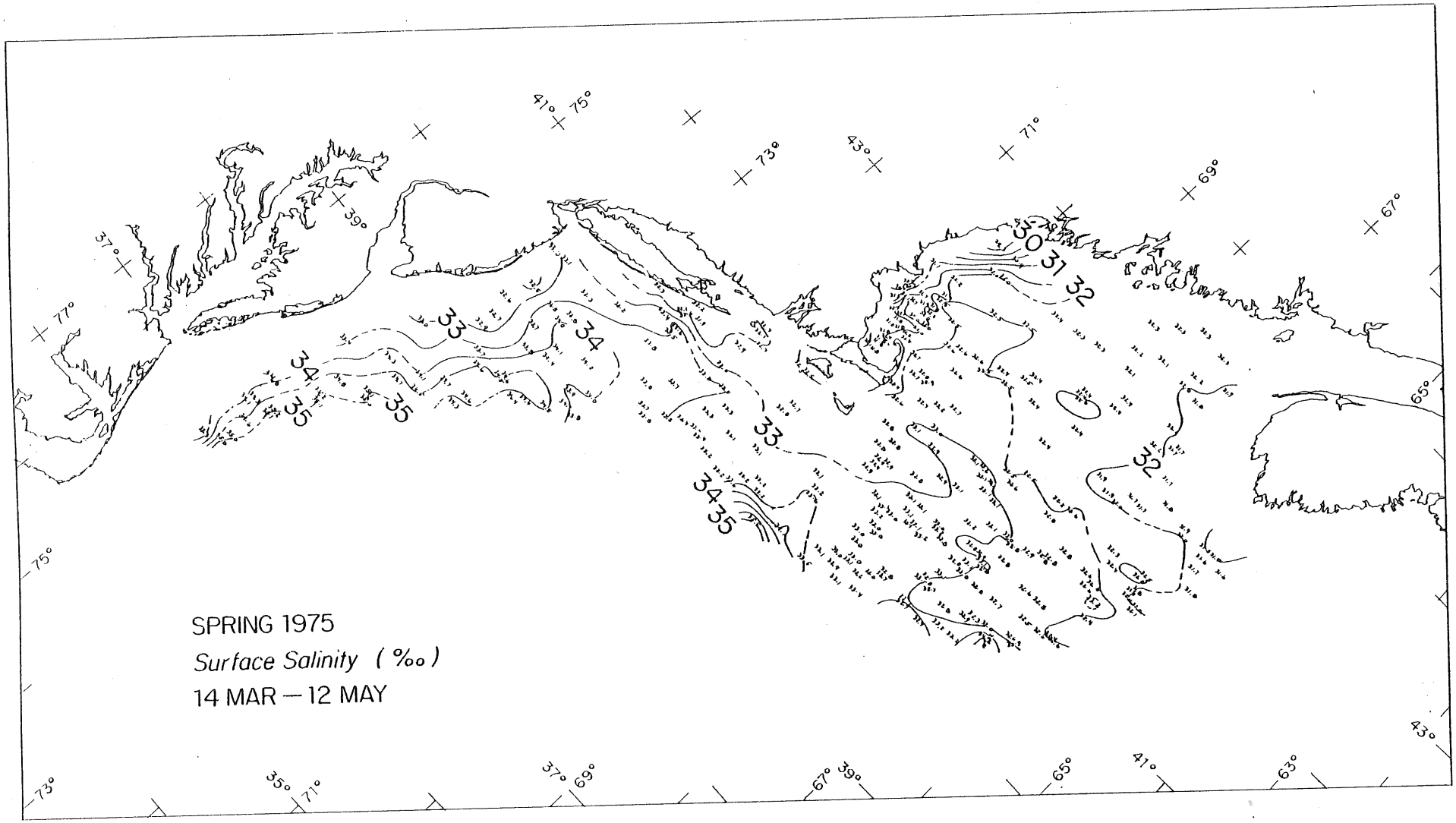

SPRING 1974
Surface Temperature (°C)
12 MAR – 4 MAY
41°
75°
73°
43°
71°
69°
67°
39°
37°
77°
65°
75°
73°
35°
71°
37°
69°
67°
39°
65°
41°
63°
43°
8
10
12
12
6
6
6
6
4
4
2
18
14

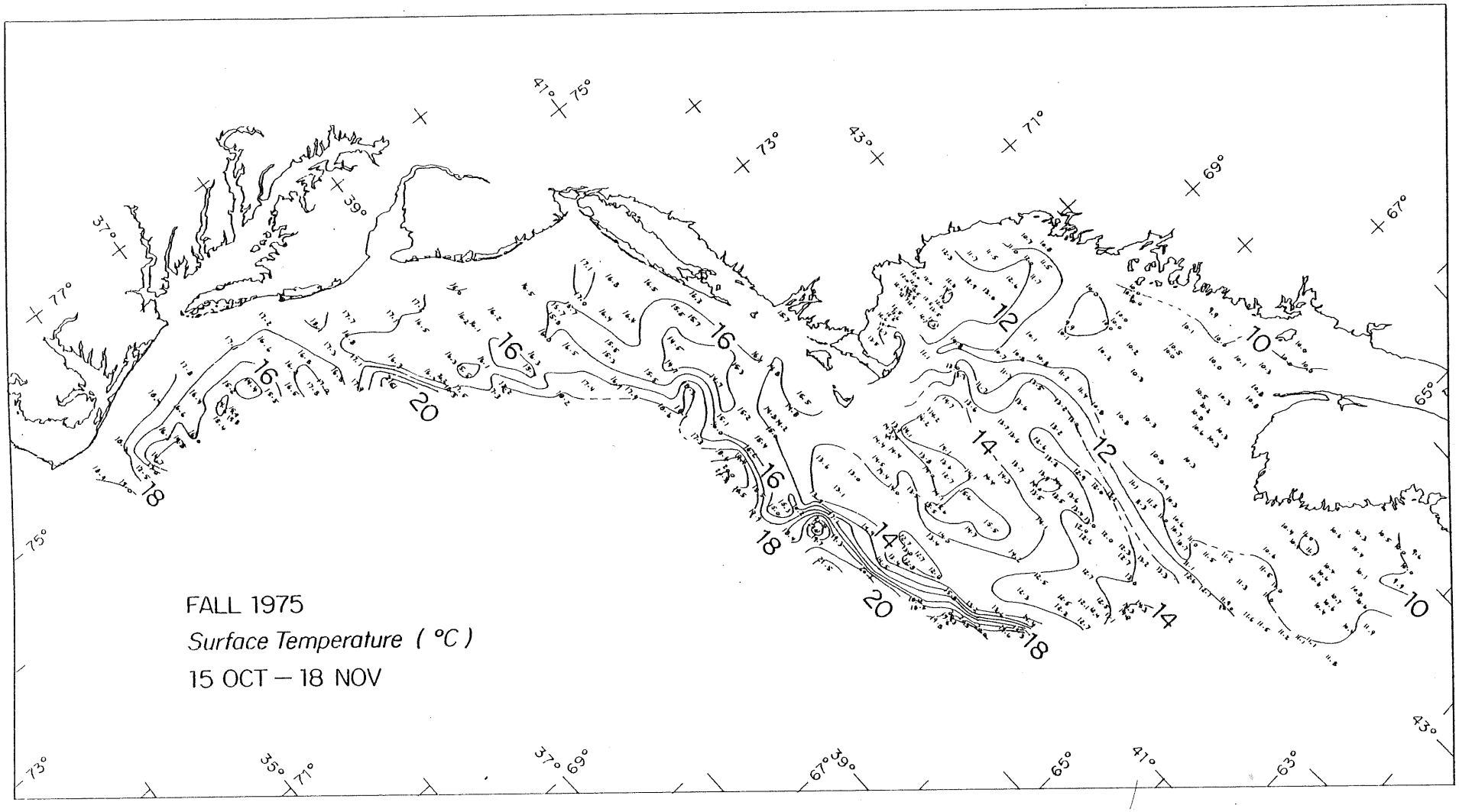

SPRING 1974
Surface Salinity (‰)
12 MAR — 4 MAY
31
32
33
34
35
36
37°
39°
41°
43°
65°
67°
69°
71°
73°
75°
77°
63°

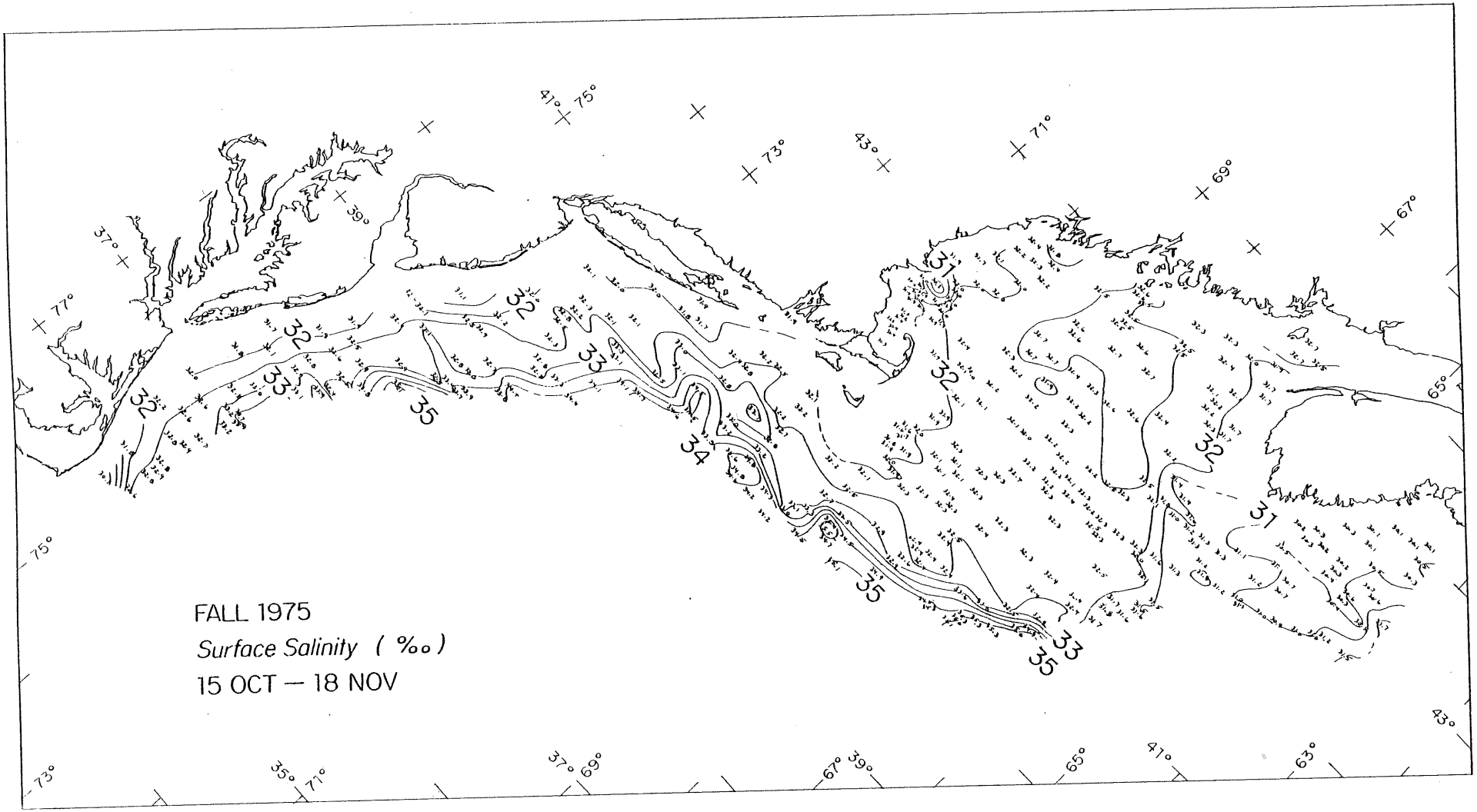

FALL 1974
Surface Temperature (°C)
23 SEP — 14 NOV
24
22
20
18
16
14
12
10
77°
75°
73°
71°
69°
67°
65°
63°
43°
41°
39°
37°
35°

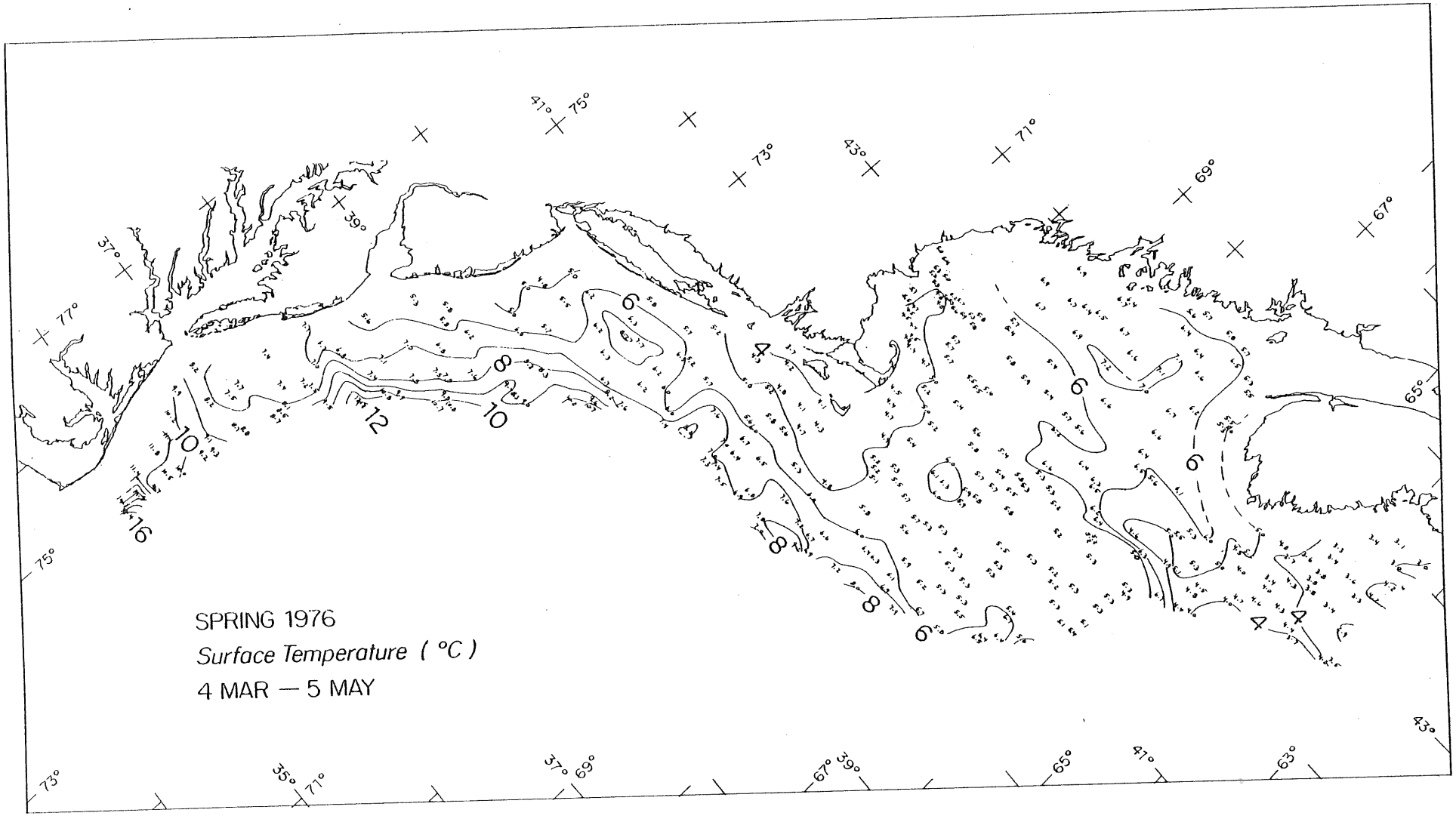

FALL 1974
Surface Salinity (‰)
23 SEP — 14 NOV
31
32
33
34
35
77°
75°
73°
71
69°
67°
65°
63°
41°
43°
39°
37°
35°
71°
73°
75°
77°
37°
39°
41°
43°
65°
67°
69°

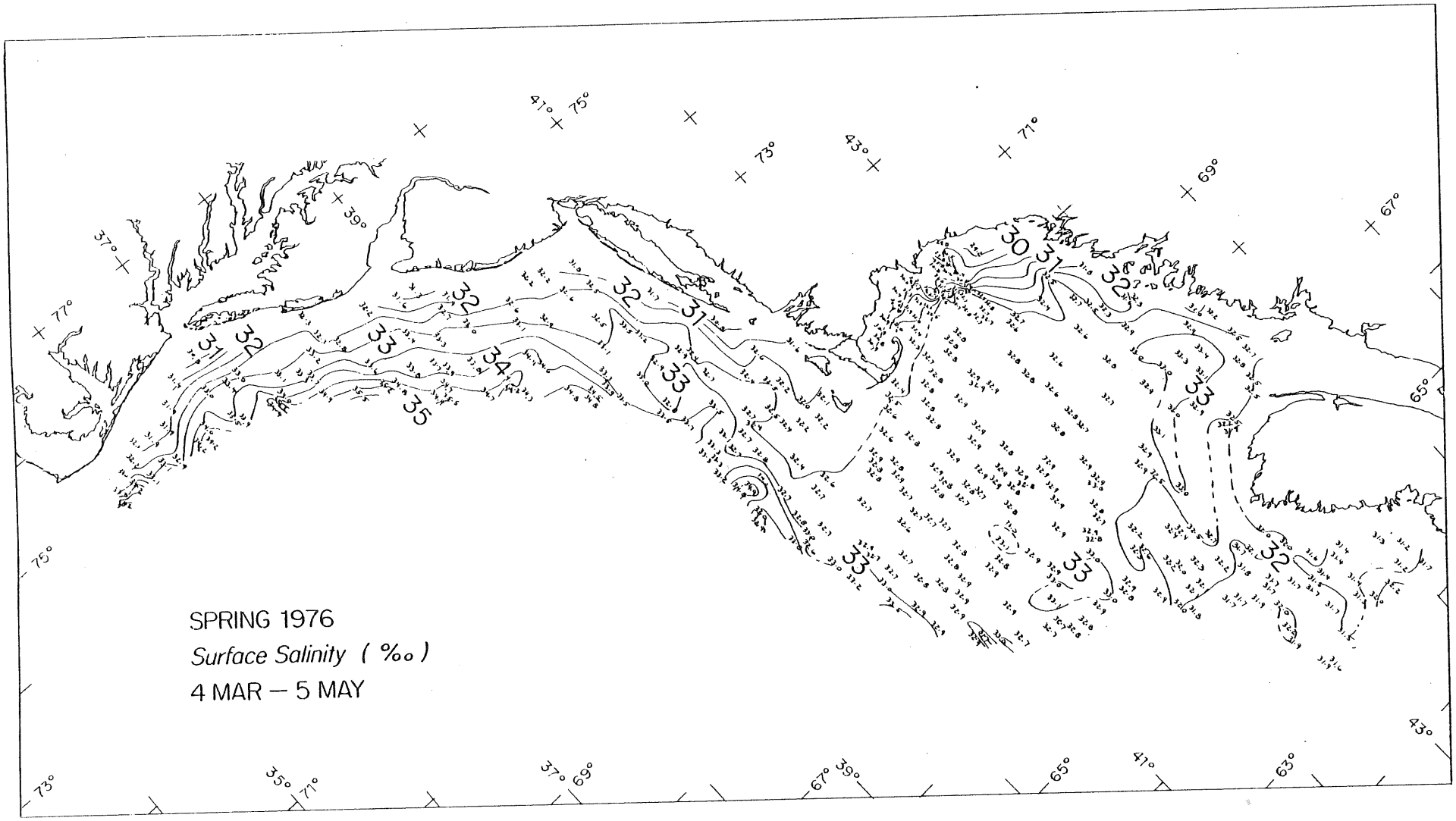

SPRING 1975
Surface Temperature (°C)
14 MAR – 12 MAY

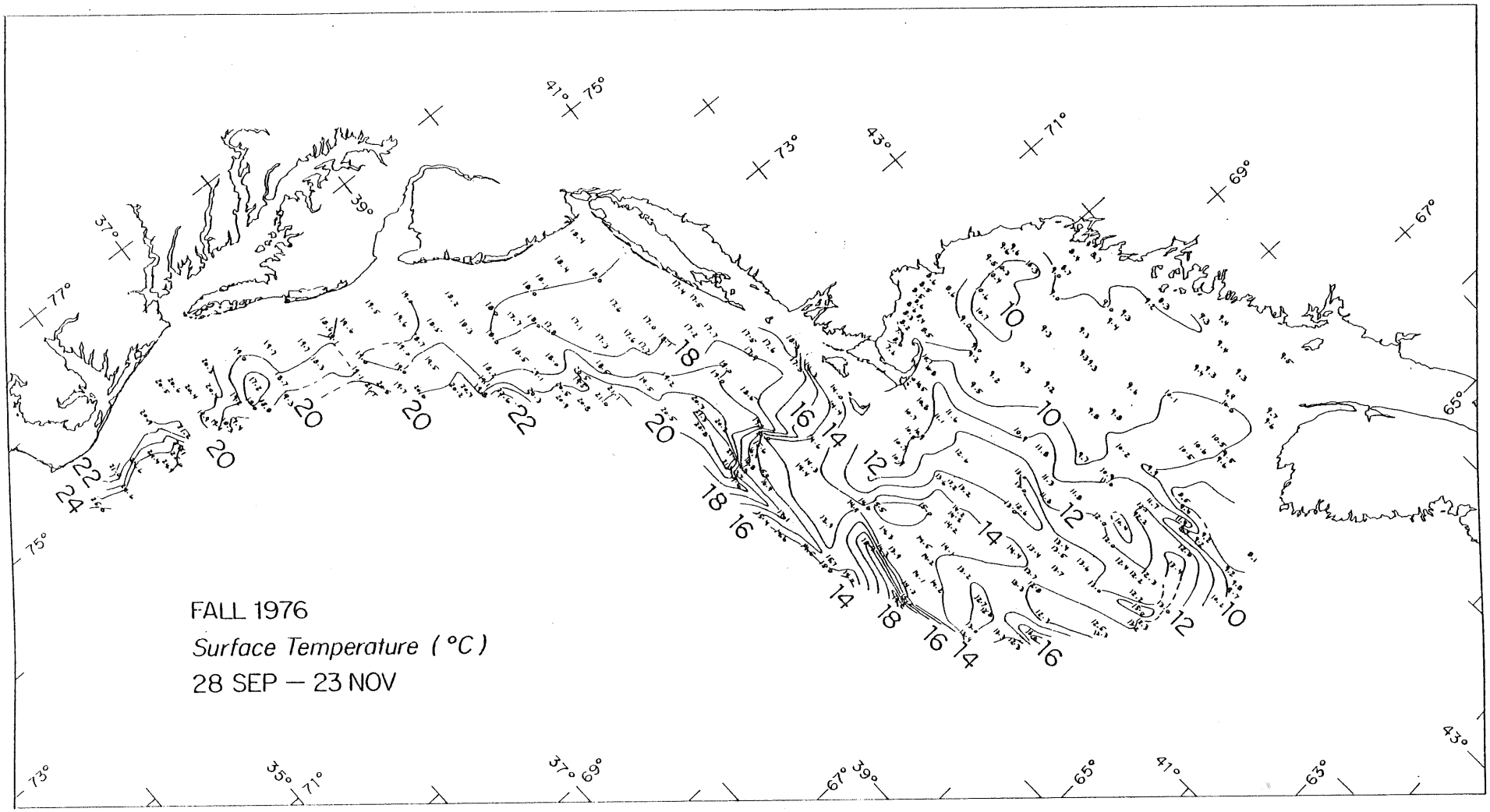

SPRING 1975
Surface Salinity (‰)
14 MAR — 12 MAY
77°
75°
73°
71°
69°
67°
65°
63°
43°
41°
39°
37°
35°
30
31
32
33
34
35

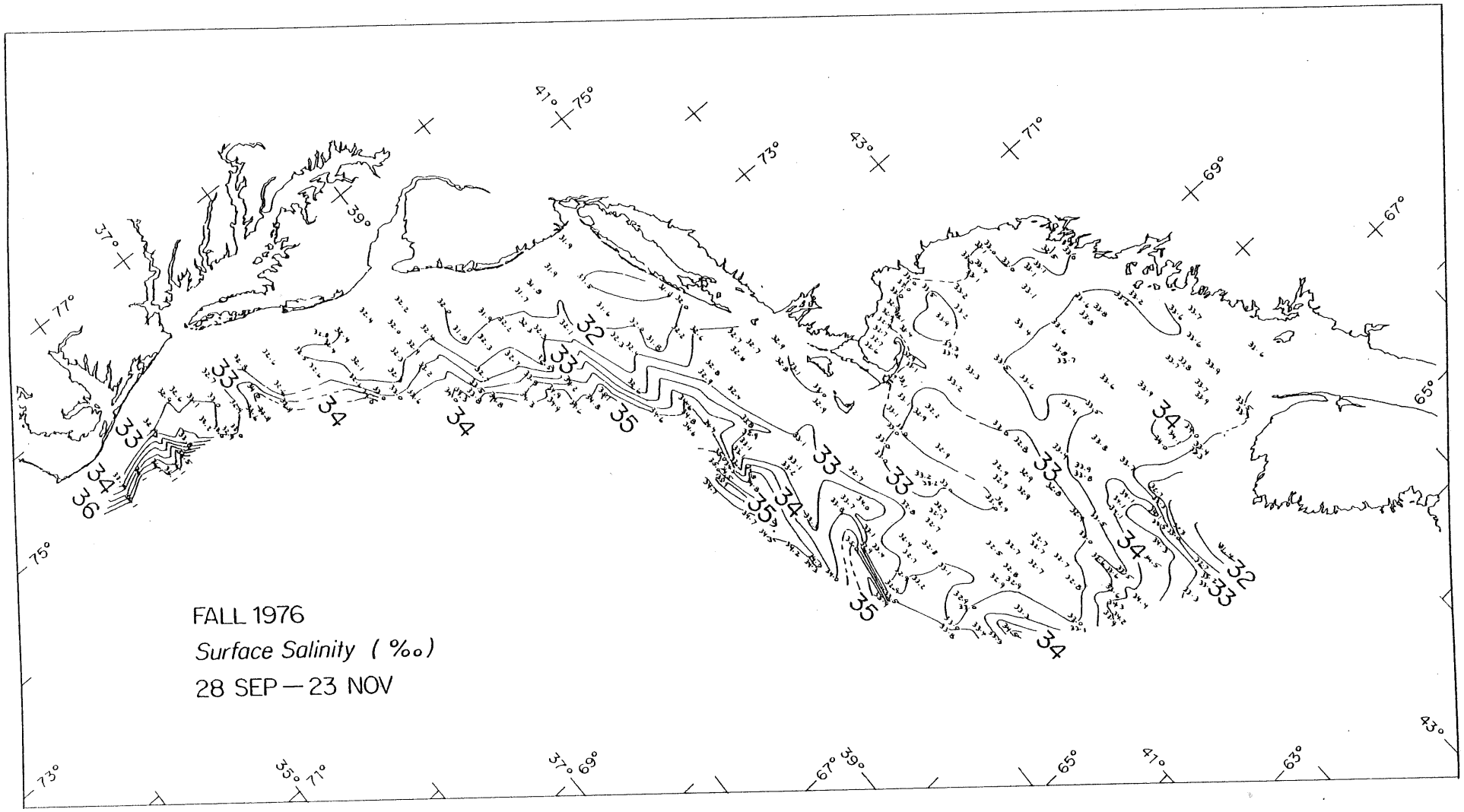

FALL 1975
Surface Temperature (°C)
15 OCT – 18 NOV

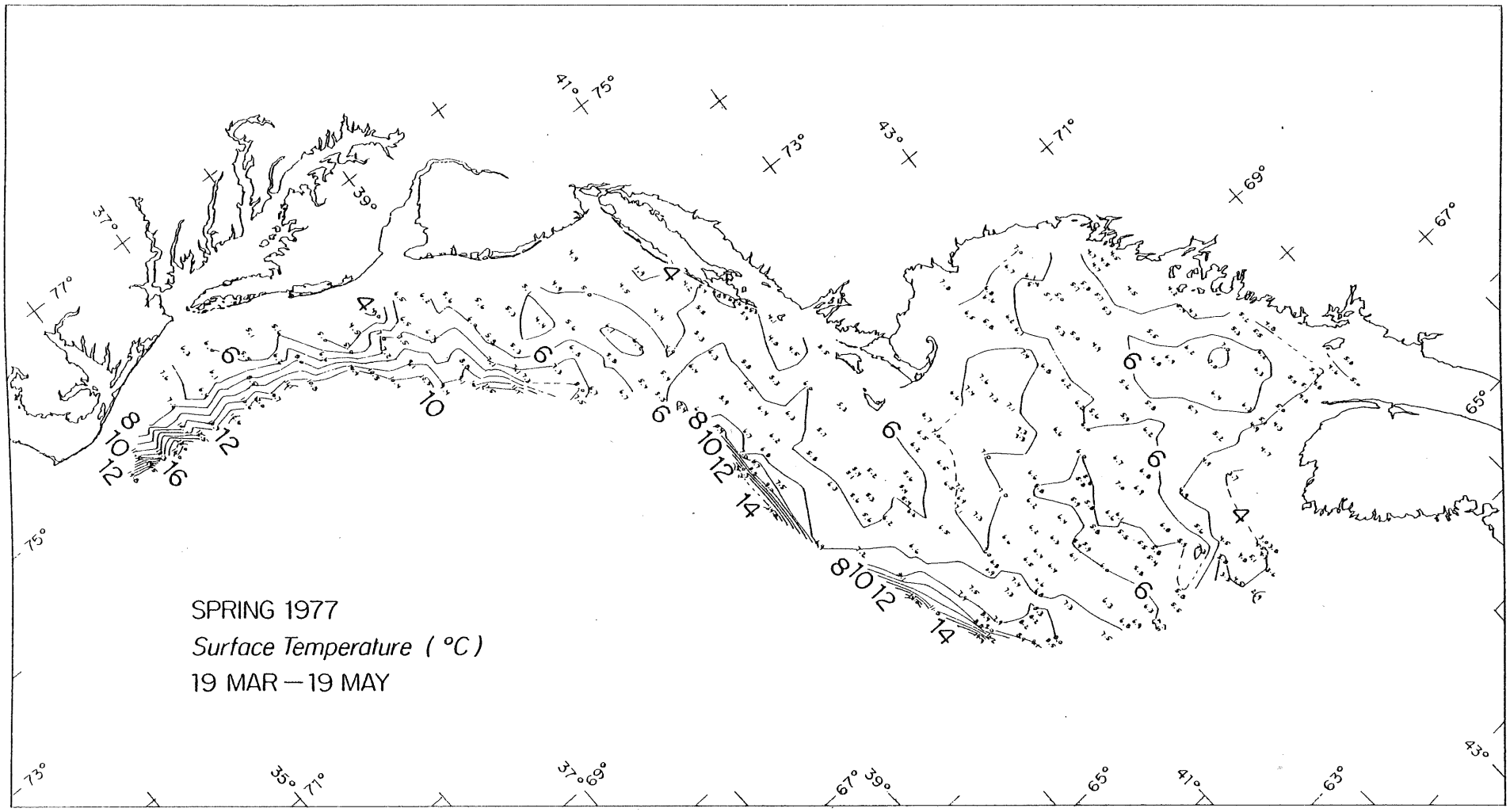

FALL 1975
Surface Salinity (‰)
15 OCT — 18 NOV

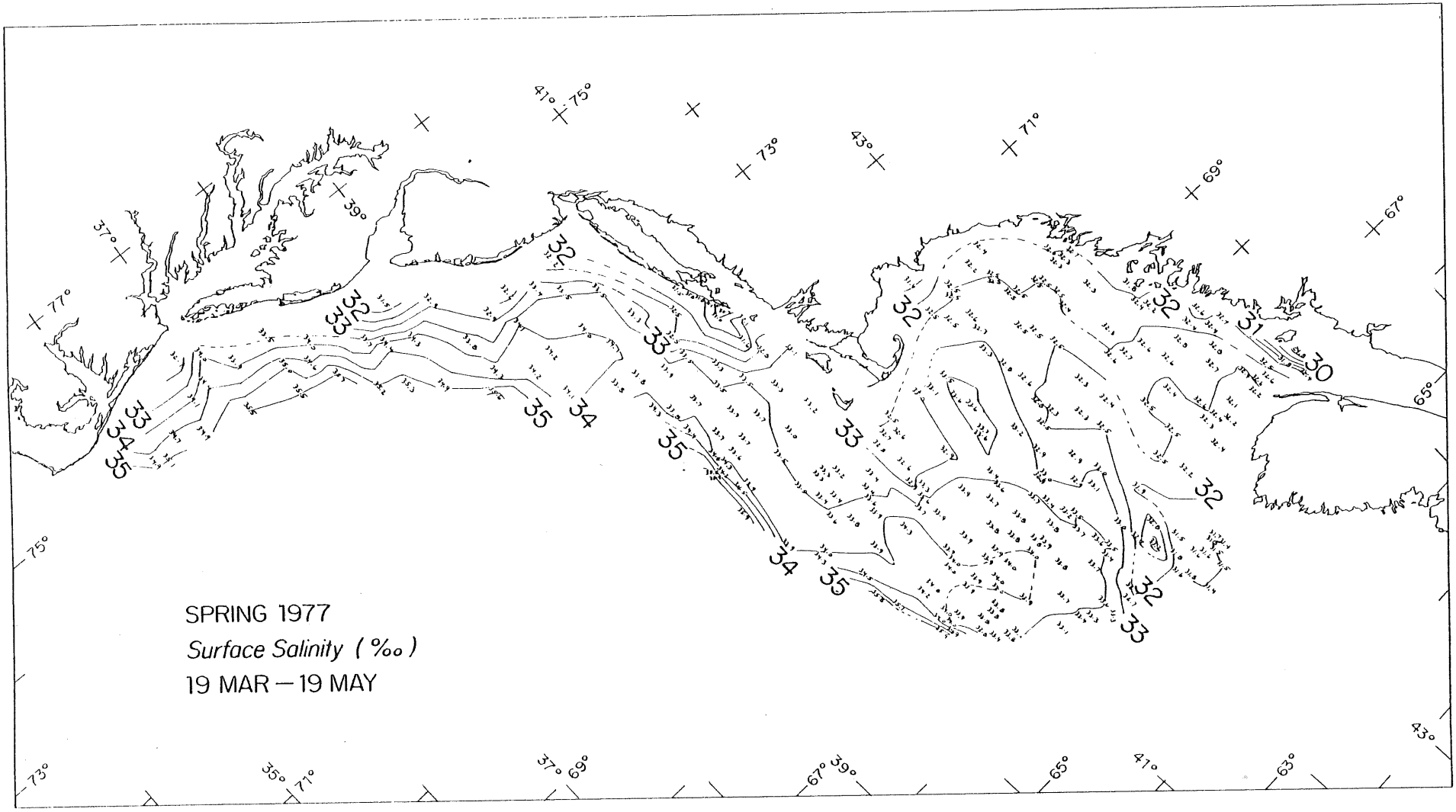

SPRING 1976
Surface Temperature (°C)
4 MAR — 5 MAY
77°
37°
39°
41°
75°
73°
43°
71°
69°
67°
65°
75°
73°
35°
71°
37°
69°
67°
39°
65°
41°
63°
43°
16
10
12
10
8
6
4
8
8
6
6
6
4
4

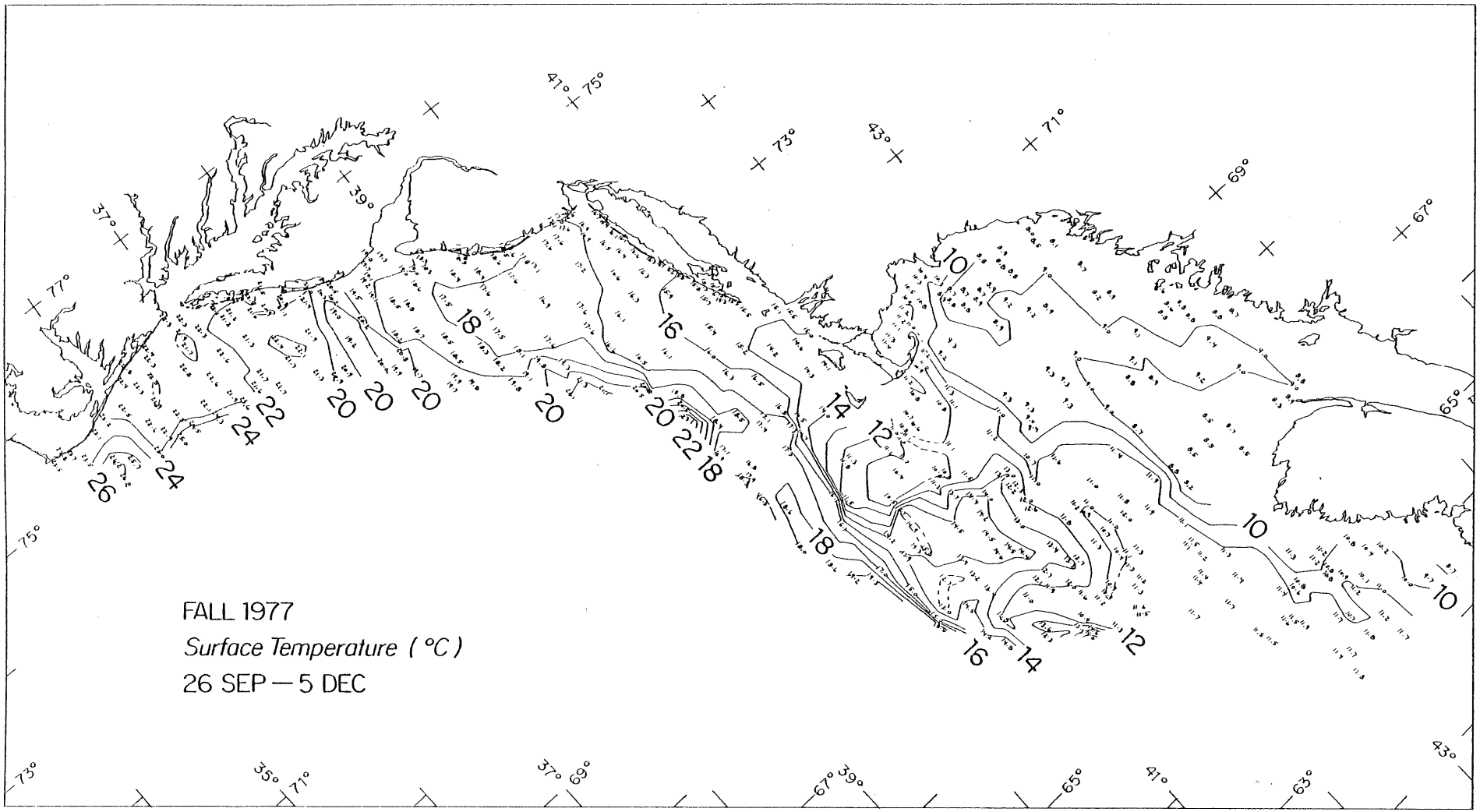

SPRING 1976
Surface Salinity (‰)
4 MAR — 5 MAY

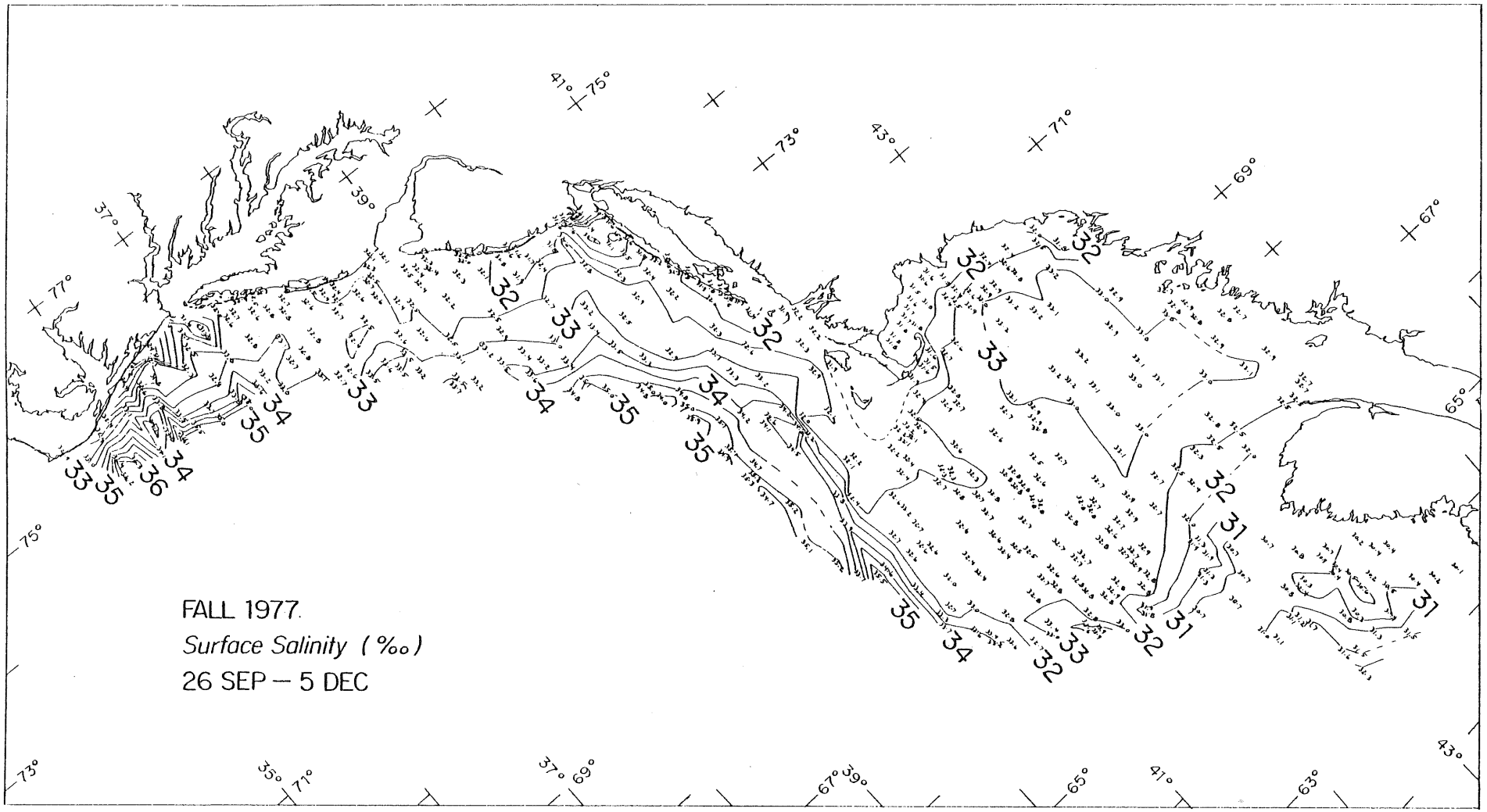

FALL 1976
Surface Temperature (°C)
28 SEP — 23 NOV


FALL 1976
Surface Salinity (‰)
28 SEP — 23 NOV


SPRING 1977
Surface Temperature (°C)
19 MAR — 19 MAY


SPRING 1977
Surface Salinity (‰)
19 MAR — 19 MAY


FALL 1977
Surface Temperature (°C)
26 SEP — 5 DEC


FALL 1977.
Surface Salinity (‰)
26 SEP – 5 DEC