

**FIRST ANNUAL REPORT
NORTHEAST MONITORING PROGRAM**

**Baseline studies on the distribution of phytoplankton
biomass, organic production, seawater nutrients and trace
metals in coastal water between Cape Hatteras and Nova Scotia**

**Environmental Chemistry Investigation
Division of Environmental Assessment
Sandy Hook Laboratory
Northeast Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration**

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1. Administrative Information

1.1 Principal Investigators:

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1.2 Organization Receiving Funding:

National Marine Fisheries Service, NOAA

1.3 Present (FY 80) Funding Level:

1.4 Title of Work Unit or Investigation:

Environmental Chemistry Investigation: Baseline studies on the distribution of phytoplankton biomass, organic production, seawater nutrients and trace metals in coastal water between Cape Hatteras and Nova Scotia.

1.5 Major NEMP Cruises participated in:

The major NEMP surveys as well as other cruises within the NEMP survey area are listed in Table 1.

1.6 Reports or Publications Produced under this Funding and Related Reports:

Esser, S., J. O'Reilly, D. Busch. 1980. Monitoring of Ceratium tripos continues between Nova Scotia and Cape Hatteras. Coastal Oceanography and Climatology News 2(3), spring 1980.

Evans, C. A., J. E. O'Reilly and J. P. Thomas. 1979. Report on chlorophyll measurements made on MARMAP surveys between October 1977-December 1978. Sandy Hook Laboratory, Report No. SHL 79-10.

Evans, C. A. and J. E. O'Reilly. 1980. Report on chlorophyll measurements made between June 1979-June 1980 during surveys AL-79-06, BE-79-01, EV-80-02, and DE-80-03/04. Sandy Hook Laboratory, Report No. SHL 80-14.

Evans, C. A. and J. E. O'Reilly. 1980. A manual for the measurement of chlorophyll a in netphytoplankton and nannophytoplankton. Ocean Pulse Technical Manual No. 3, Sandy Hook Laboratory, Report No. SHL 80-17.

Draxler, A. F. J., R. Waldhauer and A. Matte. 1979. Nutrient data from Belogorsk cruise 78-04, 16-29 November 1978. Sandy Hook Laboratory, Report No. SHL 79-07.

Matte, A., R. Waldhauer and A. F. J. Draxler. 1979. Nutrient data from the cruise of the Whiting FRC-05-06, 29-31 May 1979. Sandy Hook Laboratory, Report No. SHL 79-39.

O'Reilly, J. E. and J. P. Thomas. 1979. A manual for the measurement of total daily primary productivity on MARMAP and Ocean Pulse cruises using ^{14}C simulated in situ sunlight incubation. Ocean Pulse Technical Manual No. 1, Sandy Hook Laboratory, Report No. SHL 79-06.

O'Reilly, J. E. and D. A. Busch. 1980. Summary of measurements of primary productivity made during MARMAP surveys (Belogorsk 79-01, 79-03, 79-05). Sandy Hook Laboratory, Report No. SHL 80-15.

Steimle, F. W., J. E. O'Reilly, D. J. Radosh, and R. Waldhauer. 1980. Hydrographic data, Ocean Pulse environmental monitoring surveys April 1978 through April 1980. Sandy Hook Laboratory, Report No. SHL 80-25.

Waldhauer, R., A. Matte and J. E. O'Reilly. 1980. Summary of ammonium-nitrogen measurements made during six cooperative US-USSR MARMAP surveys. Sandy Hook Laboratory, Report No. SHL 80-16.

Waldhauer, R., A. Matte, A. F. J. Draxler and J. E. O'Reilly. 1980. Seasonal ammonium-nitrogen distributions across the New York Bight shelf. Proc. Ramapo Water Conference, 1980.

1.7 NEMP Work Unit Monitor:

Merton C. Ingham

1.8 Duration that Work Unit has Covered:

This report discusses monitoring activity from the Operational Test Phase of Ocean Pulse (spring 1978) to present. Baseline data on chlorophyll a collected within the NEMP region in late 1977 is also included.

2. Objectives

The Environmental Chemistry Investigation's main objectives in relation to NEMP are to 1) establish baseline data concerning the spatial and temporal distribution and abundance of inorganic and organic materials (nutrients, heavy metals, phytoplankton biomass/chlorophyll a, and phytoplankton organic carbon production) which affect habitats, living resources and associated food webs in coastal/shelf water between Cape Hatteras and Nova Scotia; 2) to develop and build sufficiently comprehensive baselines for these target variables such that trends and departures from trends, induced either naturally or by man's influence, may be determined.

A considerable amount of baseline data on concentrations of inorganic nutrients, heavy metals (water, sediment, organisms) phytoplankton biomass/chlorophyll a, and phytoplankton organic carbon production already exists for a few heavily-polluted areas of historical monitoring importance such as the New York sludge and dredge-spoil dump sites, the sewage-polluted highly eutrophic Raritan-Lower Bay estuarine complex, the New York Bight apex, and the 1976 anoxic area off the coast of New Jersey. However, until recently (FY 78, 79, Operational Test Phase of Ocean Pulse) these pollutants (trace metals), stimulants (nutrients) and prime ecosystem components (phytoplankton biomass and organic production) have not been systematically described and frequently monitored throughout coastal-shelf environments between Cape Hatteras and Nova Scotia, the focal area of the Northeast Monitoring Program.

3. Summary of Activities, Rationale and Methods

3.1 Activities:

Since this work unit report will be part of the First Annual NEMP Report, it is appropriate not to limit the report to activities ongoing this past year, but instead, to provide to NEMP managers a time frame in which this investigation has systematically surveyed concentrations of nutrients, heavy metals, chlorophyll a, and rates of organic carbon production by phytoplankton in NEMP coastal/shelf water. Table 1 chronologically summarizes (by survey and measurement type) this investigation's participation in surveys conducted within the NEMP region of interest. Figures 1 through 11 depict cruise tracks and sampling stations occupied during the surveys listed in Table 1. Usually, measurements of chlorophyll a are made at >95% of the stations depicted in Figures 1-11. The rate of phytoplankton production of organic carbon is measured at two stations (sunrise, noon) each day at sea throughout each of the surveys listed in Table 1. Seawater samples for nutrient analyses are taken at approximately 50% of the standard MARMAP stations and at nearly all Ocean Pulse stations occupied. Measurements of trace metals in seabed sediments and in tissue of fish and invertebrates are made at the same stations sampled for benthic community attributes (Reid),

the same stations and organisms used in physiological assays (Calabrese, Thurburg). Figures 46-87 depict locations of stations sampled for heavy metals in sediments during Ocean Pulse surveys.

Currently, survey frequency for chlorophyll a-biomass, phytoplankton production, and water column nutrients is 10-11 surveys/year. Survey frequency for trace metal monitoring is four Ocean Pulse surveys/year. Additionally, fish, invertebrate, and sediment samples were collected for trace metal analyses during an intensive NEMP survey of the New York Bight apex in August 1980.

In May 1980, the construction of a new trace metals analysis laboratory at Sandy Hook (designed to ultimately become an ultra-clean facility) was completed. While the lab was being constructed, sampling for metals continued and samples were frozen. The protracted construction delayed analyses. However, since early September, over 700 samples of sediment have been analyzed for concentrations of cadmium, chromium, copper, lead, nickel, and zinc. Mercury will be analyzed in all sediments and tissues collected during the NEMP (KE-80-07/08) New York Bight apex survey as well as in selected sediments and tissues collected during Ocean Pulse surveys listed in Table 1.

3.2 Rationale:

3.2.1 Nutrients, phytoplankton biomass, and production

Our approach to monitor phytoplankton biomass, primary productivity, and nutrient levels is highly predicted upon frequent surveys so that we may develop temporally and spatially reliable baselines, to quantify the extent of coastal eutrophication, and to further our understanding of the interrelationships between inorganic/organic contaminants, phytoplankton quantity and quality, and altered and degraded habitats (anoxia, shifts in fishing communities, etc.).

During monitoring surveys, particular emphasis is placed on delineating the relative amounts of netphytoplankton (<20 μm) and nannophytoplankton (>20 μm) biomass and production throughout the shelf over an annual cycle. Changes in the structure (size composition, species composition) of the phytoplankton community may result from nutrient pollution stress and these structural changes may lead to major alterations in the structure and function of adjacent links in the marine food chain (Steele and Frost, 1976), and altered and degraded habitats.

Parsons and Lebrasseur (1970) advanced the concept that net-phytoplankton dominated plankton communities may lead to greater energy and matter input to higher (fish) trophic levels since the netplankton-macrozooplankton-fish grazing scheme has fewer trophic transfers (and smaller energy losses) than the nannoplankton-microzooplankton-macrozooplankton-fish grazing scheme.

From our fisheries or ecosystem productivity perspective, it is important to develop baselines on the total organic production by phytoplankton as well as baselines on the size-composition of the primary producing community and standing stocks of phytoplankton.

Since nitrogen may be the "critical limiting factor to algal growth and eutrophication in coastal marine waters" (Ryther, 1971), our surveys of macro-nutrient distributions emphasize both dissolved inorganic N and dissolved organic N. Dissolved organic N (DON) may represent a significant portion of the total nitrogen in sewage effluents discharged into coastal water (Eppley et al., 1972; Thomas et al., 1979). Ratios of NH_4 :nitrite:nitrate:DON will also provide an additional "fingerprint" on water masses (estuarine, slope water) and provide insight into the relative roles played by nutrient sources from estuaries, slope water and in situ nitrogen recycling in supplying nitrogen to primary producers.

3.2.2 Trace metals

From the beginning of the Operational Test Phase of Ocean Pulse (Researcher, 1978) to the present, members of this investigation have participated in 13 Ocean Pulse/NEMP surveys for the purpose of collecting samples of seabed sediment and tissue from fish and invertebrates for analyses of trace elements. The emphasis here is in establishing trace metal baselines in areas of the shelf not previously systematically sampled, monitoring the levels of toxic trace metals in tissues of commercially important species used as food, defining tissue and sediment metal burdens in polluted areas of the New York Bight and surveying the apex area to determine if these contaminants are "spreading" to contiguous benthic habitats (KE-80-07/08).

3.3 Methods:

3.3.1 Phytoplankton biomass (chlorophyll a)

Concentrations of chlorophyll a pigment are considered to be a useful index of autotrophic phytoplankton biomass. During all surveys listed in Table I, seawater for chlorophyll a analyses was collected throughout the water column to 75 m (or bottom if less than 75 m). Standard sampling depths are surface, 5, 10, 15, 20, 25, 30, 35, 50, 75 meters. PVC 5-liter Niskin sampling bottles are used. At stations on the shelf less than 75 m deep, a "bottom trip" Niskin bottle (rigged to close when a weight contacts the seabed) is used to collect seawater near the sediment-water column interface. These "bottom trip" samples have provided us with a better

characterization of near bottom phytoplankton stocks, nutrient levels, and dissolved oxygen concentrations in water within a meter of benthic communities.

Chlorophyll *a* is measured fluorometrically. Filtration of phytoplankton, grinding, acetone extraction of pigments, and fluorescence readings are performed at sea, shortly after seawater samples are collected. Phytoplankton are size-fractionated into netphytoplankton (>20 μm) and nanophytoplankton (<20 μm) by serial filtration through 20 μm mesh nylon and ~0.7 μm mesh Whatman GF/F filters. All relevant data are recorded at sea on computer entry coding forms. The entire procedure used to measure chlorophyll *a*, from seawater collection, filtration, extraction, fluorescence readings, calibration, through calculation and computerization of data is fully described in "A manual for the measurement of chlorophyll *a* in netphytoplankton and nanophytoplankton" (Evans and O'Reilly, 1980).

3.3.2 Phytoplankton carbon production

The rate of production of organic carbon by phytoplankton is measured throughout the euphotic layer at depths corresponding to 100%, 69, 46, 25, 10, 3, and 1% of subsurface photosynthetically active radiation (PAR). Assimilation of inorganic radiocarbon-14 is measured during simulated in situ sunlight incubations lasting approximately 5 hours.

Following sunlight incubation, the photoassimilated organic carbon is size-fractionated by serial filtration through a 20 μm mesh nylon filter and a 0.45 μm mesh Millipore filter to determine the relative production by netphytoplankton (>20 μm), nanophytoplankton (<20 μm) as well as the organic carbon released by the phytoplankton community as dissolved organic carbon (<.45 μm). This filter fractionation procedure is similar to that used for chlorophyll. Consequently, photosynthetic efficiency (productivity/chlorophyll *a*/PAR) of netplankton and nanoplankton production may be compared and evaluated in light of nutrient, temperature, turbidity, and other environmental conditions.

Integral daily primary production is measured twice each day at sea, at stations occupied at sunrise and local noon. Our procedure is highly standardized. The methodological details of our procedure from sample collection through incubation, filtration, liquid scintillation counting, calibration, calculation and computerization of data are fully described in "A manual for the measurement of total daily primary productivity on MARMAP and Ocean Pulse cruises using ^{14}C simulated in situ sunlight incubation (O'Reilly and Thomas, 1979).

3.3.3 Nutrients

Methods employed for the measurement of nutrient concentrations are as follows:

Seawater samples are collected throughout the water column, at four to 12 depths determined from Table 9. Immediately after collection, seawater is pressure-filtered through precombusted, sample-rinsed glass fiber filters (Whatman GF/F, retention 0.7 μ m). The seawater filtrate is collected in polycarbonate screw cap test tubes and stored frozen until it is analyzed at the laboratory for nitrate, nitrite, phosphate, and silicate concentrations. A four channel Technicon Autoanalyzer II system is used. Nitrite and nitrate are measured using the naphthylethylenediamine-sulfanilamide system with cadmium reduction of nitrate after Wood et al. (1964). Phosphorus is analyzed using the molybdate-ascorbic acid procedure after Murphy and Riley (1962). The reactive dissolved silicon procedure is based on the use of oxalate to reduce silicomolybdate complex and at the same time decompose any phospho- or arseno-molybdates (Mullin and Riley, 1965).

Seawater filtrates for ammonium analyses are preserved at sea by the addition of phenol-alcohol (Degobbis, 1973) and freezing. Ammonium analyses are completed in the laboratory within a week or two of cruise termination, following the procedure of Liddicoat et al. (1975).

In addition to the above analyses for inorganic nutrients, aliquots of seawater and seawater filtrates (GF/F filters) are prepared at sea and frozen for subsequent analyses of total N, P and dissolved organic N + P, respectively. These analyses of organic nitrogen and phosphorus have not yet been made. Instead, our efforts have been directed at completing inorganic analyses. We expect to perform the organic N + P analyses using a continuous flow ultraviolet photooxidation reactor system developed by members of the Environmental Chemistry Investigation. The digester is still being tested. Using this system, we have achieved nearly 100% mineralization of urea to nitrate-nitrite. Urea is relatively highly refractory to photooxidation.

To evaluate the methods and techniques of both shipboard collection as well as analytical procedures in the laboratory, an intercalibration study was made with Brookhaven National Laboratory. During the AL-80-07 survey, Sandy Hook personnel sampled the water column at station 28 (39°37'N, 72°03'W) filtering and preserving for analysis later.

Brookhaven personnel aboard the Kelez sampled nearby (39°37'N, 72°03.5'W) and using their onboard autoanalyzer processed their samples immediately. Table 2 lists the results. Although winds causing a wire angle of 15° made field work difficult, agreement is good.

3.3.4 Trace metals

Samples of seabed sediment for trace metal analyses are collected using a Smith-McIntyre grab sampler. Acid-cleaned plastic core tubes are used to subsample the grab. Cores are capped and frozen until analysis. The upper 5 cm of the core is dried, weighed, pulverized, digested, and analyzed for trace metals (lead, zinc, copper, chromium, nickel, cadmium) using a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer.

Tissue samples are excised from animals captured in trawls, dredges, rakes, etc., stored in acid-cleaned plastic vials, and frozen until analysis. Species analyzed for metal burdens are primarily winter flounder, yellowtail flounder, windowpane flounder, sea scallop, surf clam, hard clam, blue mussel, rock crab, and lobster. Other species are also sampled. The species commercial importance as well as its ubiquity throughout polluted and unpolluted target areas are two of the major criteria used in species collection.

In addition to Cu, Pb, Zn, Cr, Cd, Ni, and Ag concentrations of mercury will be measured in all sediments and tissues collected during the NEMP KE-80-07/08 summer survey of the New York Bight and in sediments and tissues from selected Ocean Pulse stations sampled during surveys listed in Table 1.

An oyster tissue standard (NBS 1566) is used to determine metal recovery and analytical accuracy of our tissue analyses. A sediment sample #7460 from the New York Bight is used as an internal standard for metal analyses in sediments.

4. Summary and Interpretation of Findings

4.1 Phytoplankton Biomass (chlorophyll a):

The shelf-wide distribution of average water column concentrations of phytoplankton biomass is presented for 18 surveys in Figures 14 through 31. The weighted average chlorophyll a concentrations (mg/m^3) were calculated for each sampling station by integrating chlorophyll a concentration over the sampling depths to 75 m (or bottom if <75 m) and dividing the integral by the depth of the water column integrated. This average chlorophyll a concentration for each station was used to construct the contoured depictions presented in Figures 14-31. In dealing with averaged station data, the vertical profile of phytoplankton abundance is obscured. Nevertheless, the averaged station chlorophyll a concentrations can be used to describe the spatial and temporal distributions of phytoplankton biomass on the shelf.

Throughout the shelf over the annual cycle, recurrent patterns of phytoplankton abundance are evident from Figures 14-31. The highest phytoplankton biomass concentrations are consistently observed in the Middle Atlantic Bight inshore water off New Jersey, Delaware, and Virginia (Figures 14, 16, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 31). Phytoplankton are generally least concentrated in the deeper water near the shelf break in the Mid-Atlantic Bight, at the periphery of Georges Bank and in the Gulf of Maine.

Recurrent gradients of phytoplankton concentrations are found in the Mid-Atlantic Bight and over Georges Bank. In these two areas, average water column concentration of chlorophyll a decreases as the depth of the water column increases. Chlorophyll a is often 5-10 times more concentrated in inshore water (<40 m) in the Mid-Atlantic Bight than in water adjacent to the shelf break. This is particularly evident in Figures 14, 16, 19, 20, 22, 23, 24, 25, 27, and 29. Likewise, chlorophyll a concentrations often progressively decrease 5-10 fold from the central and shoal areas (<40 m) on Georges Bank to the perimeter of the bank (Figures 14, 15, 20, 21, 24, 28, 29, 30). The inshore band of high chlorophyll a concentration off New Jersey, Delaware, and Virginia is usually not continuous from north to south, but instead, interrupted by bands of lesser concentrations of phytoplankton (Figures 14, 16, 19, 20, 22, 23, 24, 27, 29, 31). In several chlorophyll maps we observed very high (>4 mg/m^3) concentrations adjacent to or slightly south of the Raritan-Hudson, Delaware, and Chesapeake estuaries (Figures 19, 20, 24, 25, 26, 27, 28, 31). However, in several distributional maps, these patches of relatively high phytoplankton biomass exist slightly north of the mouths of one or more of these three estuaries (Figures 14, 16, 29).

Patterns of phytoplankton abundance are not as obvious in the Gulf of Maine, partly because sampling in the Gulf of Maine is not as thorough as sampling in southern areas of the shelf. However,

during most surveys, the lowest average water column concentrations of chlorophyll *a* are found in the Gulf of Maine. When relatively high levels of chlorophyll *a* ($>3 \text{ mg/m}^3$) are observed in the Gulf of Maine, they are usually found at stations less than 70 m deep near Penobscot Bay, Casco Bay, Cape Anne, Massachusetts Bay, and Cape Cod Bay.

Phytoplankton biomass concentrations off Long Island, as in the rest of the Mid-Atlantic Bight, also generally decrease from the shoreline to the shelf break. This onshore-offshore banding off Long Island is seen in Figures 16, 20, 23, and 25. This banding is not evident in Figures 19, 22, 24, and 31 where the biomass gradients are aligned more west-east than north-south/onshore-offshore. Generally, biomass concentrations in seawater adjacent to Long Island are closer in magnitude to mid-shelf levels, and not inshore levels found next to the coast of New Jersey. Often, the mid-shelf area off Long Island has biomass levels comparable to those seen in the outer shelf off New Jersey. The inner third of the shelf adjacent to Long Island has a deeper water column (60 m) than the inner third of the shelf off New Jersey (40 m). This and associated mixing processes and estuarine runoff may partially explain the differences in phytoplankton concentrations north and south of the Hudson Canyon.

Based on the above mentioned recurrent patterns of phytoplankton biomass concentration, the shelf has been partitioned into regions (Figure 12). This was done to simplify temporal analyses of the data and to facilitate comparisons among areas of the shelf so that we may begin to understand the ecological mechanisms responsible for the distributional patterns. It should be stressed that the shelf regions depicted in Figure 12 represent a first approximation in generalizing the chlorophyll data. As the data base accrues, the partitioning will change to reflect the most representative shelf-wide generalized pattern. Already, over the past two months, it has become evident to us that chlorophyll abundance may correlate with bathymetry to a higher degree than we previously thought. Figure 13 reflects this and other refinements in the location of regional boundaries. Additionally, it has been suggested to us that we subdivide those coastal areas adjacent to estuarine outflows. However, throughout this report, discussion of trends in phytoplankton concentrations will be related to the shelf areas presented in Figure 12.

The frequency-percent histogram of average chlorophyll *a* concentration ($\text{mg Chl}a/\text{m}^3/\text{station}$) for each of the 15 shelf regions (Figure 12) is presented in Figure 32. Data collected between October 1977 and June 1980 was used to construct the histograms. In the Gulf of Maine (GM), all offshore areas in the Mid-Atlantic Bight (LI3, NJ3, DE3, CH3), deeper waters on Georges Bank (GB2) and mid-shelf off Long Island (LI2), greater than 50% of the station-averaged chlorophyll *a* concentrations are less than $1 \text{ mg Chl}a/\text{m}^3$. In offshore water in the Middle Atlantic Bight, the percent of observations

less than 1 mg Chl_a/m³ decreases from north to south. In LI3, NJ3, DE3, CH3 areas 82, 70, 60, and 56%, respectively, of the observations fall below 1 mg/m³. The percent of values greater than 1 mg/m³ progressively increases from north to south.

At inshore and mid-shelf regions of the Mid-Atlantic Bight (LI1, LI2, NJ1, NJ2, DE1, DE2, CH1, CH2) the majority of station-averaged chlorophyll a concentrations fall in the 0-2 mg Chl_a/m³ interval (Figure 32). In mid-shelf regions (LI2, NJ2, DE2, CH2) and in the LI1 region approximately 80% of the observations lie in the 0-2 mg Chl_a/m³ interval. The percent-frequency distribution for average chlorophyll a concentrations over the central area of Georges Bank (GB1) is greatly different from the distribution of values measured in deeper waters (60-200 m) on Georges Bank (GB2). Regions NJ1 and DE1 stand apart from the remaining 13 regions. In these two nearshore regions a high percent of the total observations falls between 4 and 10 mg Chl_a/m³ (Figure 32). An onshore-offshore trend of decreasing modal chlorophyll a concentrations is seen in the LI1-LI2-LI3 series, NJ1-NJ2-NJ3, DE1-DE2-DE3, and the CH1-CH2-CH3 onshore-offshore series.

Using the histograms in Figure 32, we have calculated an average chlorophyll a concentration for each of the 15 regions of the shelf. Even though the histograms and average may be biased (sample size varies greatly among regions, inherent sampling time biases, etc.), we thought that it might be interesting to construct a preliminary rank of the 15 regions, in order of decreasing average water column average chlorophyll a concentrations. The order is NJ1, DE1, GB1, CH1, NJ2, LI1, DE2, CH3, CH2, LI2, DE3, GB2, GM, NJ3, and LI3.

The annual cycle of phytoplankton abundance by month and year for each of the 15 shelf regions is presented in Figure 33. Data on average water column chlorophyll a concentrations (mg/m³) was used to develop Figure 33. Since areal coverage and sampling frequency were greatest in 1979 (1980 calculations are incomplete) data collected in 1979 will be used to describe the annual cycle of phytoplankton abundance. In inshore regions of the Mid-Atlantic Bight (LI1, NJ1, DE1, CH1) phytoplankton biomass is abundant throughout most of the year and is relatively more concentrated during early spring and late fall. Relatively high average water column concentrations of chlorophyll a were observed in December in several of these inshore regions in 1979 (Figure 33). The low abundance period of the annual cycle appears to occur in May/June. Data gathered in 1980 support this. However, in inshore regions of the Middle Atlantic Bight, chlorophyll concentrations in June are still relatively high (2 mg/m³).

In offshore regions of the Middle Atlantic Bight (LI3, NJ3, DE3, CH3), intra-annual variation in biomass is relatively smaller than that observed in inshore regions. Offshore, phytoplankton biomass

averages 0.5 mg/m^3 throughout most of the year. There is some indication of a peak in phytoplankton biomass in November-December in these offshore regions, and a peak in March in some of these regions. It appears from Figure 33 that elevated levels of phytoplankton biomass were maintained for longer periods of time in spring and fall in coastal water than in mid-shelf and offshore water.

The annual cycle of phytoplankton abundance is less clear in the Gulf of Maine and on Georges Bank (Figure 33). Sampling during the early part of the year is scanty. On Georges Bank, considerable inter-annual variation in biomass was seen in the August 1978, 1979 samples (Figures 19 and 27).

4.2 Phytoplankton Organic Carbon Production:

We present here the first shelf-wide, Cape Hatteras to Nova Scotia, estimates of annual phytoplankton carbon production. Measured daily integral rates of phytoplankton carbon production have been grouped according to areas defined primarily on the basis of recurrent patterns of average water column concentration of phytoplankton (chlorophyll a) and on the basis of hydrographic and bathymetric considerations. The approach here is to begin to define differences in rates of primary production in geographically and ecologically dissimilar areas of the Cape Hatteras to Nova Scotia shelf so that we may begin to define the extent of cultural eutrophication of coastal waters and the relative roles which natural forcing events and man's wastes play in stimulating production of carbon at the base of the food chain.

Most annual primary productivity estimates are derived from daily measurements made frequently at the same site over an annual cycle. Since the productivity data presented here were gathered during multidisciplinary intensive Ocean Pulse/MARMAP surveys, it was not feasible to reoccupy the same "station" from survey to survey and perform simulated in situ sunlight incubations. Instead, primary productivity was measured at stations occupied at sunrise and at noon.

Phytoplankton productivity data are grouped according to the regions or sections of the shelf depicted in Figure 12. This is done primarily so that primary productivity measurements can be related to phytoplankton biomass measurements, but also so that a sufficient number of pooled daily observations occur within a region per month to allow us to define the skeletal features of the annual cycle of production.

Another approach, underway at present, is the derivation of annual production estimates for areas smaller in size than the regions in Figures 12 and 13 approaching the scale of a "station" by grouping station data over the smallest possible area having at least one observation per sampling interval.

In Table 3 is presented a sample of "section E" computer output (O'Reilly and Thomas, 1979) which lists according to sampling station and date, daily integral rates of phytoplankton production as well as nanoplankton/netplankton production; euphotic rates of phytoplankton release of dissolved organic carbon, euphotic depth, and photosynthetically active radiation (Einstein's/m²/d) for one of the 20 surveys used to construct the annual plots of regional production depicted in Figure 34. It should be emphasized that these annual baselines are preliminary. Few measurements were made in December, January, and February. Considerable variability

in rates of production exist within sampling periods. Additionally, it should be pointed out that the annual plots presented by region in Figure 34 are constructed by pooling data (August 1978 through March 1980, plus a spring and summer survey in 1977) to make a "composite" year for the purpose of better defining the average annual features of the phytoplankton productivity cycle. Annual estimates will be more precise when we include 1980 monitoring data which will fill in and round out the features of the curves in Figure 34. Data collected in 1980, when processed, will also provide an indication of interannual variation in shelf production baselines. Wulff provides some data on variability of annual estimates in a paper entitled "The effects of sampling frequency on estimates of the annual pelagic primary production in the Baltic". The author visited a station in the North Baltic 38 times in one year to generate what he believed to be a reliable "true" figure for annual production (127 gC/m²/yr). Using portions of the available yearly data base (38 surveys), Wulff examined the discrepancy between "actual" and estimated annual production based on simulated reduced field sampling frequency. At sampling frequencies of 4-6 surveys/year, 10-12/year, and 17-26/year, the discrepancy can amount to 50%, 30, and 10%, respectively.

Despite these inherent limitations in the data base, several interesting patterns emerge:

Annual phytoplankton carbon production (particulate and dissolved) for the period surveyed ranges between 405 and 726 gC/m²/yr (Figure 35). These estimates of production place the Cape Hatteras to Nova Scotia shelf among the most productive shelf areas in the world. Using comparable methods based on phytoplankton assimilation of inorganic ¹⁴C, annual phytoplankton production has been estimated at 90-100 gC/m²/yr in the North Sea (Steele, 1974); Japan (Hogetsu, 1979) at 90 gC/m²/yr in coastal water; 102-128 gC/m²/yr on the eastern Scotian Shelf (Mills and Fournier, 1979); 127 gC/m²/yr in the northern Baltic (Wulff, 1979), 250-250 along the Shinnecock transect of the shelf off Long Island, New York (Falkowski, pers. comm.); 300 gC/m²/yr in Block Island Sound (Smayda, 1973), 370-480 gC/m²/yr in the New York Bight apex (Malone and Chervin, 1979), 434 gC/m²/yr in India's coastal water <50 m (Quasim, 1979), 547 gC/m²/yr along the coast of Georgia off the Altamaha River (Thomas, 1966) and 750-1053 gC/m²/yr in the sewage-polluted Raritan-Lower Bay estuarine complex (O'Reilly, et al., 1975).

It should be mentioned that the majority of the above cited studies measured and reported particulate carbon assimilation while our results include both particulate and dissolved organic carbon production by phytoplankton. We have not, at this time, computed annual percent extracellular release of carbon by phytoplankton for each region of the shelf. However, an inspection of computer listings reveals that about 16% (average) of the total carbon photoassimilated by phytoplankton is released as dissolved organic matter <0.45 um and 84% is retained in nanoplankton and netplankton (particulate).

Annual phytoplankton production of carbon in the section of the shelf adjacent to New Jersey is estimated to be 726 gC/m²/yr for the period surveyed. This value is higher than values for all other regions of the Cape Hatteras-Nova Scotia shelf. The shoal area of Georges Bank (GB1, Figure 12) is probably the second most productive region of the shelf. Annual production is estimated at 665 gC/m²/yr (Figure 35). The histogram depicted in Figure 36 provides an additional perspective of the NJ1 region. Twenty-six percent (11 daily rates) of the 42 daily productivity integrals measured in the NJ1 area exceeded 3 gC/m²/d. Eight of these 11 high values were measured outside the New York Bight apex in the NJ1 region.

Other regions have proportionately fewer observations greater than 3 gC/m²/d (Figure 36). Additionally, the highest rates of daily phytoplankton production, measured during this survey, (7.5, 8.3 gC/m²/d) occurred within the NJ1 region.

In an earlier study, Thomas et al. (1979) measured a daily production rate of 12.74 gC/m²/d in the vicinity of the sludge dumping area in the New York Bight apex. This value is among the highest recorded in the scientific literature for phytoplanktonic systems.

The histogram in Figure 36 also reveal some interesting regional differences in modal levels of organic production. Many of F-% distributions for the 13 regions have modes either centered at 1.25 gC/m²/d (GM, GB2, Li1, Li2) or two modes roughly symmetric about 1.25 gC/m²/d (Li3, DE3).

Production histograms for NJ1, NJ2, NJ3, DE1 are also bimodal, with a high percent of total observations at 2.25 gC/m²/d. Distributions for the DE2 region and CHI,2,3 region have a strong mode at 0.75 gC/m²/d, lowest among the 13 regions considered. Also apparent from Figure 36 is the difference in modal production values between the shallow area of Georges Bank (GB1, mode = 1.75 gC/m²/d) and the relatively deeper water, greater than 50 m, over Georges Bank (GB2, mode = 1.26 gC/m²/d).

We have not yet applied rigorous statistical analyses or confidence belts to the annual production curves given in Figure 34.

However, some trends appear which will be evaluated in the near future. In the mid-shelf region off Long Island (LI2) and in the mid-shelf region between Cape Henlopen and Cape Charles (DE2) annual production estimates are lower than inshore and offshore regions bordering these two mid-shelf areas (Figures 35 and 12). This trend of high production inshore, lower production at mid-shelf and relatively higher annual production again in regions adjacent to the shelf break, is not seen in the NJ1, NJ2, NJ3 series off the coast of New Jersey.

The three regions ranking lowest in annual carbon assimilation are DE2 (402 gC/m²/yr), LI2 (405 gC/m²/yr), and the Gulf of Maine (GM, 415 gC/m²/yr). Even though annual production in these three areas is relatively lower than production in other areas of the Cape Hatteras-Nova Scotia shelf, it should be stressed that production in these three areas is still greater than that recorded for most shelf ecosystems.

At first inspection, the very high levels of annual production in regions adjacent to the shelf break (LI3, NJ3, DE3) seems at odds with the recurrent pattern of decreasing water column average phytoplankton biomass (chlorophyll *a*) concentration from the shore to the shelf break (Figures 32 and Section 4.1). Euphotic depth increases two to fourfold from the shore to the shelf break. Phytoplankton are considerably more dilute offshore than inshore, however relatively deeper light penetration offshore establishes a deep productive euphotic layer, comparable in integral (m²) production to inshore areas.

Seasonal trends in phytoplankton production parallel the seasonal trends in phytoplankton abundance described in Section 4.1 of this report. High daily rates of phytoplankton production are observed during most of the months sampled and are not limited to "spring bloom" period. Rates measured in February are generally lower, at about .5-1 gC/m²/d (Figure 34). A vigorous October "fall bloom" appears to be a main event in the annual cycle in several regions. Throughout the shelf, production is sustained at high levels (1-2 gC/m²/d) throughout the summer period. This pattern is contrary to the "classical" description of annual cycles of production on continental shelves at temperate latitudes (Ryther, 1953).

4.3 Inorganic Nutrients:

To date, approximately 18,000 samples of seawater have been collected for nutrient analyses (Table 1). Approximately 19,000 separate analyses have been completed. Ammonium, nitrite, nitrate, phosphate, and silicate are routinely analyzed. Table 5 gives the status of our nutrient analyses by survey. Rate of analysis is lagging considerably behind collection rate due largely to lack of laboratory technical support prior to FY 81. Nevertheless, our efforts have been directed at obtaining geographically extensive and frequent collections of seawater throughout the Cape Hatteras-Nova Scotia shelf so that spatially and temporally reliable nutrient baselines may be developed parallel to the development of chlorophyll (biomass) and phytoplankton production baselines. In this report we discuss three pieces of information on nutrients: cross-shelf Hudson Canyon vertical sections depicting ammonium-nitrogen ($\text{NH}_4\text{-N}$) concentrations for seven surveys made during 1979; description of the distribution of nitrate, nitrite, ammonium, and phosphate throughout the shelf area during a survey in May 1979 (DE-79-05); results of a study conducted in September 1980 (AL-80-09) on the flux of nutrients at the seabed.

Presented in Figures 38 through 44 are cross-shelf profiles of ammonia measured along the Hudson Canyon transect during seven surveys. Ammonium nitrogen is the dominant form of inorganic nitrogen in sewage effluents discharged into the New York Bight apex (O'Connors and Duedall, 1975).

Ammonium is also considered to represent recently regenerated nitrogen (Dugdale and Goering, 1967).

Figure 37 and Figures 1 to 11 depict the location of transects and stations occupied during the seven surveys discussed here. In April 1979 a well-mixed water column existed. Ammonium-nitrogen isopleths were generally vertical (Figure 38). Concentrations of $\text{NH}_4\text{-N}$ progressively decreased tenfold from the mouth of the Raritan-Hudson estuary (4.0 $\mu\text{M/L}$) to mid-shelf (0.4 $\mu\text{M/L}$). Low (<0.2 $\mu\text{M/L}$) ammonium levels were measured in the deep water (400-1000 m) of the Hudson Canyon. In May 1979 low concentrations of $\text{NH}_4\text{-N}$ were observed in surface water throughout the transect area (Figure 39). Ammonium isopleths are horizontal, and reflect vertical stratification. In May, the highest concentrations of $\text{NH}_4\text{-N}$ were observed in subpycnocline water ~100-140 km from the coast. The overall pattern observed in June (Figure 40) is similar to the pattern in May, except that very high concentrations (4-9 $\mu\text{M/L}$) were measured near the seabed at the inshore apex station. These high standing stocks are probably the result of estuarine input combined with an accumulation of NH_4 resulting from benthic and subpycnocline nutrient mineralization. In the May and June profiles there is no indication of strong estuarine-offshore gradients in concentrations of NH_4 in apex surface water

as is seen in the March and July profiles (Figures 38, 41). The low concentrations of NH_4 observed in surface water within 100 km of the shore in May and June is probably the net result of relatively high nutrient removal by phytoplankton relative to additions of $\text{NH}_4\text{-N}$ from the estuary and in situ mineralization. In the May, June, and July profiles (Figures 39, 40, 41) NH_4 concentrations increased with depth at mid-shelf stations. These relatively high NH_4 levels at depths of 50-60 m are probably the result of very active in situ mineralization of organic matter and resultant accumulation of NH_4 in subpycnocline mid-shelf water, since the high values observed are bounded on the seaward and shoreward side and above pycnocline by lower concentrations.

Very low concentrations ($<.2 \mu\text{M/L}$) of NH_4 were measured in offshore water at the shelf break in July. This pattern contrasts with the relatively high (2-4 $\mu\text{M/L}$) levels of NH_4 observed at the shelf break in June and August.

In August, the concentrations of $\text{NH}_4\text{-N}$ increased with depth along the entire transect (Figure 42). Again, as was observed in June, low concentrations were found in the surface euphotic layer and high concentrations of $\text{NH}_4\text{-N}$ were found in subpycnocline water in the New York Bight apex.

The lowest levels of $\text{NH}_4\text{-N}$ were measured during the September survey (Figure 43). The only appreciable amount of NH_4 (2 $\mu\text{M/L}$) was found below the pycnocline near the seabed at stations in the apex.

The profile in October reveals high levels of $\text{NH}_4\text{-N}$ (8 $\mu\text{M/L}$) in surface water near the estuary. In October, isopleths of NH_4 concentration are generally less horizontal at mid-shelf compared to the strong layering seen in July and August, when the water column was strongly stratified.

The above series of observations as well as those made by Garside et al. (1976) and Thomas et al. (1979) demonstrate that concentrations of sewage-derived ammonium nitrogen decrease steeply from the mouth of the Raritan-Hudson estuary to the perimeter of the New York Bight apex, about 50 km seaward of the estuary. This does not mean that the full seaward extent of nutrient enrichment is defined by the perimeter of the apex. Ammonium nitrogen may represent the preferred and the predominant form of nitrogen used by phytoplankton in coastal water enriched with sewage (Eppley et al., 1979). Ammonium nitrogen is biologically very labile and consequently not a conservative property, useful in tracing the actual seaward extent of nutrient enrichment of coastal water. Dissolved organic forms of nitrogen discharged into the Bight apex may be as abundant as the combined concentrations of inorganic nitrogen (ammonium, nitrate, nitrite)

entering the apex from the estuary (Thomas et al., 1979). According to the "Expanded Apex Hypothesis" of Thomas et al. (1979), the "initial effects of sewage-derived inorganic nitrogen is the stimulation of autotrophy in the Bight apex. The "unused" apex DON compounds plus the organic compounds photosynthesized in the apex stimulate heterotrophy. However, the full effect of this heterotrophic stimulation ($P/R \ll 1$, and reduced oxygen concentrations) is delayed in time and occurs down the plume of the estuary, seaward of the apex along the New Jersey coast". It should be pointed out that this "heterotrophic stimulation" will generate inorganic nitrogen which is readily assimilated by phytoplankton outside the apex. We need a clearer understanding of the "background" nutrient processes (shoreward and seaward transport, assimilation, excretion, mineralization) and of the distribution of the various forms of nitrogen nutrients before we can evaluate the extent of the role which man's wastes play in stimulating organic carbon production to the high levels reported here for coastal water off New Jersey outside the apex (see section 4.2).

Estuarine neritic sources of nutrients are superimposed on nutrient stocks actively supplied by benthic and water column organic mineralization processes and from inputs to the shelf. This is evident in Figures 38 through 44.

Rates of ammonium flux from sediments of the continental shelf were measured in cores collected on the September 1980 Ocean Pulse survey (AL-80-09) to quantify the potential role which the seabed plays as a source of nutrients. Other nutrients were measured (nitrate, nitrite, phosphate, silicate) but are not discussed here. The shelf-wide distribution of rates of ammonium nitrogen flux at the seabed is presented in Figure 45. Rates (average of rates measured 2-4 seabed cores) of ammonium flux ranged from a maximum of $494 \text{ } \mu\text{mole-N/m}^2/\text{h}$ in the sewage sludge dumping area to $-47 \text{ } \mu\text{mole-N/m}^2/\text{h}$ at the mouth of the Raritan-Hudson estuary. Measured fluxes of $\text{NH}_4\text{-N}$ from the sediment into the overlying interface water in cores taken in September near the mouth of the Delaware estuary were almost equal to rates measured at the New York dump site. Measurements made at the mouths of the Chesapeake and Raritan-Hudson estuaries were lower by at least an order of magnitude (33 and $-47 \text{ } \mu\text{mole/m}^2/\text{h}$, respectively). Generally, rates of ammonium flux were relatively higher at inshore stations than at stations offshore (Figure 45). Generally, excluding estuaries and dump sites, rates were higher on the shelf between Cape Cod and Delaware ($22 \pm 13 \text{ } \mu\text{mole-NH}_4/\text{m}^2/\text{h}$, 95% confidence limits) than areas of the shelf to the north ($5 \pm 1 \text{ } \mu\text{mole-NH}_4/\text{m}^2/\text{h}$) or south ($-3 \pm 4 \text{ } \mu\text{mole-NH}_4/\text{m}^2/\text{h}$).

Several factors influence the rate of ammonium release from the sediment. These include the amount and nature of oxidizable organic matter, bacterial populations, temperature, ambient oxygen concentration and distribution and condition of macrobenthic and meiobenthic fauna.

The amount of organic matter in the sediment is a function of the resuspension of particulate fallout (Hartwig, 1976). Reworking will generally be higher in shallow water than in deeper water. Low energy depressions will tend to accumulate material. The amount of fallout reaching the sediment, on the other hand, will decrease as the depth of the water column increases, partially as a result of slightly lower integral production on the outer shelf, but also because water column regeneration will generally have longer to operate on a descending particle. Mineralization is considered to be essentially complete (ca 95%) in 200-500 m (Menzel, 1974).

The source of the organic matter will affect the rate of mineralization. Phytoplankton, for example, are broken down more rapidly than zooplankton (Iturriaga, 1979). The formation of fecal pellets by zooplankton and filter feeders accelerates deposition although these materials degrade slowly (Carlucci et al., 1970) probably because easily mobilized nutrients are released during digestion. Studies of 14 freshwater algae (Gunnison and Alexander, 1975) and two marine diatoms (Kamutani and Riley, 1979) showed marked differences in cell wall structure. Exogenous material is probably most resistant to degradation having been exposed to extended periods of oxidation during transport. This does not apply to sewage or dredge spoil material which is dumped on the shelf.

The number and species of bacteria present in a sediment will affect the type of conversions which take place and the rates at which they proceed (Carlucci et al., 1970); that is whether ammonium, N_2 , N_2O , nitrite, nitrate is formed from organic nitrogen. The bacterial activity is, of course, temperature dependent (Terry and Nelson, 1975; Nedwell and Floodgate, 1972). Thus, it is not surprising that our most negative ammonium flux ($-47 \text{ ugat/m}^2/\text{hr}$) was found at the mouth of the Hudson estuary which has a large and continuous outflow of ammonium rich water and presumably an inoculum of ammonium oxidizing bacteria. Samples were collected for nitrate and nitrite but have not yet been analyzed. We expect that these fluxes may have been high at this station, offsetting the ammonium consumption.

The high variability among rates of NH_4 flux measured in replicate cores within a station (c.v. = $\sim 180\%$) may be reduced when the combined flux of three forms of inorganic nitrogen is considered. This was the case in three bell jar experiments off the northwest coast of Africa (Rowe et al., 1977). They found ammonium fluxes of 110, 235, and 360 $\text{ugat/m}^2/\text{hr}$, while the sums of inorganic nitrogen fluxes were 460, 410, and 360 $\text{ugat/m}^2/\text{hr}$ respectively. The release of other forms of nitrogen (e.g. N_2 and soluble organic nitrogen) may further ameliorate the disparities between cores at a station. Finally, on the question of intrastation variability, at this point we have made no attempt to exclude cores in which a few macroinvertebrates were found. Their contribution may be considered a part of the mineralization process, however; in at least one core, fragments of an asteroid were found. As this

animal is ammonotelic, dismemberment can be expected to greatly increase the observed ammonium flux.

The ammonium flux values we found over most of the shelf (except areas of high estuarine and waste dumping influences and the low energy, high sedimentation area of the Hudson Shelf Valley adjacent to both of these) ranged from -8 to 30 $\mu\text{g}/\text{m}^2/\text{hr}$. This is considerably below the rates measured by Rowe et al. (1977) off northwest Africa (ca 400 $\mu\text{g}/\text{m}^2/\text{hr}$) or those estimated by Rowe et al. (1975) for the New York Bight (144 $\mu\text{g}/\text{m}^2/\text{hr}$) from the water column gradients. On the other hand, our values for September 1980 in Buzzards Bay (56 $\mu\text{g}/\text{m}^2/\text{hr}$) is fairly close to the 69 $\mu\text{g}/\text{m}^2/\text{hr}$ reported for November 1973 (Rowe et al., 1975); especially in view of the fact that while the rates of oxygen consumption were 23 and 22 $\text{ml}/\text{m}^2/\text{hr}$, the temperatures were 7.7 and 20.2°C respectively. It is likely that most of our shelf values represent an intermediate state of ammonium flux in a seasonal cycle which has its minimum in late winter, when fallout and temperature are lowest, and its maximum following plankton population collapses (March-June) and sediment warming (July-August).

The significance of mineralization in the sediment as a nutrient source for plankton productivity has been suggested to range from over 30% of their requirements inshore, to less than 20% at the shelf break (Harrison, 1980). In September, rates of daily phytoplankton carbon production in the shelf are about 1.4 $\text{gC}/\text{m}^2/\text{d}$. If one assumes that phytoplankton assimilate nitrogen and carbon at an atomic ratio of 6.63C:1N, then the daily N requirements of phytoplankton are 17,610 $\mu\text{moles}/\text{m}^2/\text{d}$.

Rates of ammonium flux from sediments in September (roughly equal to 10 $\mu\text{mole}/\text{m}^2/\text{h}$) is equivalent to about 1.4% of the nitrogen required by phytoplankton. If ammonium flux represents a third of the total dissolved inorganic nitrogen flux, then this percentage is elevated to 4%. The highest ammonium flux rates observed in September (300-500 $\mu\text{mole}/\text{m}^2/\text{hr}$) are equivalent to 40 to 68% of the daily assimilation of nitrogen by phytoplankton. Walsh (1980) estimated that approximately 46% of the annual nitrogen demand of phytoplankton in the New York Bight is supplied by recycling mineralization processes.

Studies of the New York Bight and Georges Bank (Thomas et al., 1978, 1979) have pointed out that organic mineralization in the water column may represent a major source of recycled nutrients. More shelf-wide baseline studies of heterotrophic metabolism and of nutrient mineralization are needed to quantify the relative importance of the seabed, and overlying water column as sources of nutrients capable of sustaining the high levels of organic production performed by phytoplankton throughout the shelf over most of the year. Though we have not yet determined the concentrations of nitrite, nitrate, phosphate, and silicate in seabed

cores from the AL-80-09 survey, in the near future we will be evaluating the usefulness of seabed nutrient flux data as a sensitive indicator of changes in the magnitude (flux rate) as well as changes in the type (ratio of $\text{NH}_4:\text{NO}_3$, DIN:DON, etc.) of benthic metabolism.

The following section discusses the distribution of nitrate, phosphate and ammonium measured during a survey of Cape Hatteras to Nova Scotia shelf water in May 1979. On the DE-79-05 survey the largest of dissolved inorganic nitrogen (DIN) observed was in the form of nitrate. This was in water near the edge of the continental shelf generally at depths greater than 100 m. The approximate ranges were 8-15, 15-25 and 20-50 $\mu\text{mole/l}$ at 100, 200 and 300 m respectively, along the entire shelf from Cape Hatteras to the Northwest Channel including the Gulf of Maine. At deep water stations (bottom >300 m) nitrate occasionally was found in quantity (8 $\mu\text{mole/l}$) to a depth of 35 m while shoreward, in 75 m of water, concentrations were 3-5 $\mu\text{mole/l}$ at 30 m. Above this depth, in the euphotic zone, concentrations of nitrate were generally low. To the south of Cape Cod, nitrate depletion was generally throughout the water column at stations having bottom <50 m. Although occasional concentrations of 0.5-2 $\mu\text{mole/l}$ were found at the bottom in association with ammonium (perhaps as the result of benthic regeneration).

On Georges Bank the situation was quite different. In May 1979, upper water column nitrate values were generally 0.8 to 3 $\mu\text{mole/l}$ at shallow stations. Nitrate increased to 6-8 $\mu\text{mole/l}$ lower in the water column and, at some stations, decreased below the detection limit near the bottom. An exception to this generalized nitrate profile was seen at station 122 at the center of Georges Bank (Figure 5). There, nitrate levels were near zero throughout the water column.

Concentrations of nitrate in the upper water column in the Gulf of Maine (0-4 $\mu\text{mole/l}$) in May 1979 were generally higher than upper water column levels of nitrate in the Mid-Atlantic Bight. Relatively high concentrations of nitrate were measured below 50 m in the Gulf of Maine. Water in the Southwest Channel was distinctly different from surrounding water in May. It contained less than 1 $\mu\text{mole nitrate/l}$, uniformly, from surface to bottom, in waters up to 100 m depth. One interpretation of this distributional pattern is that no large portion of the large nitrate pool in the Gulf of Maine was passing through the Southwest Channel at the time of the May 1979 survey.

South of Chesapeake Bay, ammonium was relatively concentrated in the upper water column (1-4 $\mu\text{mole/l}$), decreased through the middle and tended to increase again toward the bottom. In the upper water column, over the remainder of the survey area, ammonium concentrations were below 1 $\mu\text{mole/l}$.

In bottom water at stations of less than 100 m depth, ammonium concentrations generally increased from south to north, from Virginia to Long Island, then decreased from there northward. The highest concentration was found at station 67 (6.2 $\mu\text{mole/l}$) near the bottom. Throughout the shelf, during the May survey, ammonium concentrations generally were much greater below than above the developing pycnocline. It is clear from the discussion of the cross-shelf ammonium sections that this pattern reflects the onset of extensive subpycnocline ammonium production. At the shelf edge, the ammonium maximum was located in mid-water column, typically near the upper extent of the deep water nitrate intrusion.

The most notable feature of the phosphorus data for this survey is the paucity of inorganic phosphorus south of Delaware Bay. At six stations no phosphorus was detected and was detected only at the bottom depth at four additional stations sampled in this area.

Inorganic phosphorus values in the remainder of the study area were generally higher. Water on Georges Bank contained 0.2 to 0.4 $\mu\text{mole/l}$ at the surface.

The highest values (up to 1.5 $\mu\text{mole/l}$) were found in the deeper water at the shelf edge and in the Gulf of Maine in association with the high nitrate concentrations.

4.4 Trace Metals:

In this section of the report we discuss the shelf-wide distribution of trace metals in sediments collected during seven NEMP surveys (see Table 1 and Section 5). Over 800 samples of sediment were analyzed for six metals, cadmium, chromium, copper, nickel, lead, and zinc. In Figures 46 through 87 we present distributional maps of these metals in sediments. The data are in units of ppm dry weight. Data are plotted at the sampling location. Subscripts are the number of replicate Smith-McIntyre grabs taken at a station (one metal core/grab). Superscripts indicate the coefficient of variation among replicate grab samples. We are interested in variability and sampling error at all stages of sampling and analysis. During the AL-80-09 survey, three replicate cores were taken (middle and opposite ends of the grab) from each grab sample to better define small spatial scales of variability. Superscripts in figures for the AL-80-09 survey represent C.V. percent among replicates taken within a grab.

To simplify discussion of distributional patterns of metal concentrations in sediments, we have partitioned the observed range for each metal into "low", "medium" and relatively "high" levels (Table 6). Below we summarize data in Figures 46-87 for each of several areas of the shelf.

Along the Chesapeake Bay transect (4 surveys) relatively "low" levels have been observed for all six metals analyzed. No readily discernible onshore-offshore patterns are evident from the data.

Along the Delaware Bay, onshore-offshore transect (7 surveys) relatively low levels are also observed for all six metals. Again, no strong recurrent pattern emerges. There is, however, some indication in the data of higher levels at stations near the shelf break and mid-shelf than at inshore stations away from the mouth of the estuary. This trend is seen for chromium in Figures 53, 54, 55, 57, 59; for copper in Figures 60, 61; for nickel in Figures 67, 68, 69, 71; for lead in Figures 74, 75, 76, 78; and for zinc in Figures 81, 82, 83. Harris et al. (1977) reported a west to east increase in metal concentration in an area just north of our Delaware Bay cross shelf transect.

Along the cross shelf transect off Block Island, "medium" concentrations have been found for all six metals analyzed. In this area we find a recurrent pattern. Highest concentrations usually exist inshore. Relatively low concentrations exist at mid-shelf and high levels are again seen in outer shelf sediments. The coefficient of variation among replicate grabs is high but variable inshore, high at mid-shelf, and low at the outer shelf station. The relatively high sediment metal concentrations inshore near Block Island may be attributed to that area's proximity to shore and the mouth of Long Island Sound. Sediment collected in Long Island Sound during the KE-79-10 survey had relatively high concentrations of all six metals (Figures 49, 56, 63, 70, 77, 84).

One would expect the mid-shelf station to exhibit lower, more highly variable metal concentrations since it is further offshore and the area should be swept by westerly and/or southwesterly currents originating in the Georges Bank area (Warsh, 1975). But that leaves unexplained the relatively high levels found in the outer shelf station, levels comparable to those found at the sludge dumping site in the New York Bight apex. Bumpus (1972) describes surface circulation in the Mid-Atlantic Bight region as a two part system, separated by the Hudson Canyon. The area northeast of the Hudson Canyon receives indrafts from below Nantucket. These move westward, and finally southward off the shelf into slope water northeast of the Hudson Canyon. Meade (1969) indicates that bottom waters moving toward the mouths of estuaries transport sediments that are similar to those found offshore. Examination of our sediment data from stations along the Hudson Canyon reveal high metal levels from the Bight apex to the edge of the shelf. Sediments in Great South Channel have elevated levels of metals. Great South Channel may be the source of contaminants found at the Block Island transect stations, but this is not reflected in our data from the mid-shelf area. With these observations in mind, perhaps sediments are transported by slope water from the Hudson Valley area to the Block Island outer shelf area, although Reid (1981, personal communication) indicates that the source of the fine-size sediment at the Block Island outer shelf is thought to be Georges Bank. This silt-clay is deposited at the outer shelf rather than the mid-shelf because the latter is too shallow and mixing energy is too great to allow the sediment to settle. This seems to contradict Wigley (1961), however, who found that the sediments of Georges Bank are comprised mostly of medium sand.

Sediments on Georges Bank contained relatively low concentrations of all six metals during the four surveys of this region. During the September 1979 survey (AL-79-10), lowest metal concentrations on Georges Bank were observed near the northeast corner whereas highest levels were observed in the southern station near the 200 m isobath (Figures 55, 62, 76, 83). Our observations on Georges Bank are consistent with the nature of this area - offshore, relatively shallow, well mixed water, and a seabed generally of medium sand. High metal concentrations and high levels of organic contaminants (Boehm, 1980) are usually associated with sediments having fine particle-size composition and high organic carbon content (Harris et al., 1977).

The Gulf of Maine has been sampled during three surveys. Areal and temporal sampling has been sparse. Areas sampled include Jeffrey's Ledge, a site off Portland, Maine, one east of Boston in Massachusetts Bay, and a station in the deep area (260 m) of the Gulf. In general, "medium" concentrations of all metals (Table 6) have been observed in these sediments. Concentrations of metals in sediments at the Jeffrey's Ledge site appear to be lower than levels in other sediment samples in the Gulf of Maine (Figures 55, 62, 76, 83) during the AL-79-10 survey.

The highest concentrations of metals are found in sediments in the New York Bight apex and at stations along the Hudson Shelf Valley. High contaminant levels exist throughout the Christiaensen Basin. The highest levels seen in this study are found at the sludge dumping site and at the sludge settling site in the Christiaensen Basin. Data from selected sites in the New York Bight apex collected during shelf-wide surveys as well as data collected during an intensive summer 1980 survey (KE-80-07/08) of the New York Bight are compared with an earlier 1973-1974 apex study in Table 7. Trace metal concentrations in these data sets are comparable to concentrations published by Carmody et al. (1973). In our 1979/1980 data and the earlier data of Carmody et al., metals in sediments decrease from the Hudson Valley area to the Hudson Canyon. Metal levels in sediments near the canyon are relatively higher than adjacent areas.

Sediment metal concentrations measured in the apex in August 1980 (KE-80-07/08) are closer in magnitude to levels measured in August 1973 than in August 1974. It appears from the 1980 data set that the distributional pattern of sediment metals in the apex has not changed significantly over the past five years. Sediments at the sewage and dredge disposal sites having "medium" to "high" levels of metal contaminants in 1973/1974 (SYMAP #33, 36, 35, 34) have similar levels in 1980 (KELEZ #6, 4, 40, 5). Sediments in the apex having "low" to "medium" levels of metals in 1973/1974 (SYMAP #39, 40, 59) have similar levels in 1980 (KELEZ #41, 42, 43) (Table 7). The correlation between high contaminant levels, high organic matter content, and fine particle size in sediments is widely accepted (Harris et al., 1977), and unpublished data (Reid, pers. com) appear to support this relationship. The relationship apparently does not apply to sediments at the sludge settling area. Evidently, contaminant levels in this area are associated with sewage treated sludge of larger particle size, relatively high organic content, but metal concentrations an order of magnitude higher than expected from the sediment size-contaminant relationship (Table 8).

5. Inventory of Data Acquired

Table 1 lists data acquired by members of this investigation. In this report we present data on chlorophyll a distribution collected from October 1977 to December 1979, data on phytoplankton organic production collected from August 1978 through March 1980, data on seawater nutrients from a survey in May 1979, data on ammonium from six transects of the Hudson Canyon (May 1979-October 1979), and data on trace metals in sediments collected on seven surveys conducted between spring 1978 and September 1980.

6. Statement of Problems:

A considerable quantity of data on chlorophyll a, phytoplankton production, nutrients and trace metals has been collected by members of this investigation. This is evident in Table 1. For efficient and timely graphical and statistical (univariate and multivariate) depictions and analyses, it is necessary to establish a large data matrix (by date, location, depth, survey, etc.) which can be accessed easily by scientific staff. The ADP unit at Sandy Hook has been understaffed. Only recently, within the last three months, through the hiring of an additional senior programmer, have we been able to effectively address the need to manipulate and extract computer-calculated-archived field data. Presently we are constructing a data matrix which couples chlorophyll production and nutrient baseline data. We hope to be "up and running" by March 1981.

A similar matrix is planned to unify benthic related data (trace metals, benthic species, physiological assays, seabed oxygen uptake, bottom water inorganic and organic chemical assays) collected during NEMP surveys. The lack of these matrices and related user programs has hampered the development of this annual report.

A second problem concerns the very slow "turn around time" for data on phytoplankton production. Presently there is a period of 8-9 months delay between the end of a survey and the generation of data on ¹⁴C-primary production. At least six months of the delay is the result of a "bottle neck" in liquid scintillation counting. Our counter is operational full time, but cannot keep pace with collection rate. The solution to this problem is to purchase an additional liquid scintillation counter, and continue to make frequent measurements of phytoplankton production in the NEMP region. Furthermore, our present liquid scintillation counter is eight years old and according to Packard Instrument Company, approaching the end of its expected "lifetime" in terms of the functioning of the counter as well as in terms of the company's ability to continue to supply parts for this model.

A third problem, technical in nature, is the analysis of dissolved organic forms of nitrogen and phosphorus in archived frozen samples of seawater filtrates collected during most of the surveys from the April 1974 Advance cruise to present. These samples will be extremely useful in constructing budgets for nitrogen and phosphorus and useful in mapping organically bound nitrogen in coastal water adjacent to estuaries. In the Mid-Atlantic Bight, we expect to perform these determinations using a continuous ultraviolet digestion module connected in-line with our Technicon Autoanalyzer. We feel that analytical precision and sensitivity are highest when using U.V. methods. In earlier tests on the oxidation efficiency of the photoreactor, we achieved 99% efficiency in the mineralization of urea to nitrite/nitrate. Urea represents a class of organics naturally occurring in seawater and particularly refractory to digestion. A major technical problem, heat buildup in the U.V. reactor system, has hindered these analyses. Recent modifications in the cooling system resulted in our

first successful run a few weeks ago. More testing is needed (residence time, flow rates, testing oxidation efficiency for a variety of organic compounds naturally occurring in seawater, etc.) but we feel we are close to having a functional system.

Another problem concerns the need to learn more about short-term variability in standing stocks of nutrients in shelf water. Most surveys during which water samples were collected for nutrient analysis have been primarily designed for marine monitoring. The Evrika 80-02 survey departs from others in that it is more site-specific. Its experimental design provides for a complete series of physical-biological observations at frequent intervals in waters on Georges Bank known to contain high numbers of larval gadids in order to study factors which contribute to larval survival and year class success. For nine days water samples were collected at the study location (Figure 9). Thus far, only the analyses for ammonium have been accomplished. Differences between the 0600 and 1100 EST observations for most days over the period sampled show substantial decrease in the ammonium present indicating uptake by phytoplankton. When analyses of the other nutrients are complete correlations and associations with productivity and biomass will be explored. During the multidisciplinary monitoring surveys, it is not feasible to remain on site to investigate temporal scale of variability of seawater parameters, since a large area of the shelf must be surveyed in a relatively short period of time. Research vessel time is scarce. However, if other NEMP investigations have similar needs, perhaps a special survey might be designed which focuses on this dimension of the baselines being developed by NEMP.

It has been difficult to consistently obtain seabed and tissue samples for trace metal analyses in certain areas of the shelf sampled during the Ocean Pulse surveys. During the seven surveys of trace metals discussed in this report, the Chesapeake area has been sampled four times, the Gulf of Maine three times, and sampling on Georges Bank has been scanty. More ship time is needed for the Ocean Pulse monitoring surveys to effectively survey the NEMP region.

Results of our work surveying trace metal levels in sediments have pointed out the unexpected presence of shelf areas (near the shelf break off Block Island, see Figure 55) which have relatively high levels of metals. Further sampling in and around these areas is needed to quantify the area encompassed by high trace metal concentrations. Similar patches or even large areas having relatively high trace metal levels may exist elsewhere on the shelf but have gone undetected with the present Ocean Pulse station pattern. We suggest that a one-time survey be conducted, where sampling intensity approaches 300-400 stations/shelf, an intensity slightly greater than the NEFC MARMAP I effort. If a survey similar to the Gulf-Atlantic Survey (GAS I, Albatross 80-01) of hydrocarbon distribution in fish tissue and sediments is planned, then we suggest that parallel intensive sampling of trace metals and hydrocarbons be conducted in relation to the sediments.

7. Figures

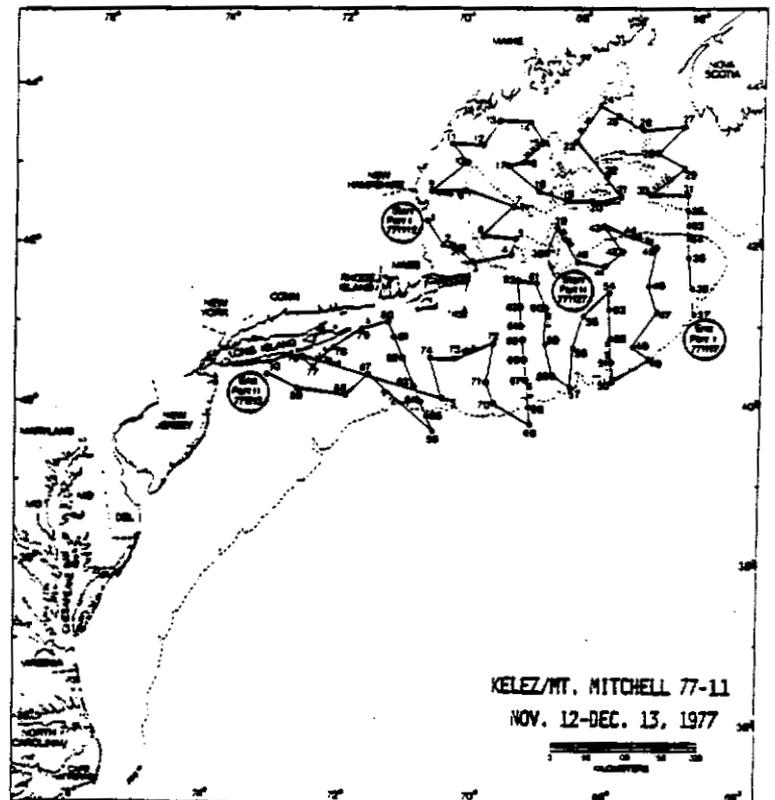
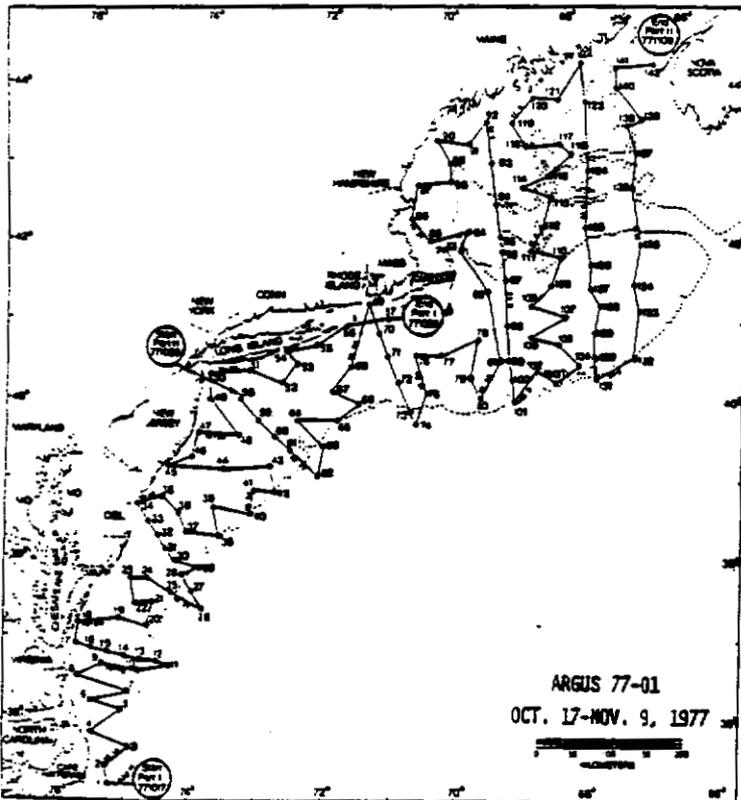
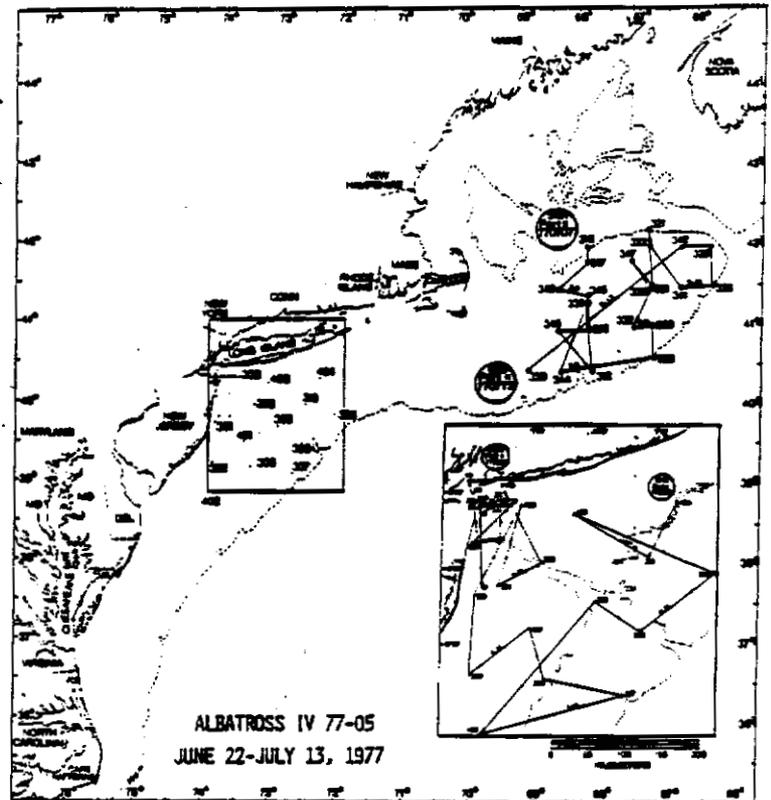
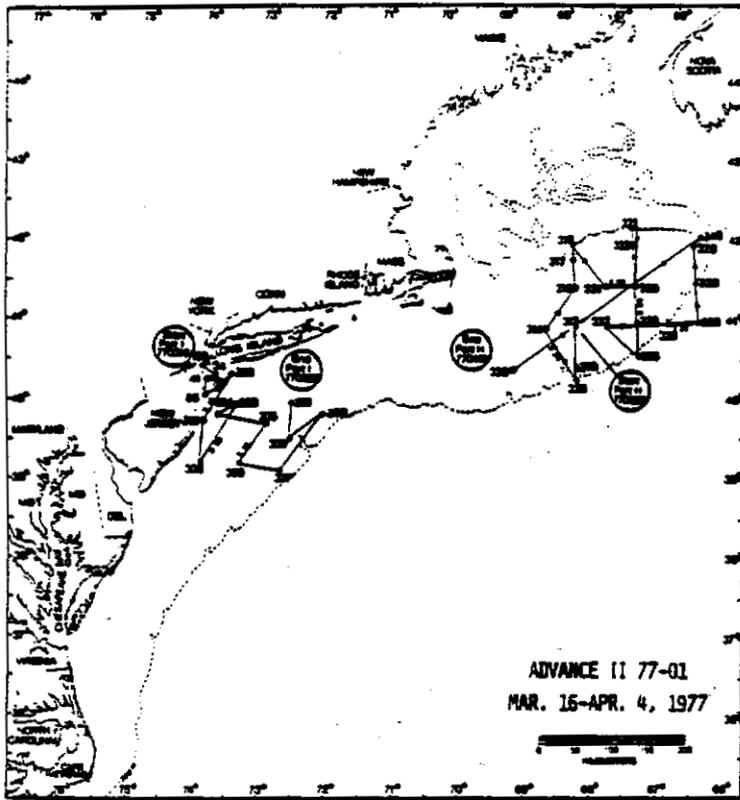


Fig. 1. Cruise tracks for ADVANCE II 77-01, ALBATROSS IV 77-05, ARGUS 77-01, and KELEZ/MT. MITCHELL 77-1.

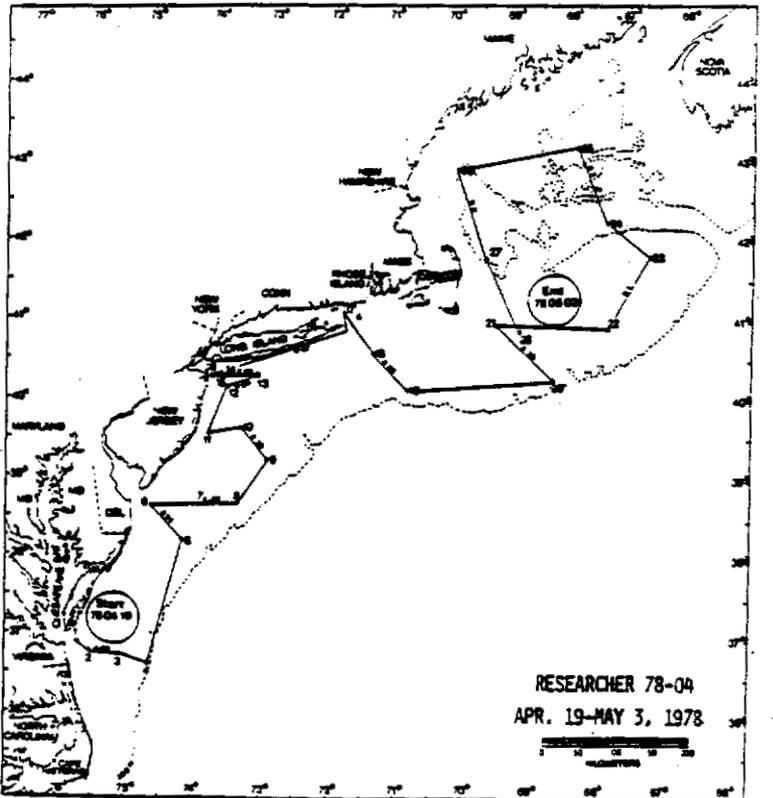
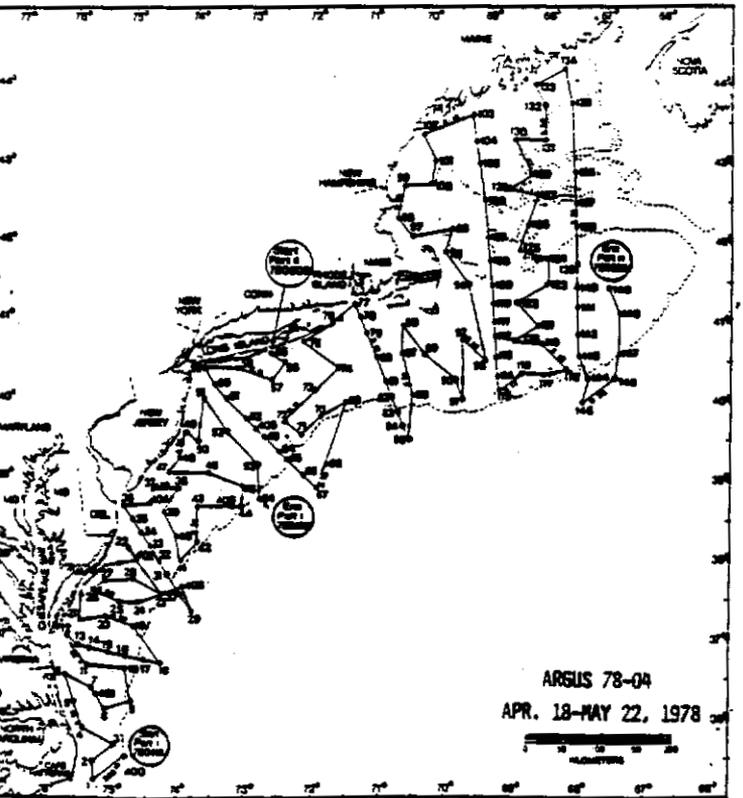
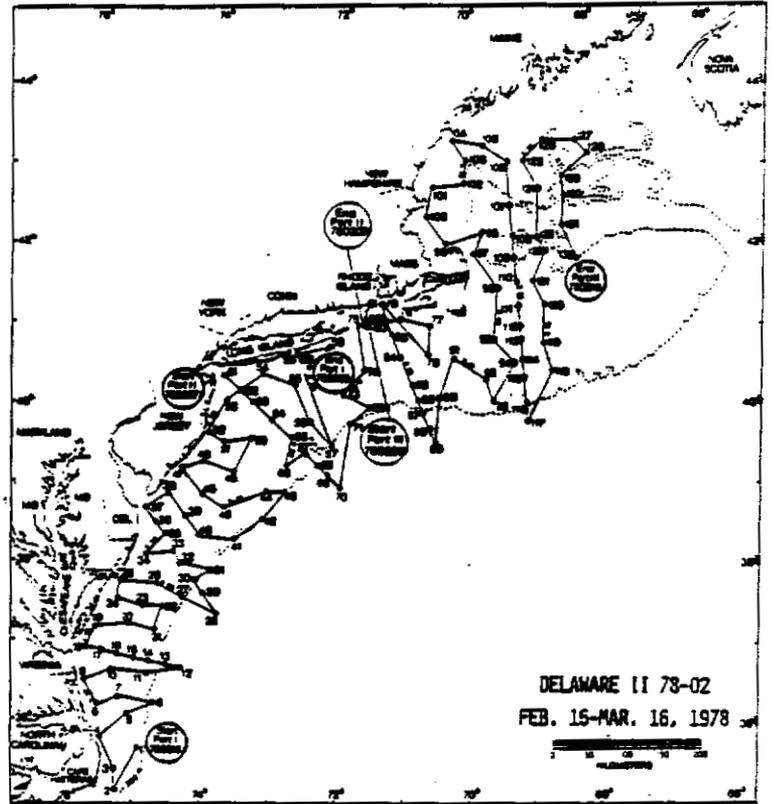
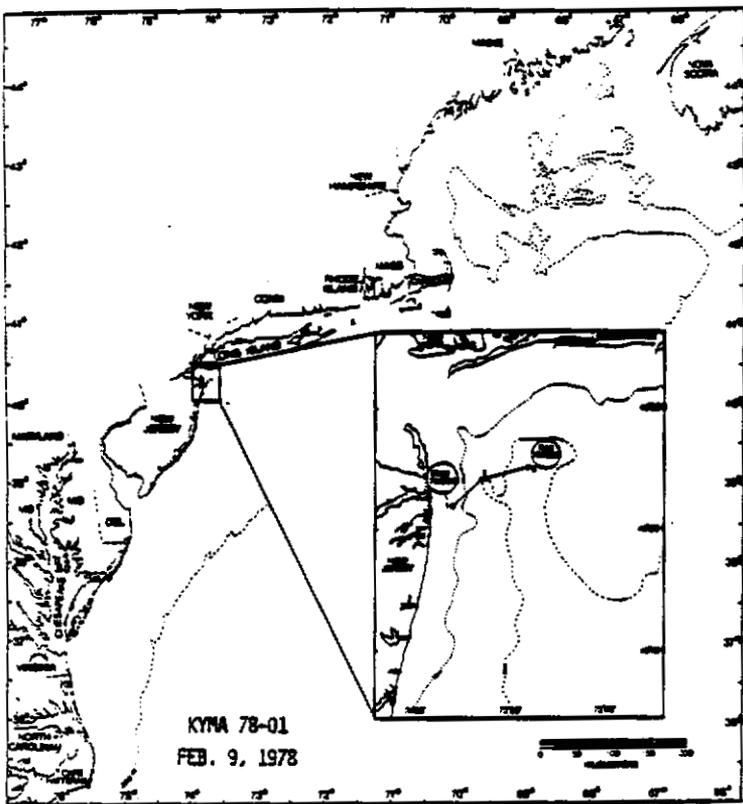


Fig. 2. Cruise tracks for KYMA 78-01, DELAWARE II 78-02, ARGUS 78-04, and RESEARCHER 78-04.

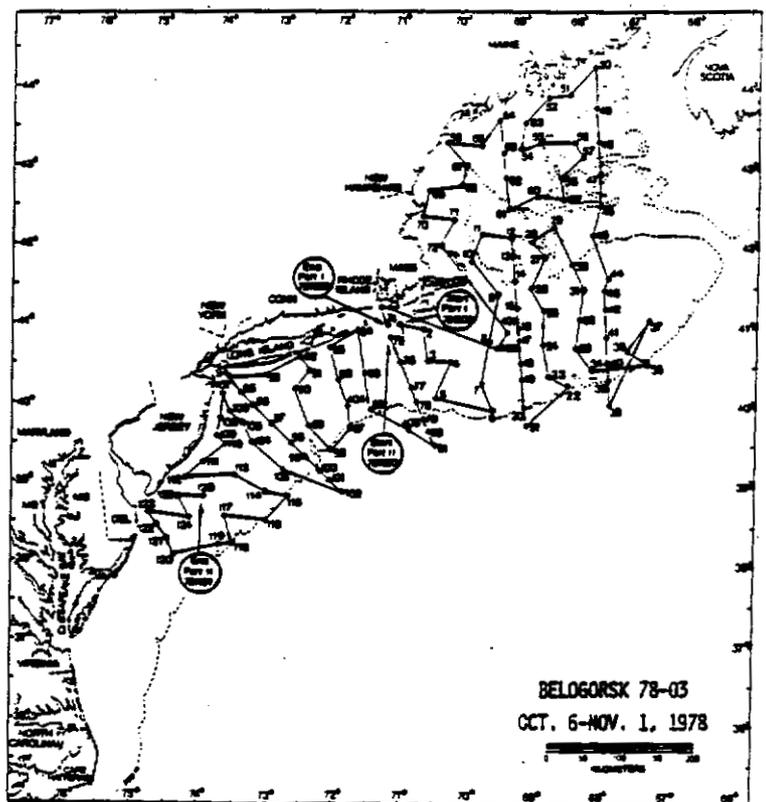
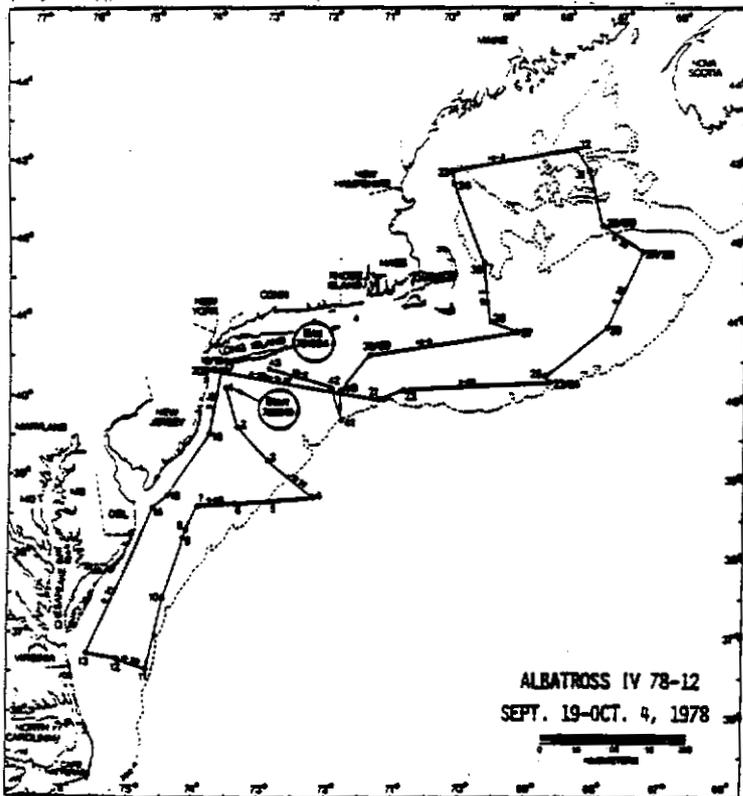
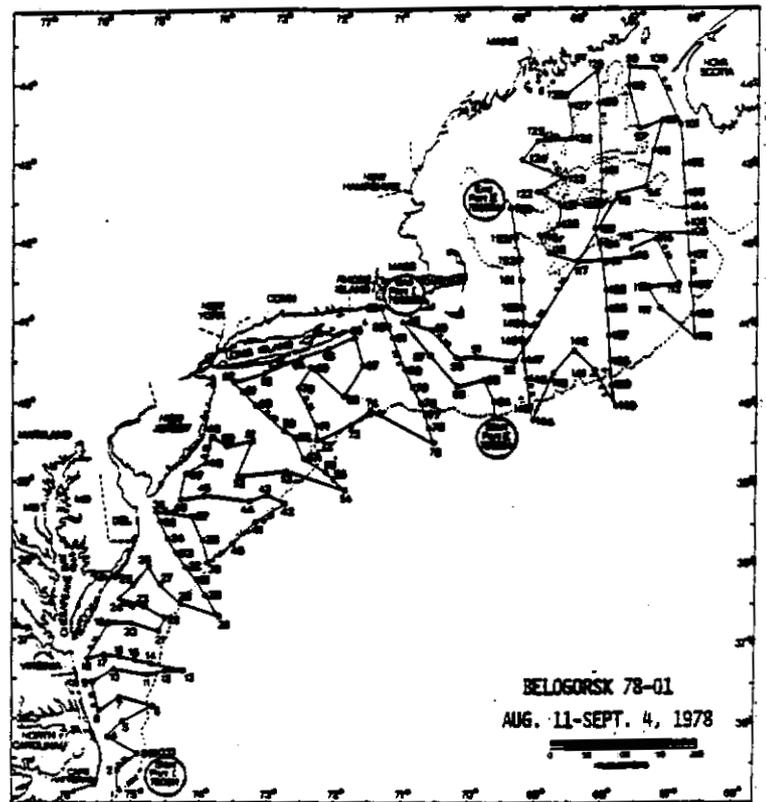
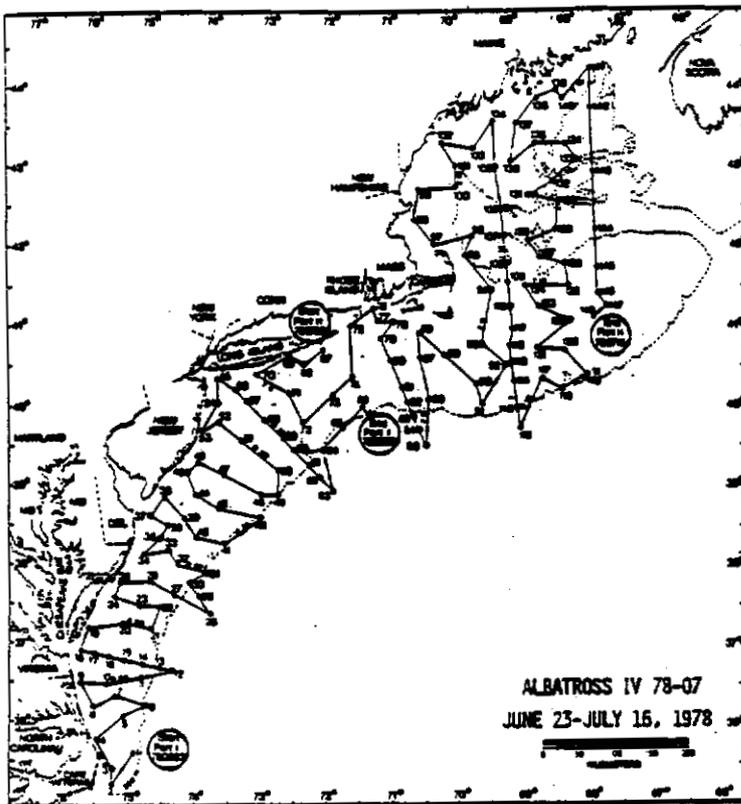


Fig. 3. Cruise tracks for ALBATROSS IV 78-07, BELOGORSK 78-01, ALBATROSS IV 78-12, and BELOGORSK 78-03.

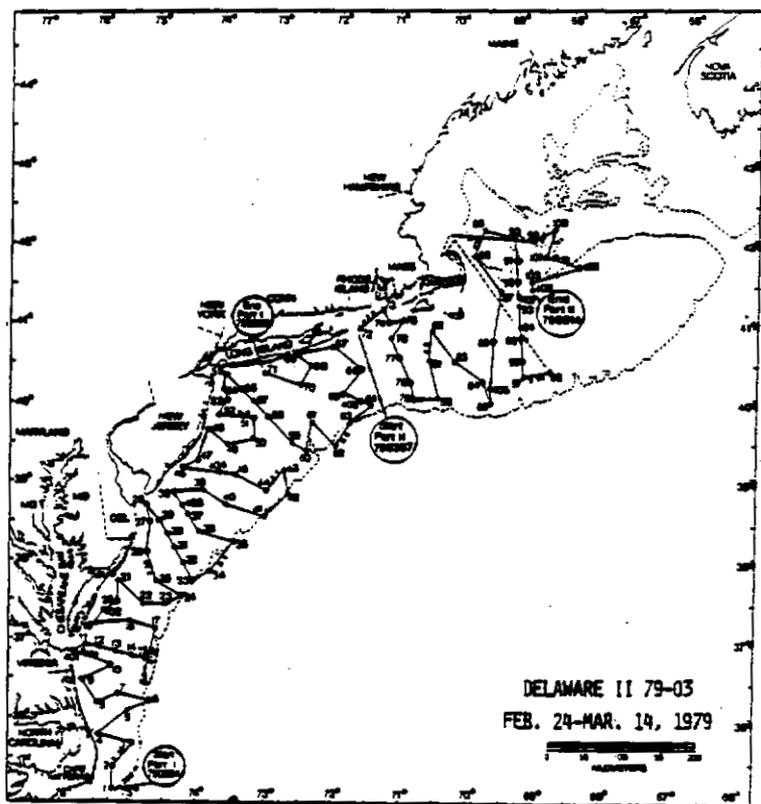
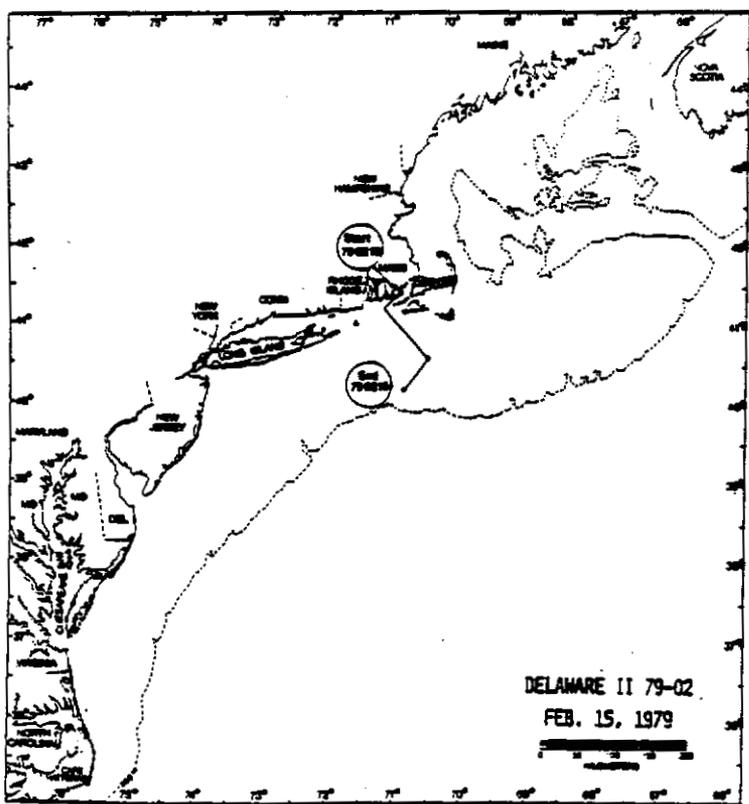
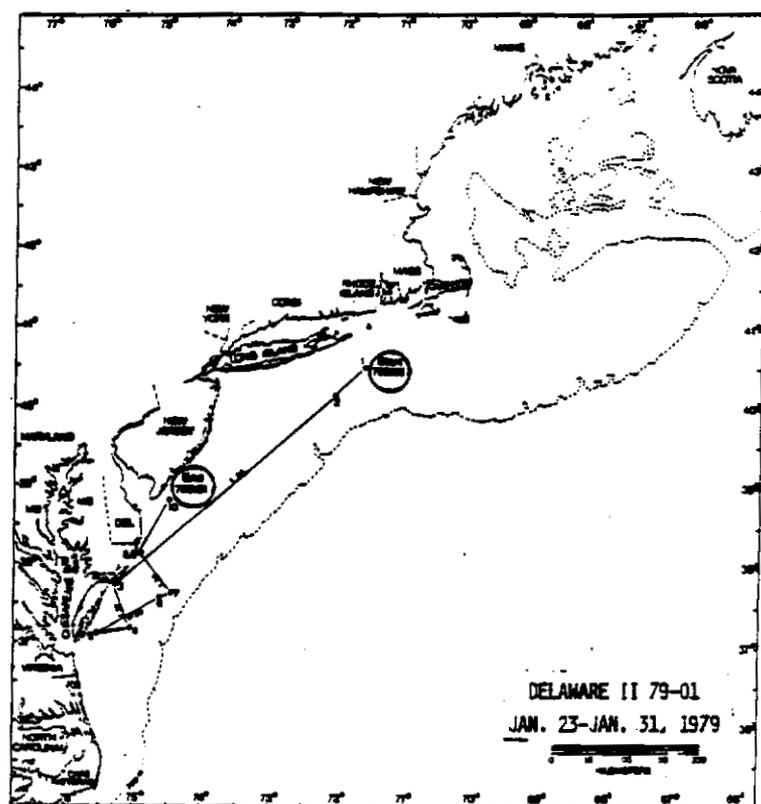
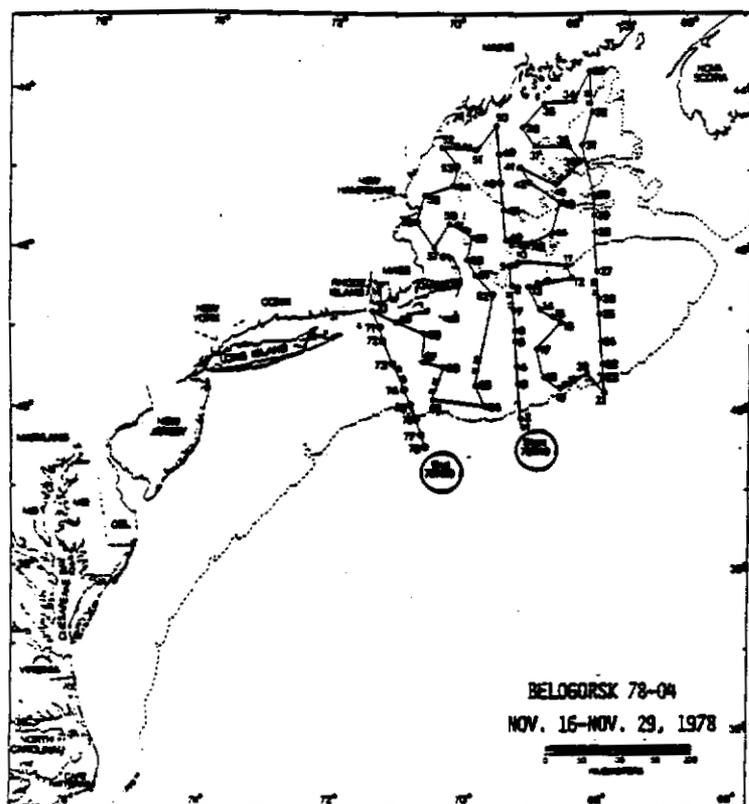


Fig. 4. Cruise tracks for BELOGORSK 78-04, DELAWARE II 79-01, DELAWARE 79-02, and DELAWARE II 79-03.

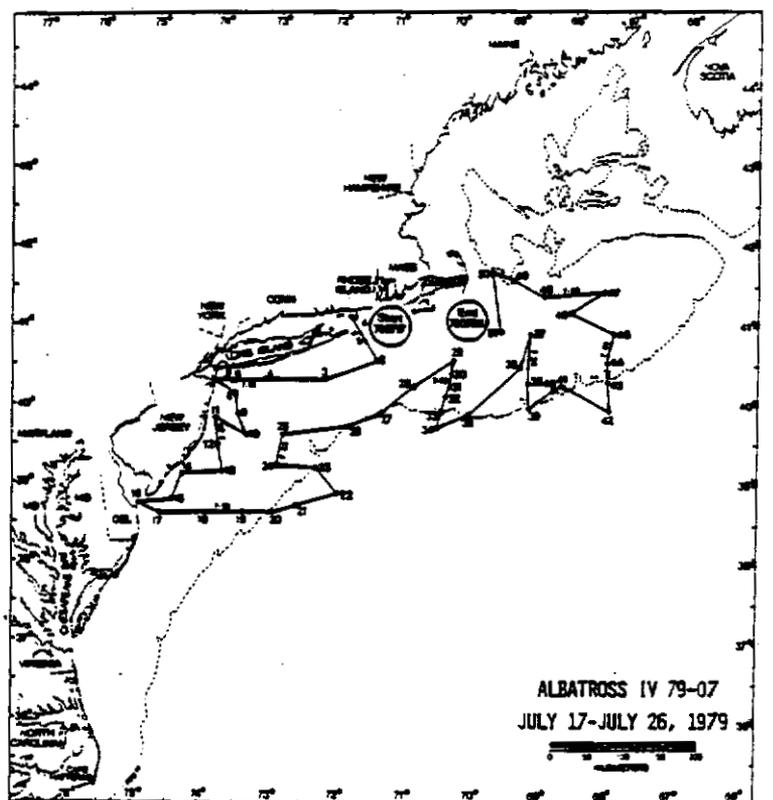
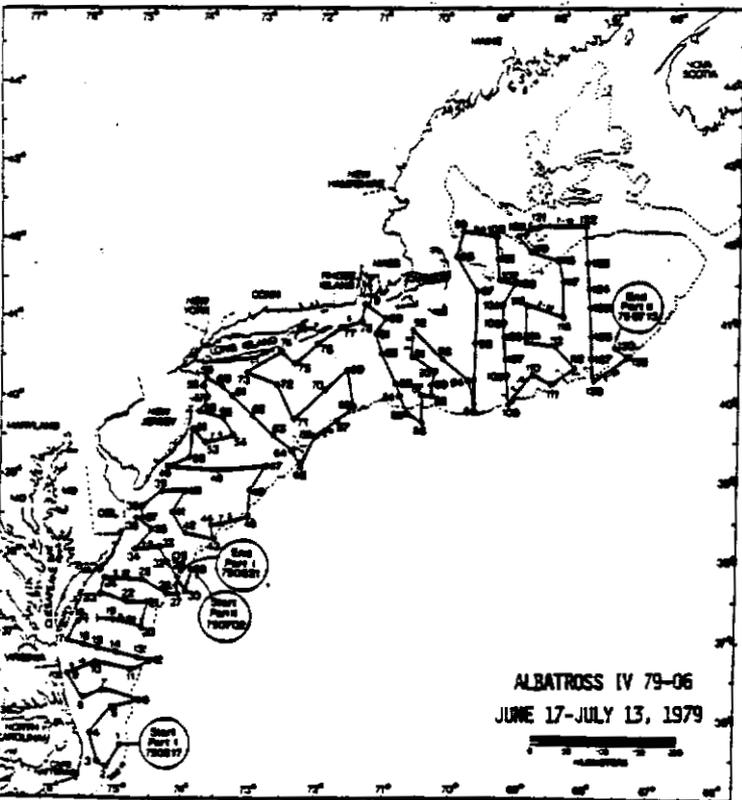
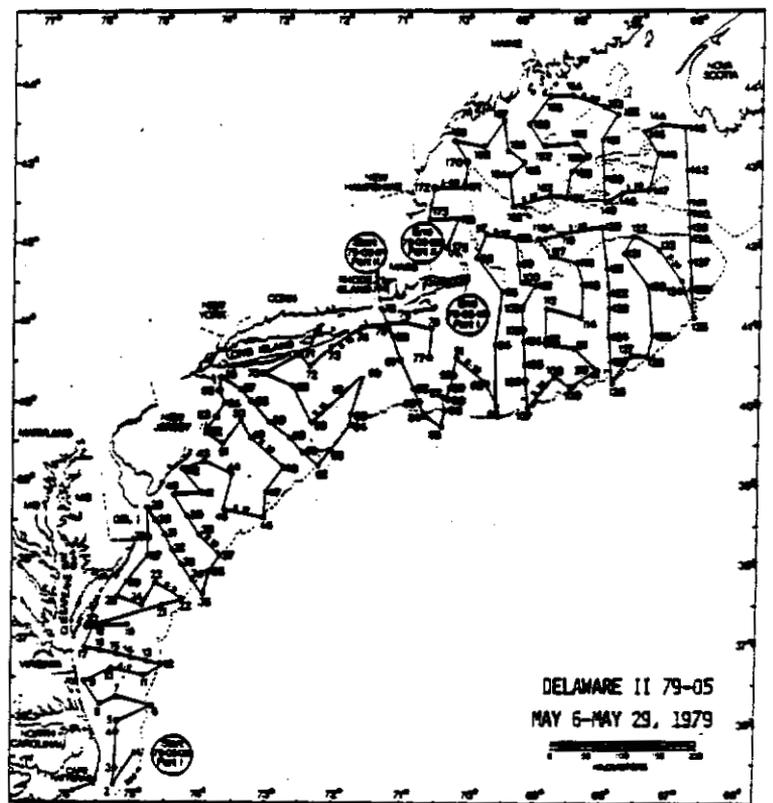
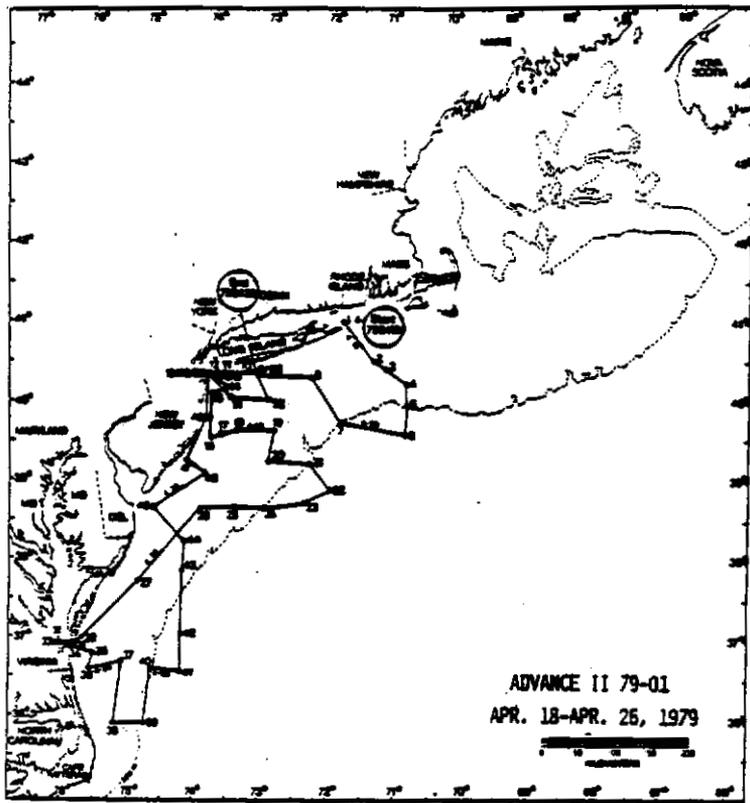


Fig. 5. Cruise tracks for ADVANCE II 79-01, DELAWARE II 79-05, ALBATROSS IV 79-06, and ALBATROSS IV 79-07.

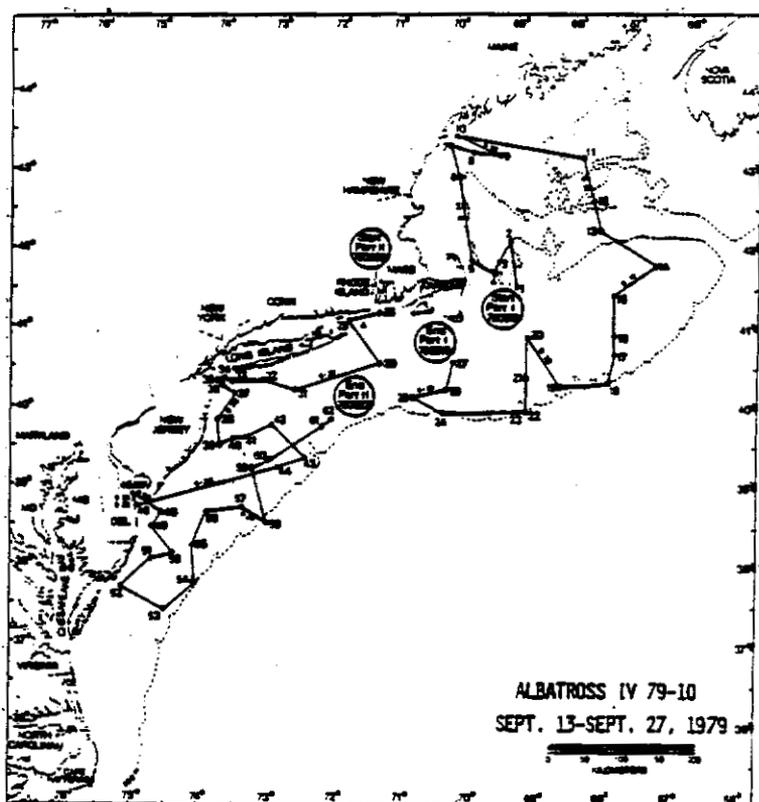
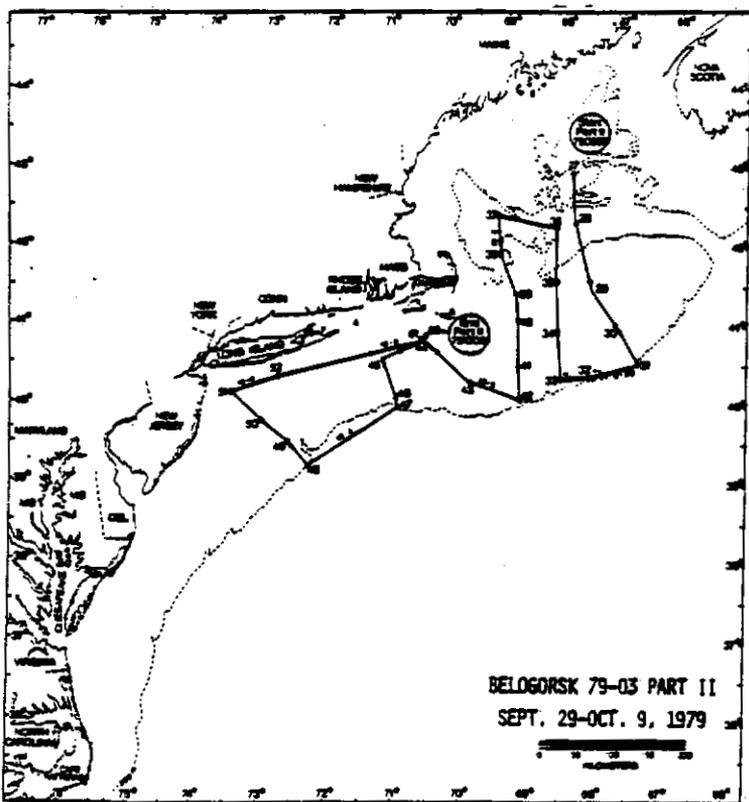
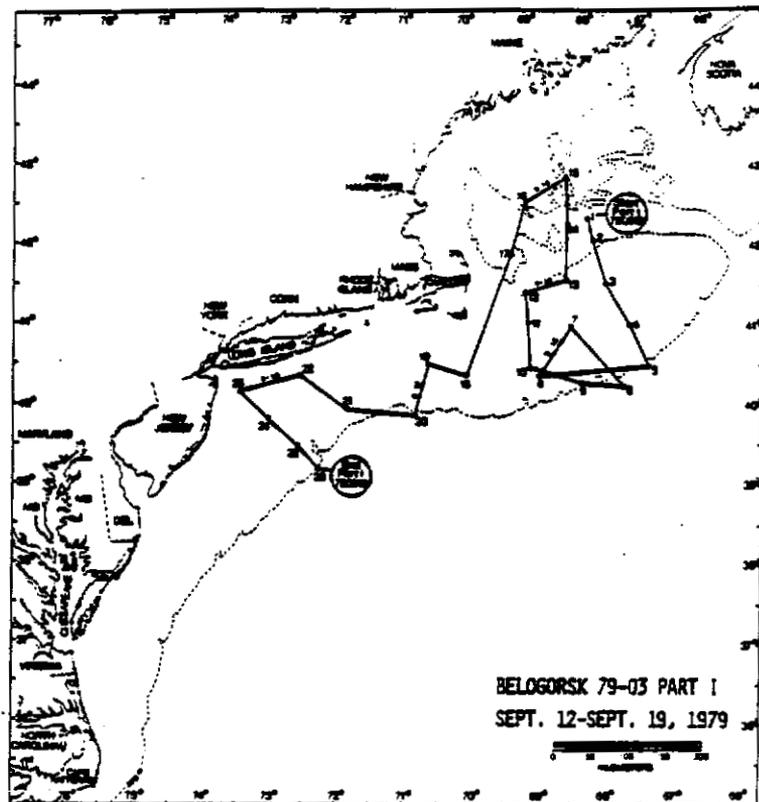
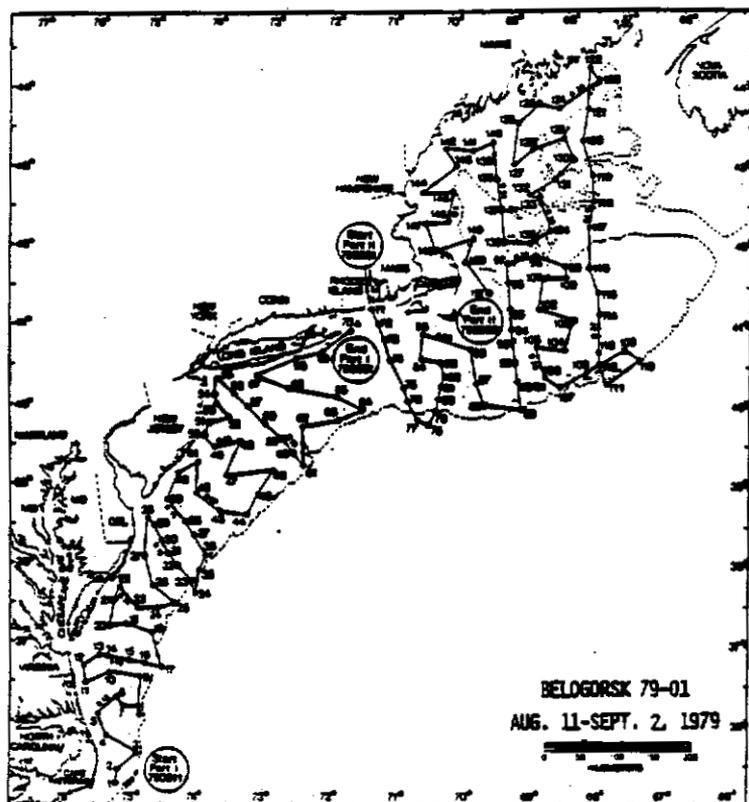


Fig. 6. Cruise tracks for BELOGORSK 79-01, BELOGORSK 79-03 Part I, BELOGORSK 79-03 Part II, and ALBATROSS IV 79-10.

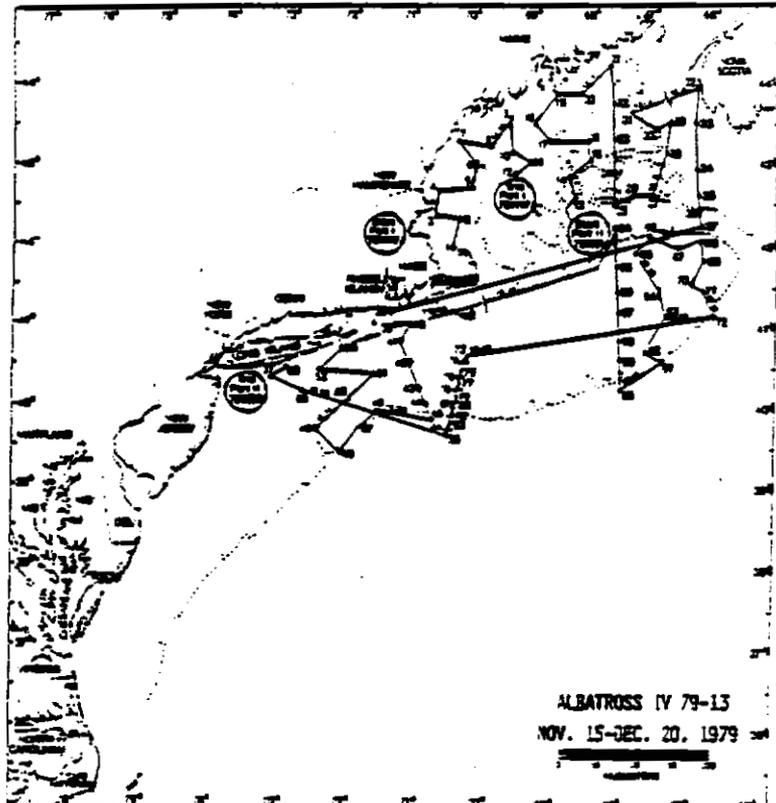
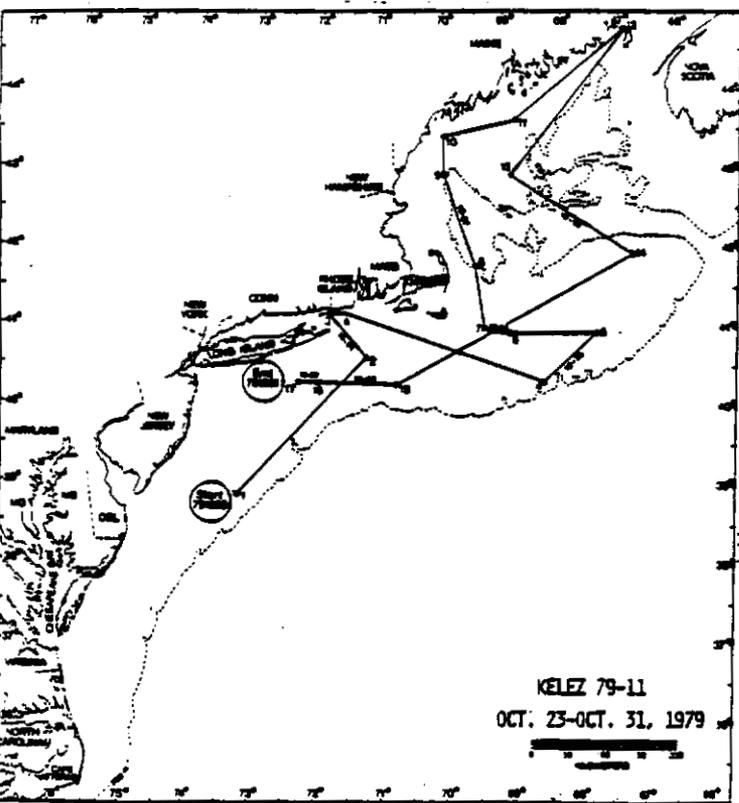
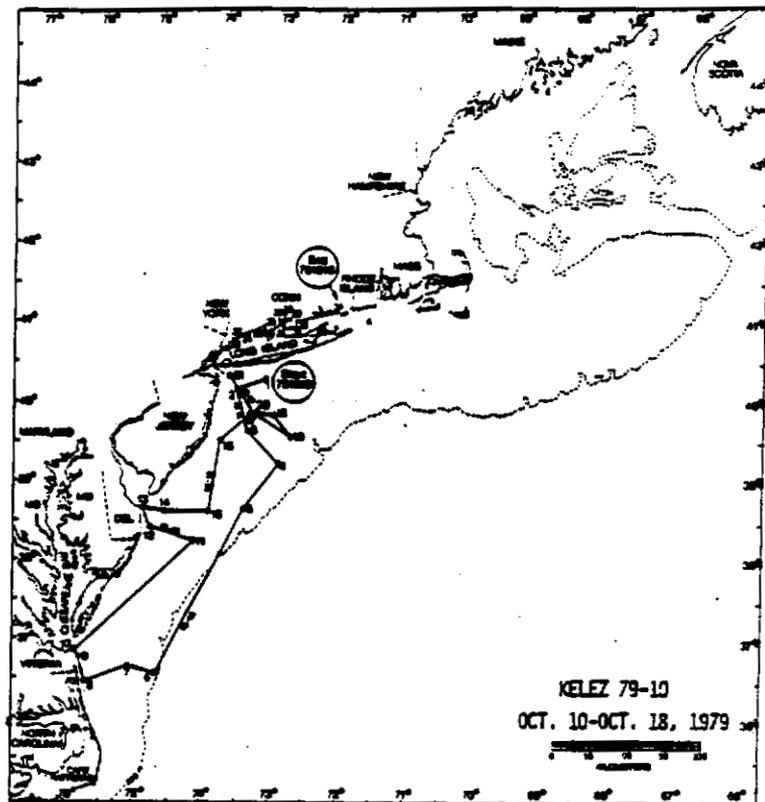
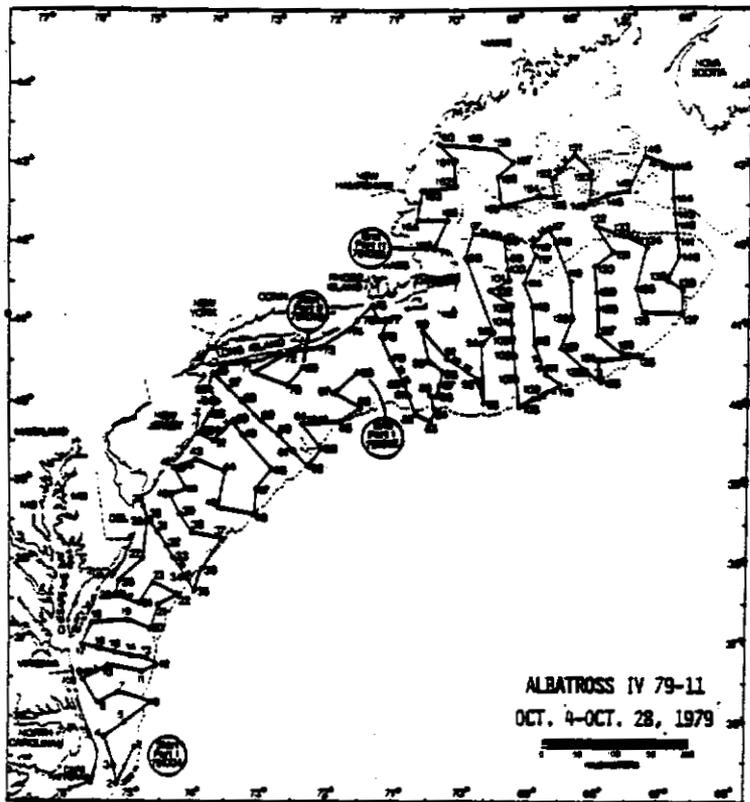


Fig. 7. Cruise tracks for ALBATROSS IV 79-11, KELEZ 79-10, KELEZ 79-11, and ALBATROSS IV 79-13.

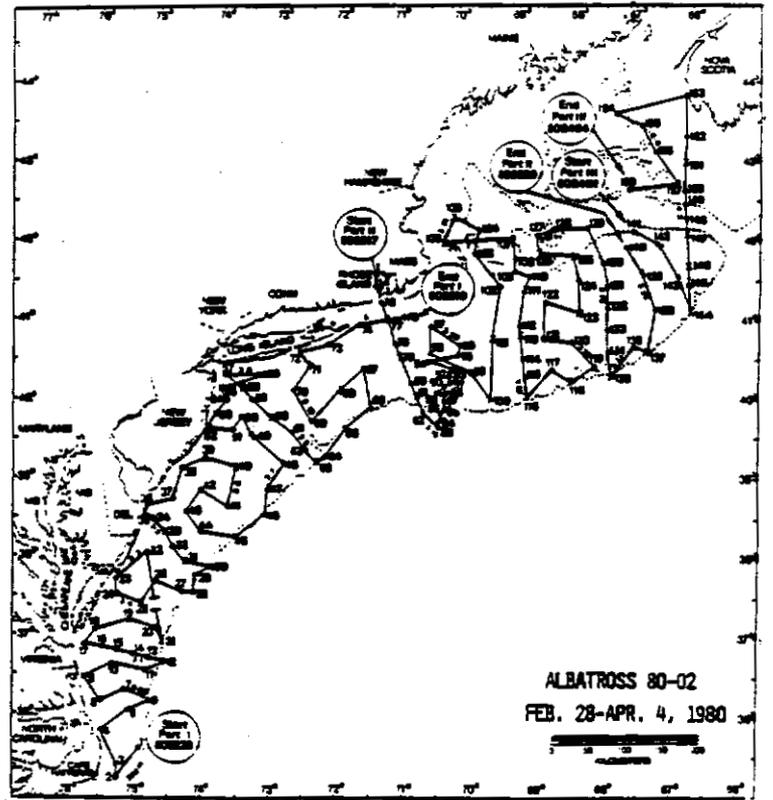
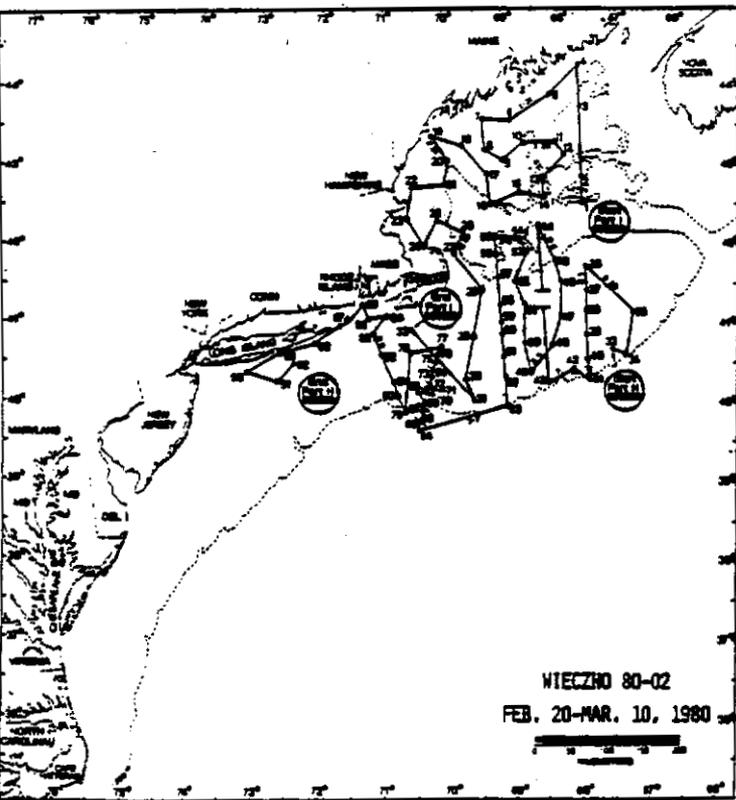
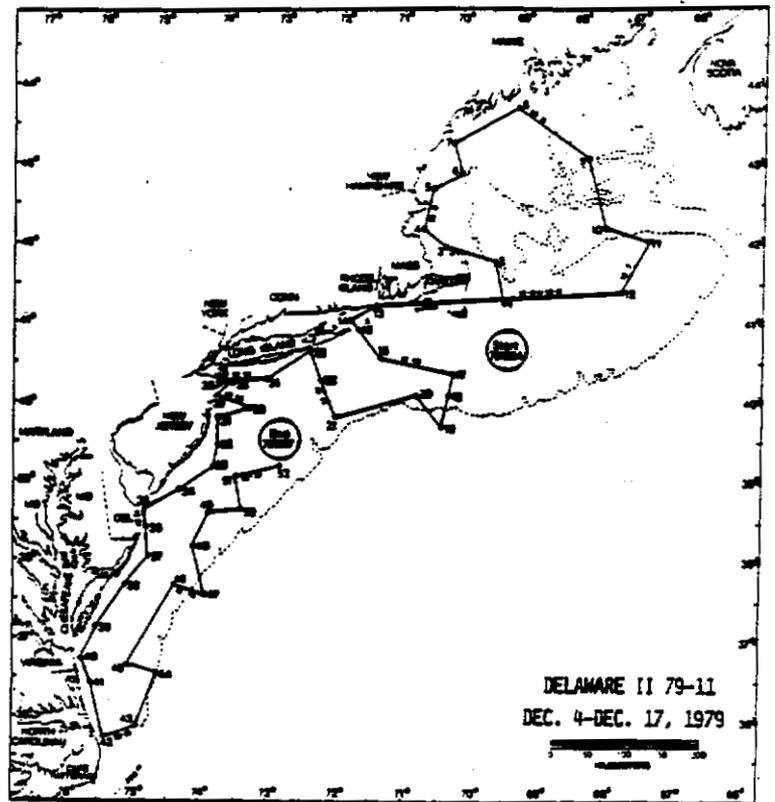
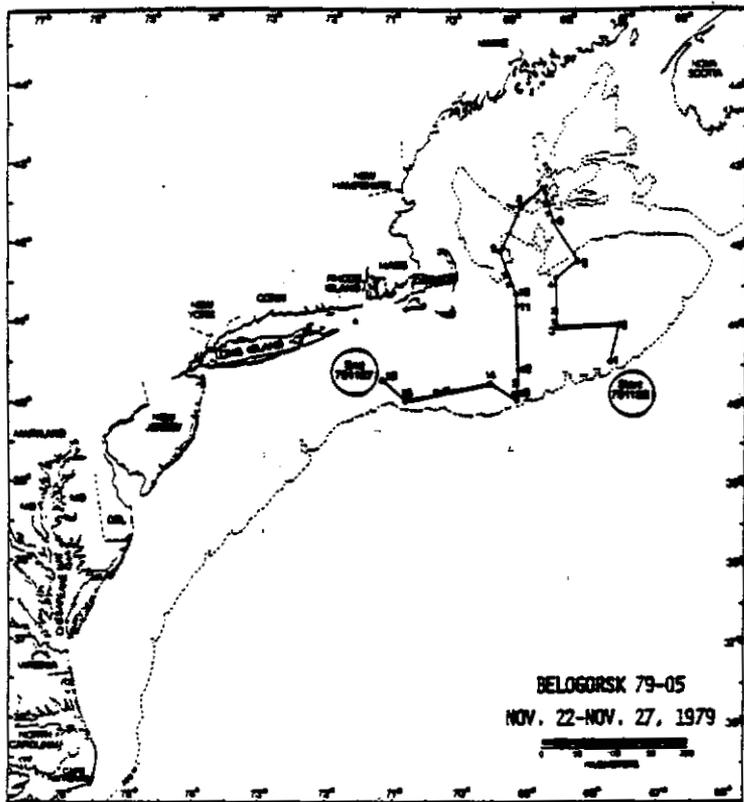


Fig. 8. Cruise tracks for BELOGORSK 79-05, DELAWARE II 79-11, WIECZNO 80-02, and ALBATROSS IV 80-02.

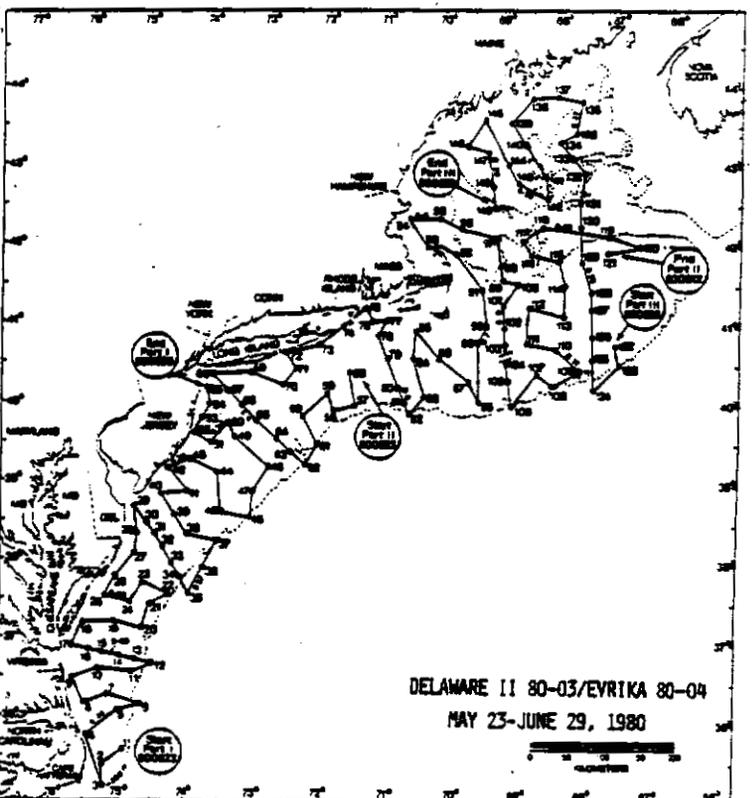
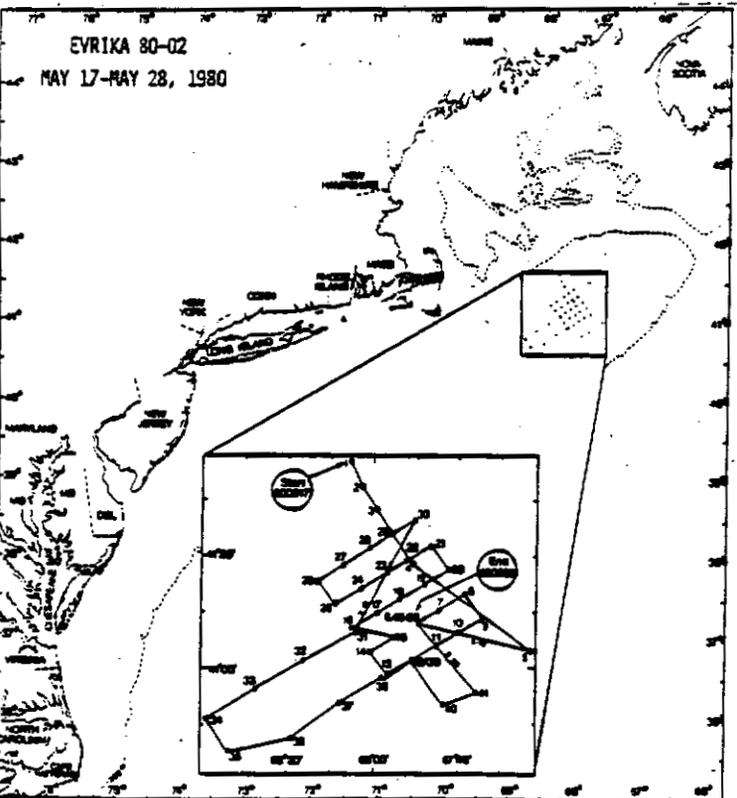
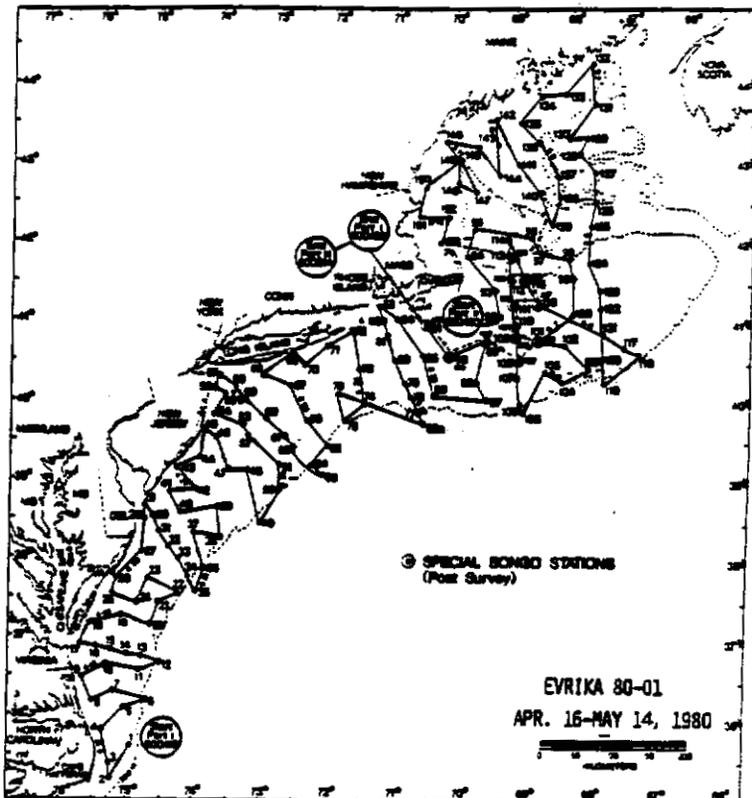
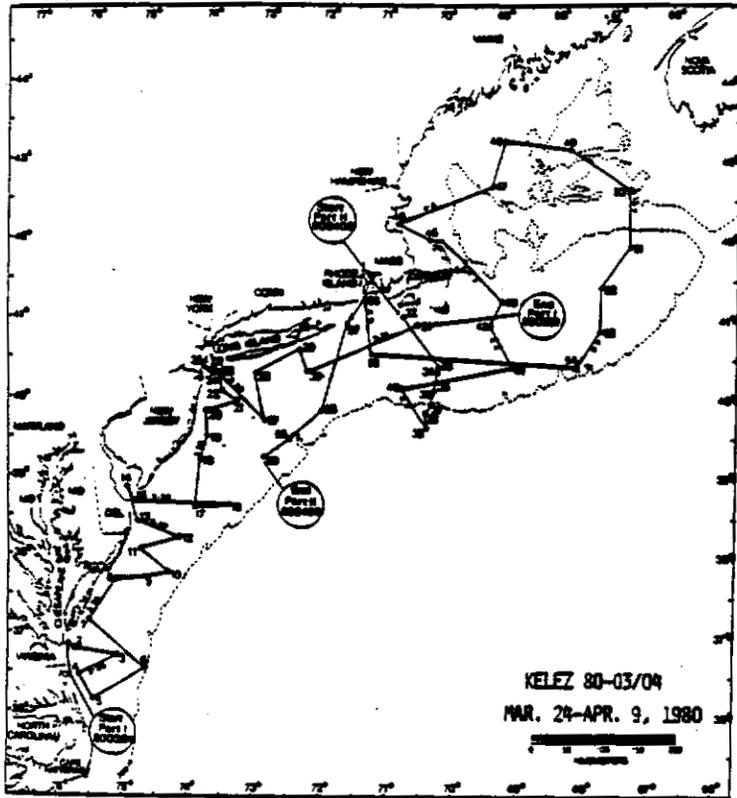


Fig. 9. Cruise tracks for KELEZ 80-03/04, EVRIKA 80-01, EVRIKA 80-02, and DELAWARE 80-03/EVRIKA 80-04.

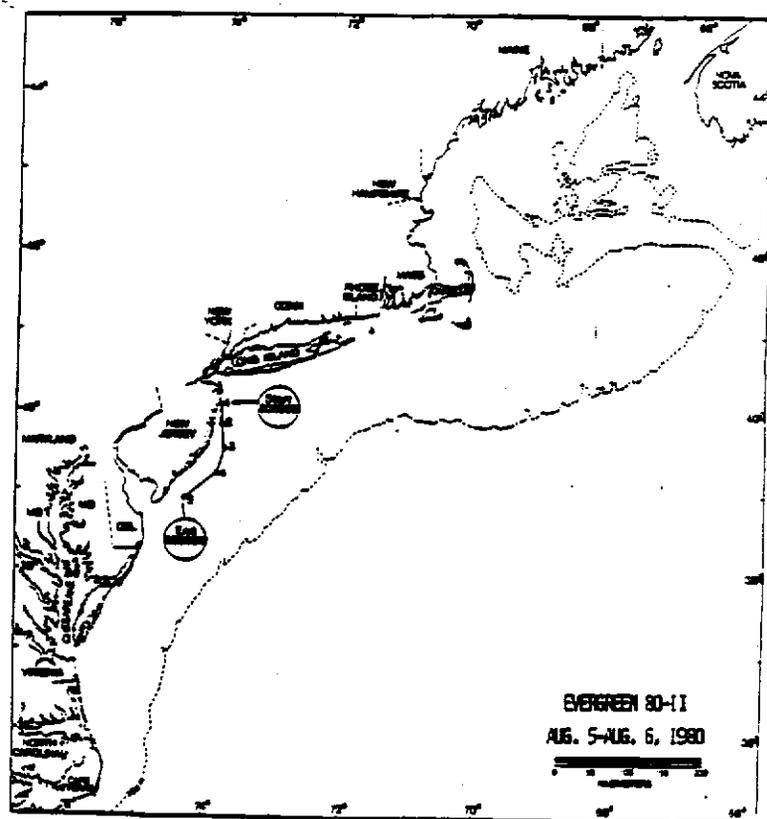
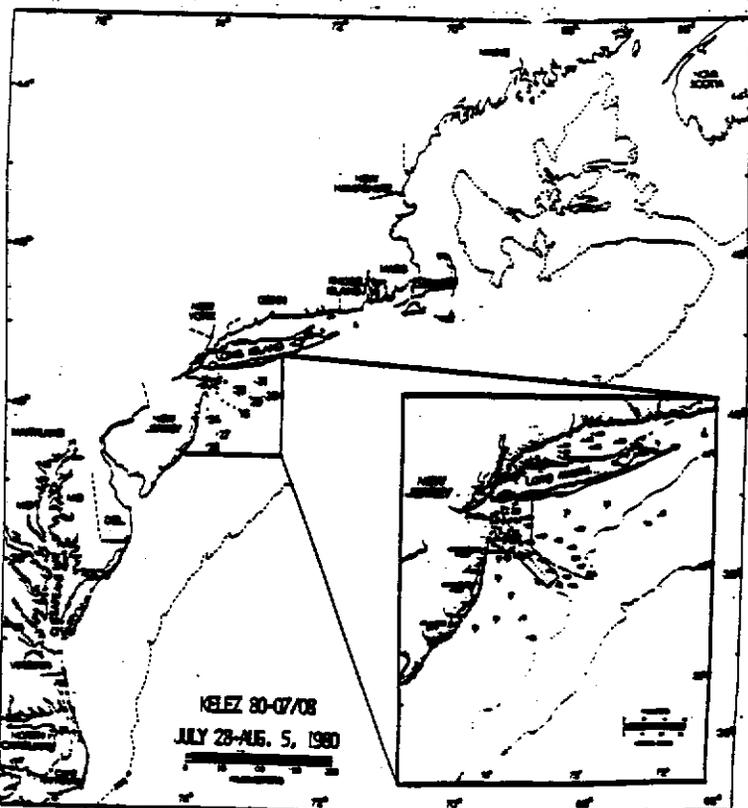
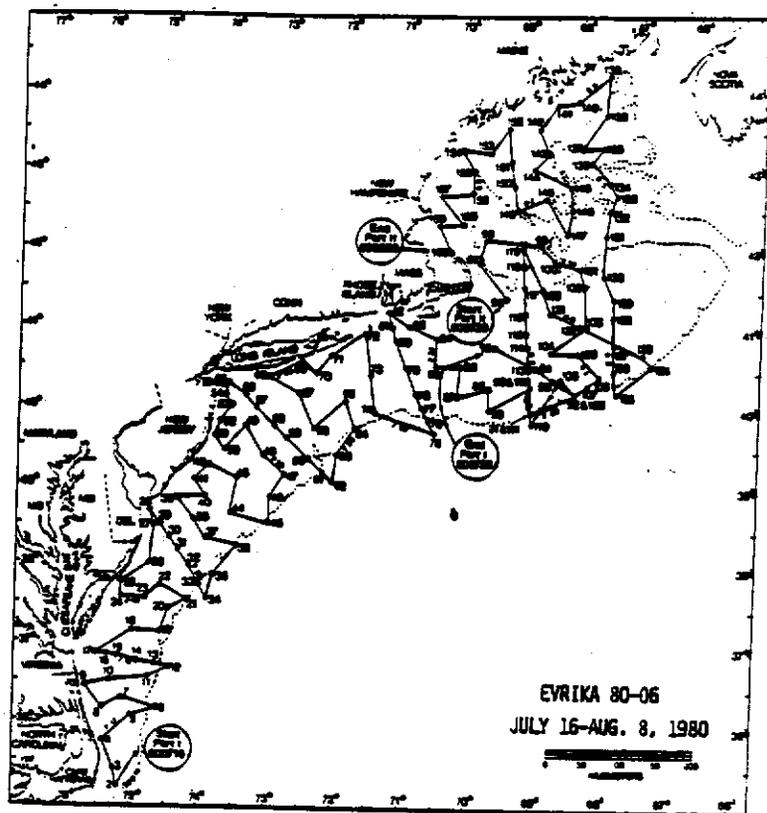
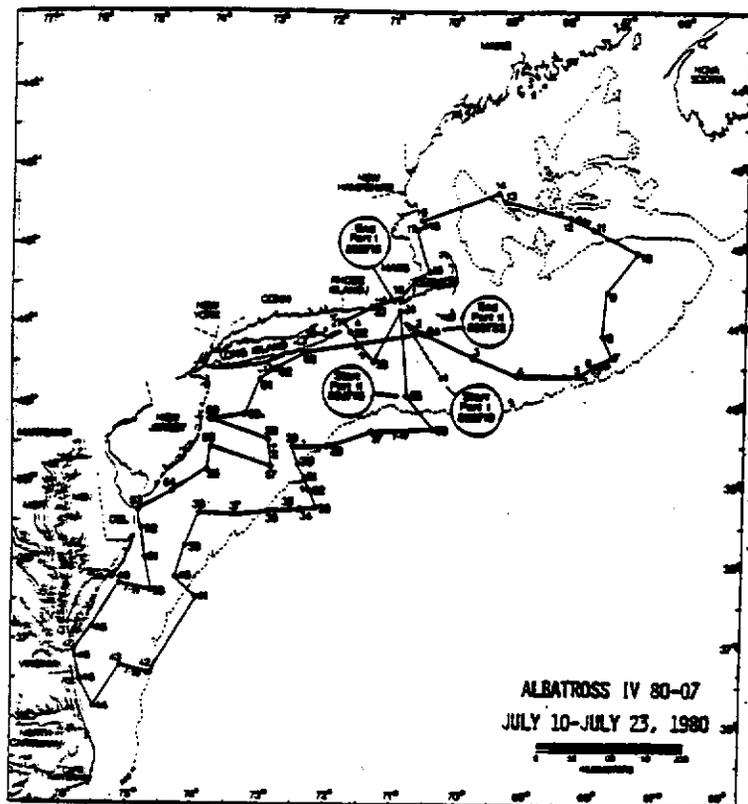


Fig. 10. Cruise tracks for ALBATROSS IV 80-07, EVRIKA 80-06, KELEZ 80-07/08, and EVERGREEN 80-II

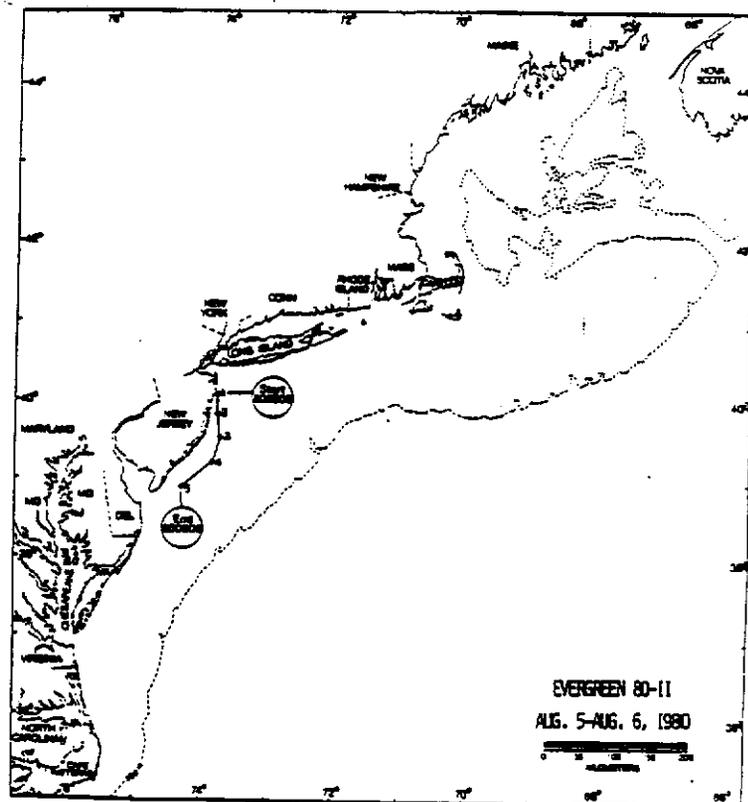
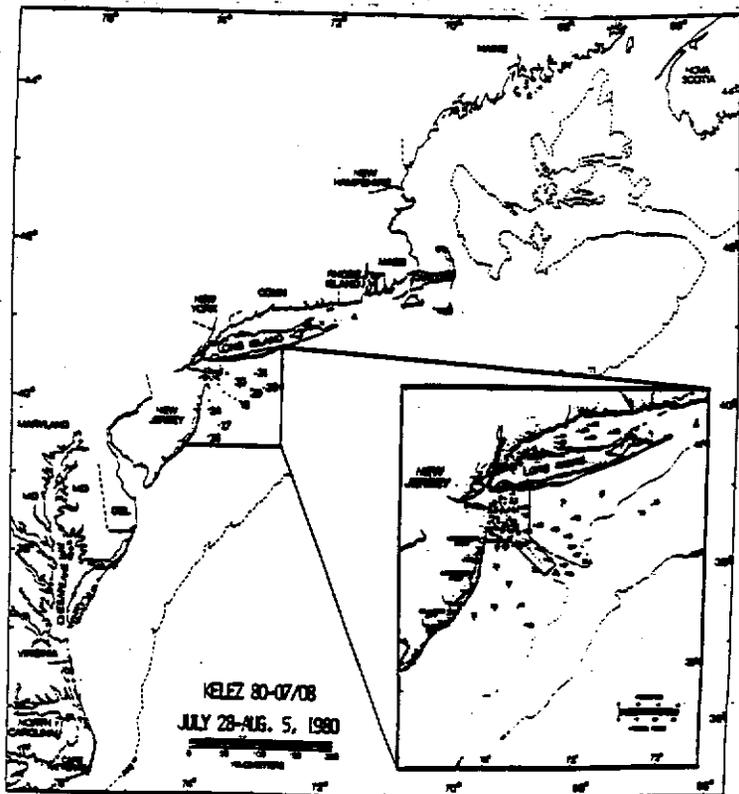
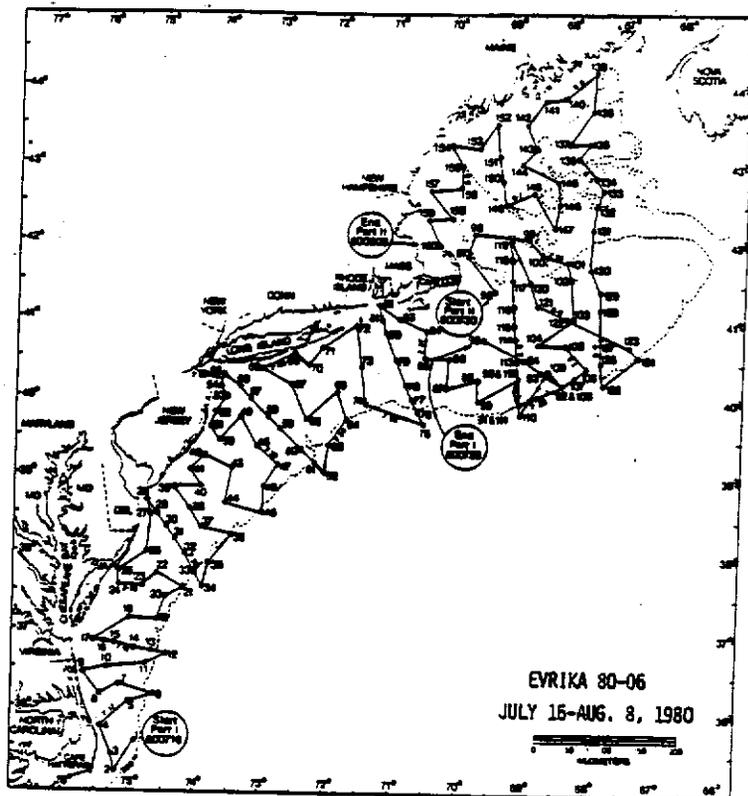
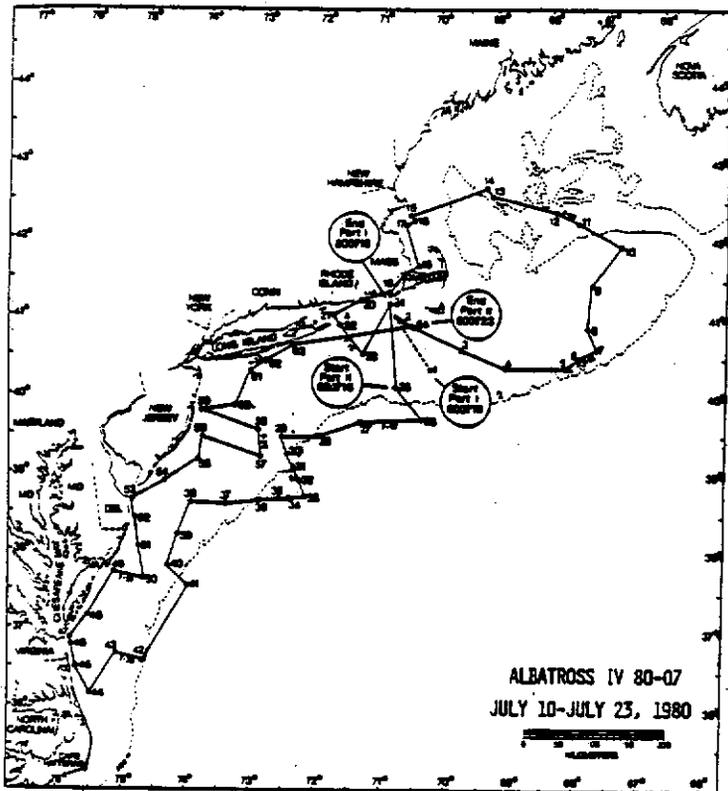


Fig. 10. Cruise tracks for ALBATROSS IV 80-07, EVRIKA 80-06, KELEZ 80-07/08, and EVERGREEN 80-II

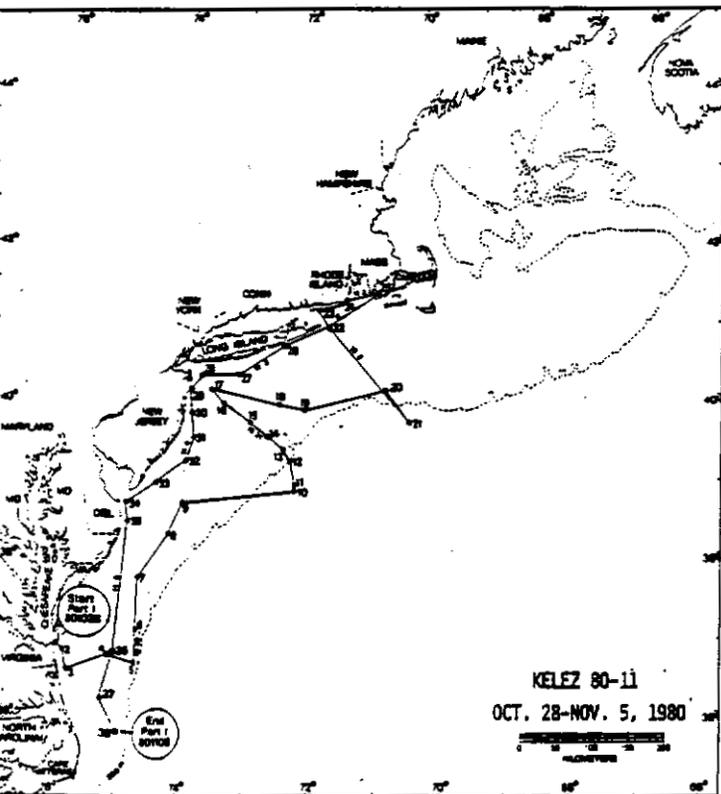
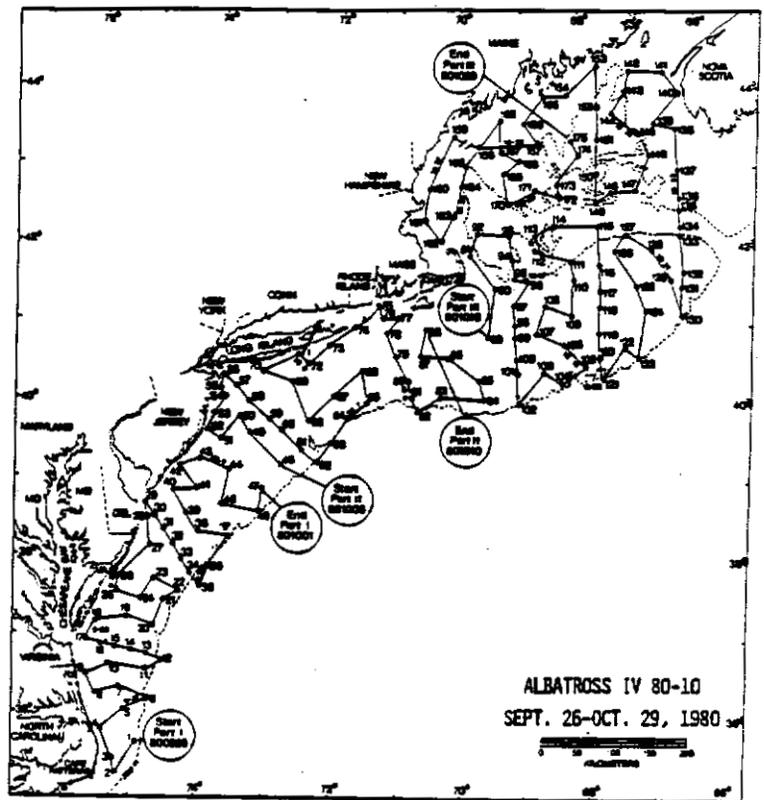
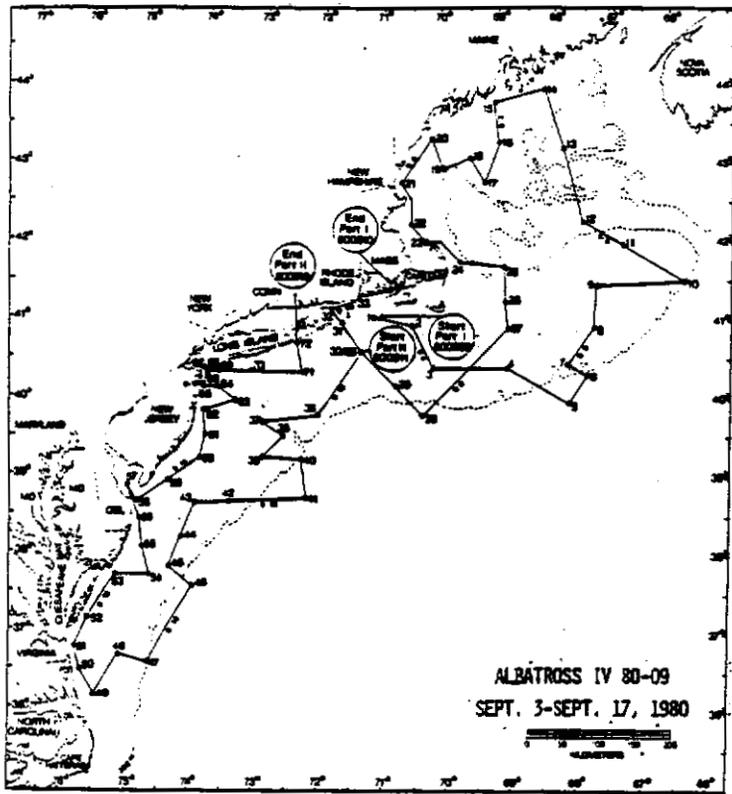


Fig. 11. Cruise tracks for ALBATROSS IV 80-09, ALBATROSS IV 80-10, and KELEZ 80-11.

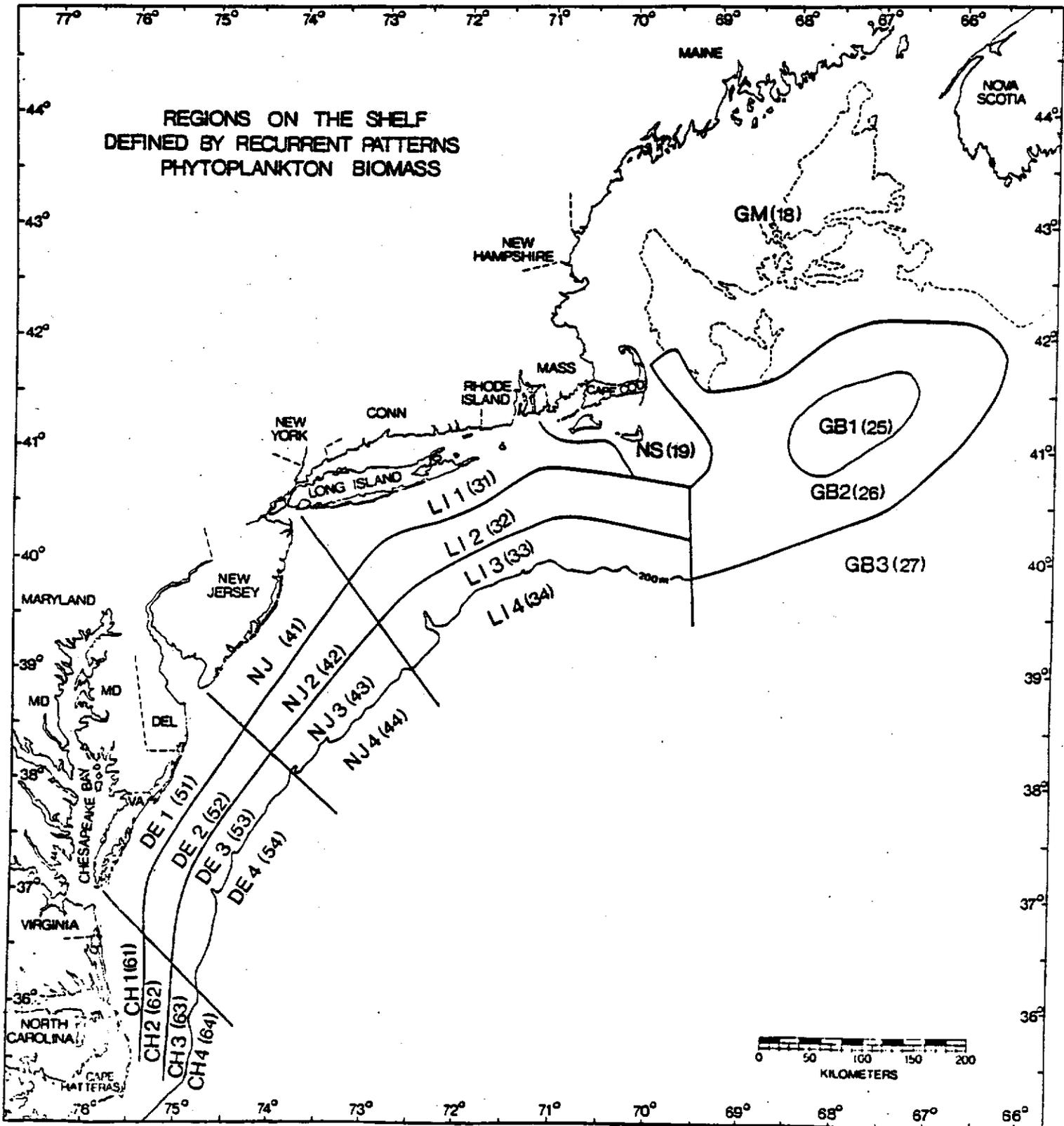


Figure 12. Regions on the shelf defined by recurrent patterns of phytoplankton biomass concentrations.

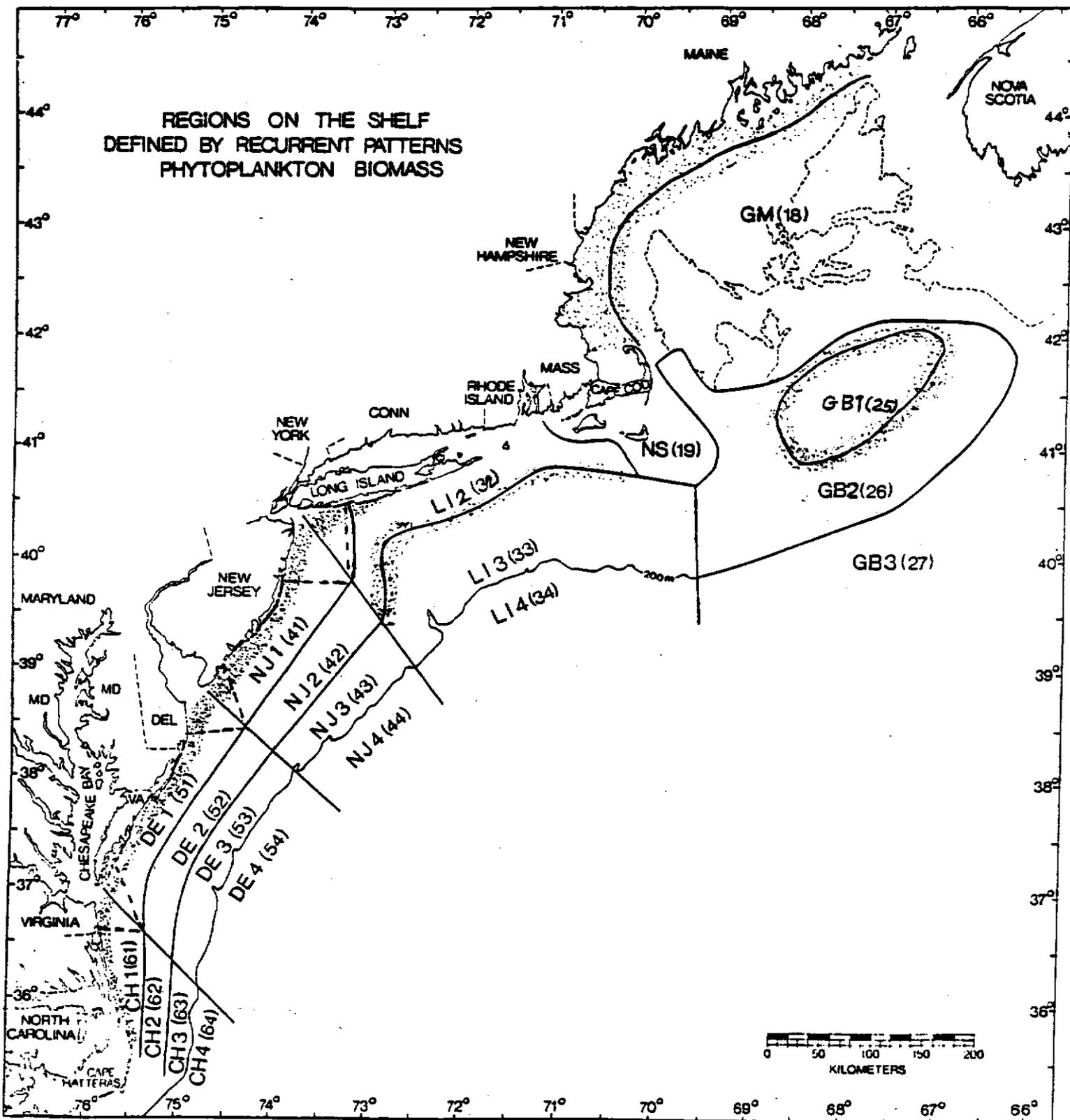


Figure 13. Tentative revisions of Figure 12. Stippled and boxed areas near estuaries are under consideration for further subdivision.

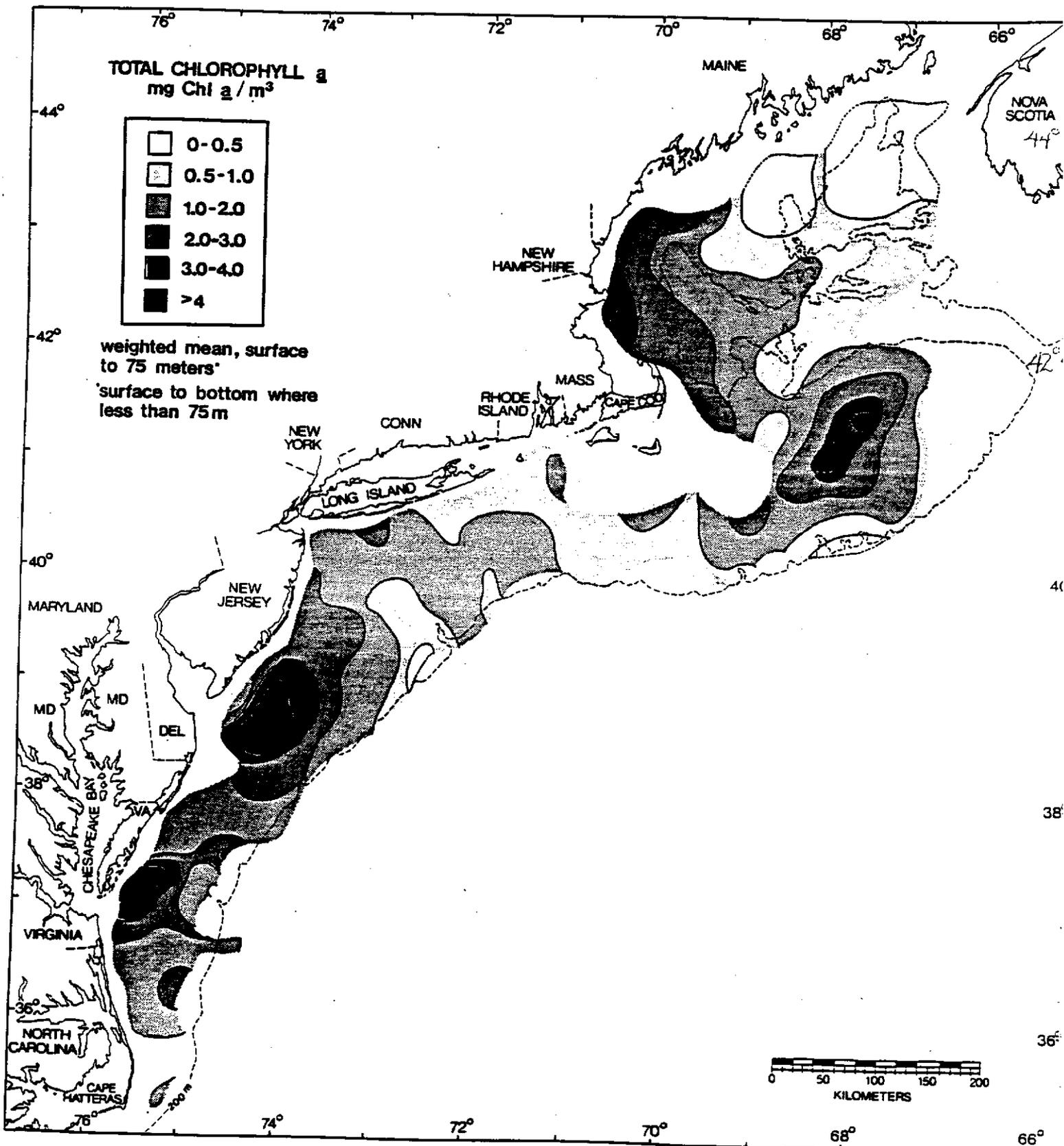


Figure 14. Distribution of chlorophyll a during Argus 77-01, October 18-November 9, 1977.

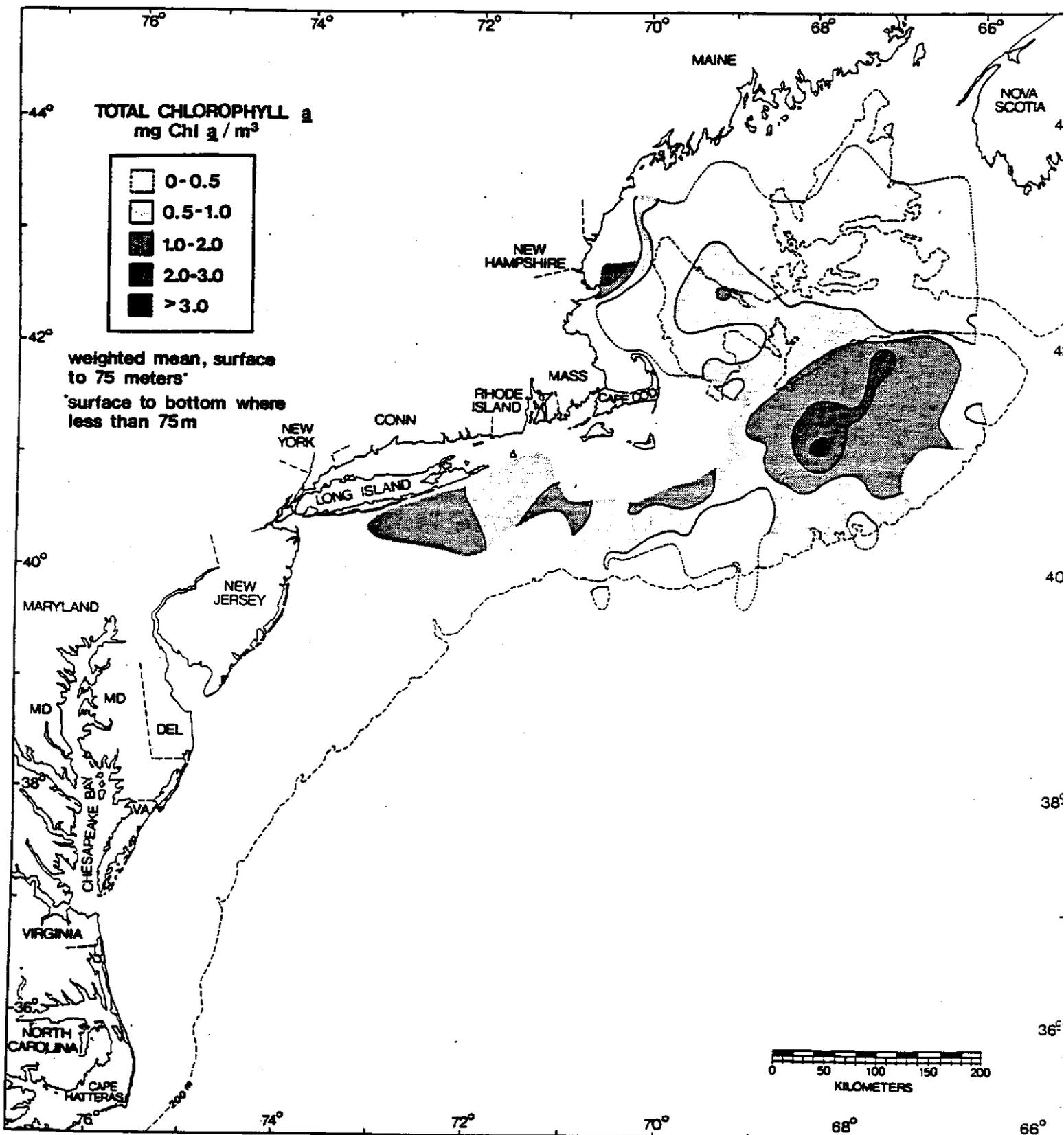


Figure 15. Distribution of chlorophyll a during Mt. Mitchell/Kelez 77-11, November 12-December 13, 1977.

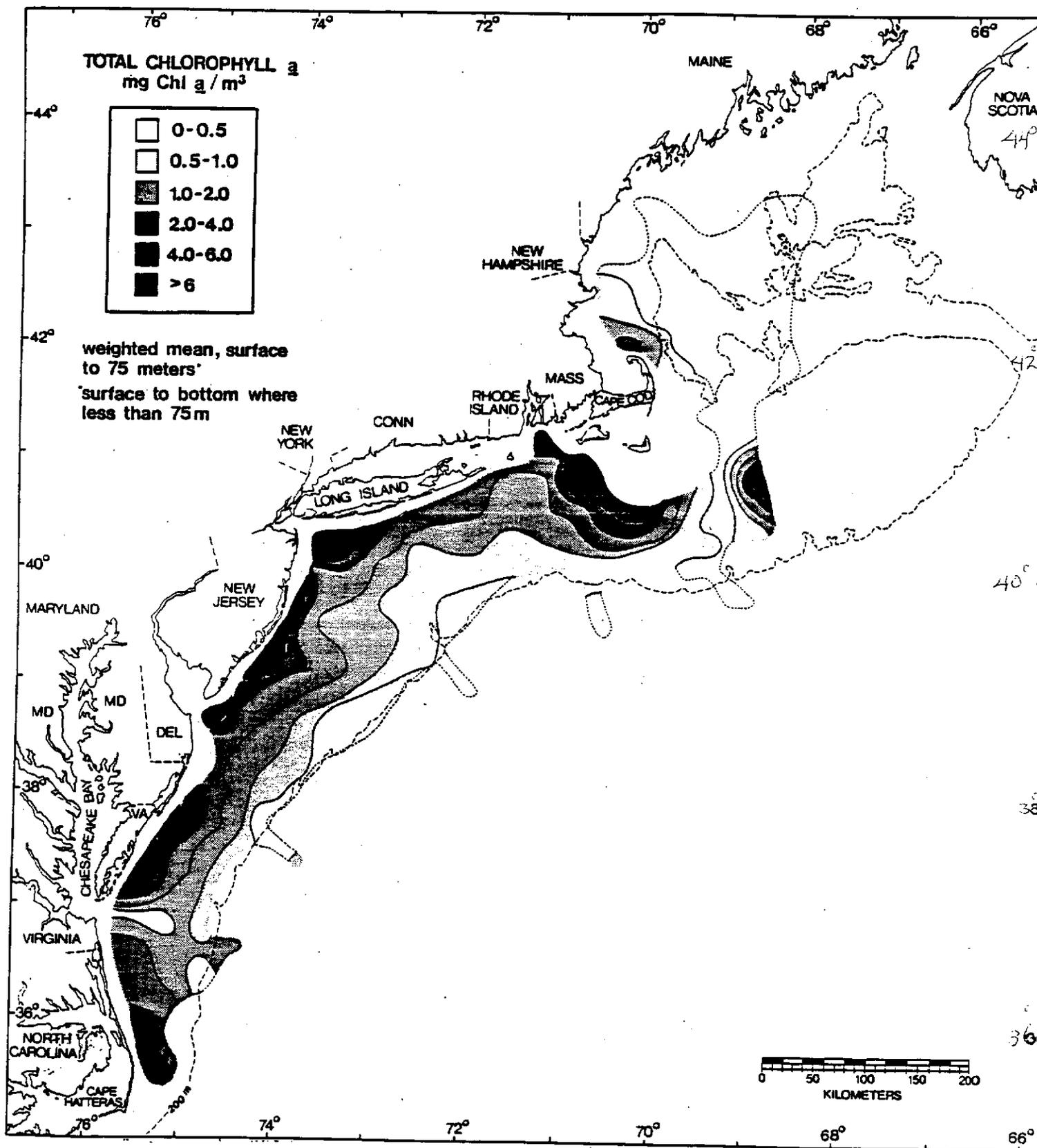


Figure 16. Distribution of chlorophyll *a* during Delaware II 78-02, February 16-March 16, 1978.

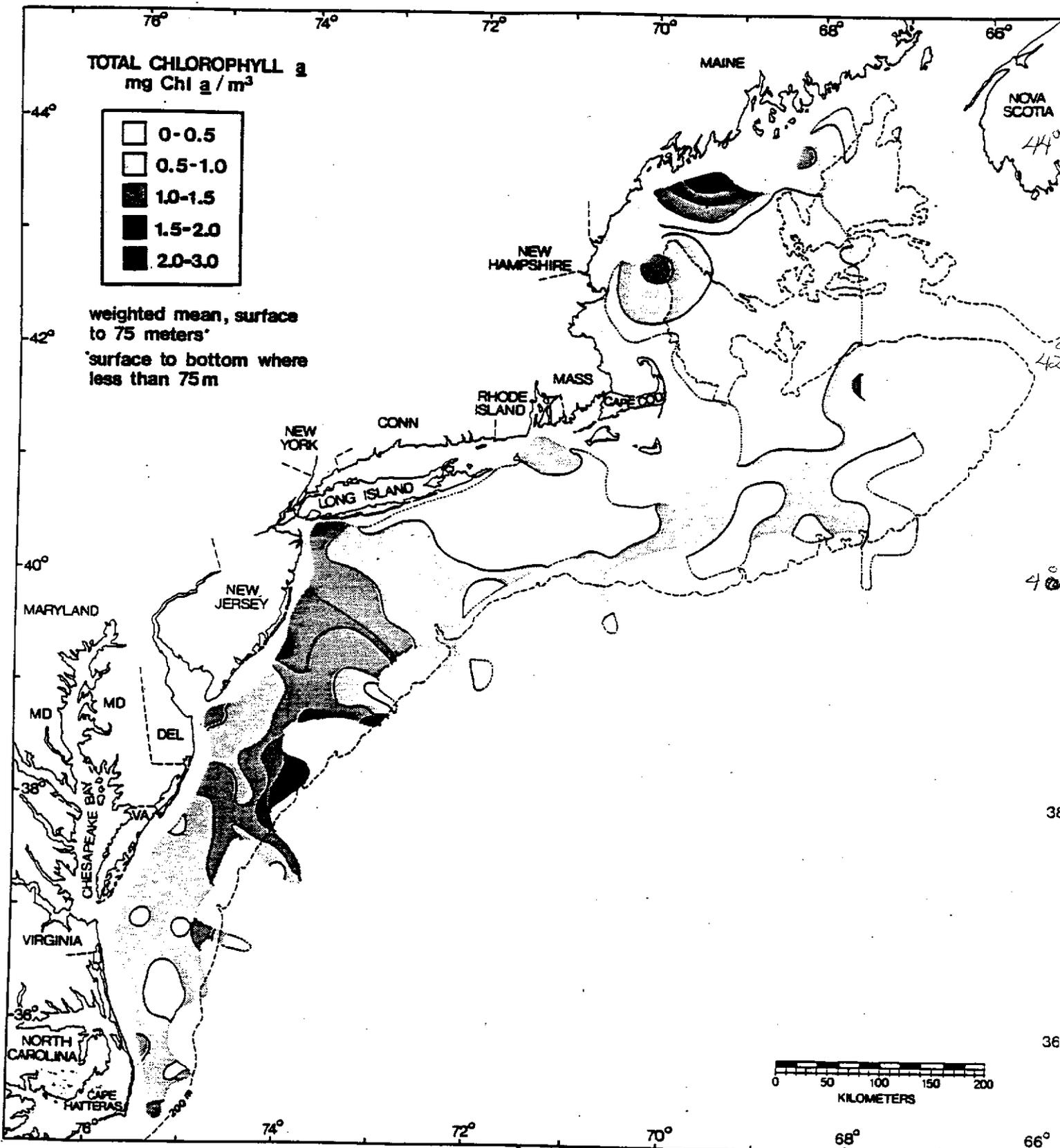


Figure 17. Distribution of chlorophyll *a* during Argus 78-04, April 18-May 22, 1978.

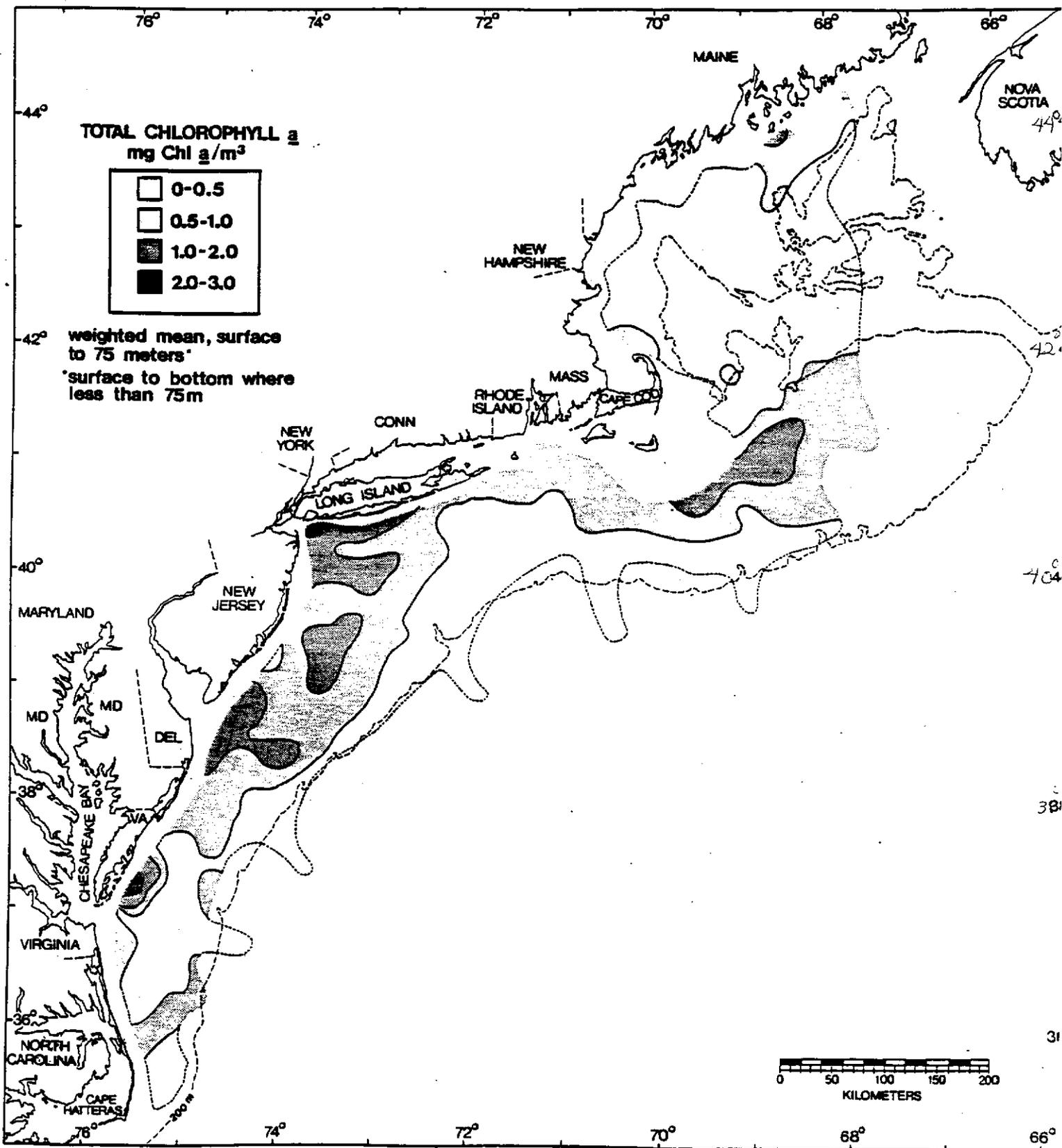


Figure 18. Distribution of chlorophyll *a* during Albatross IV 78-07, June 23-July 16, 19

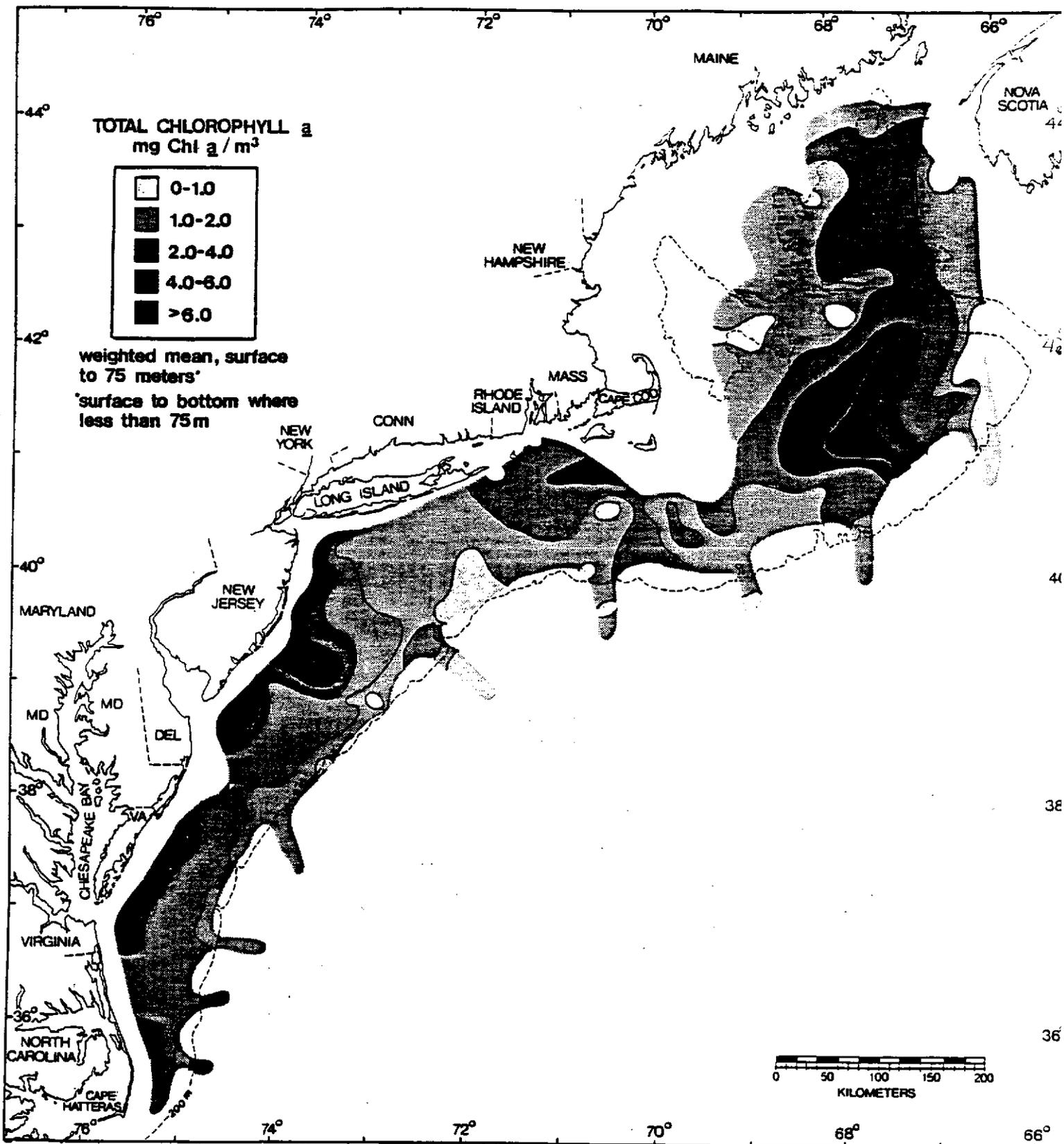


Figure 19. Distribution of chlorophyll *a* during Belogorsk 78-01, August 11 -September 4, 1978.

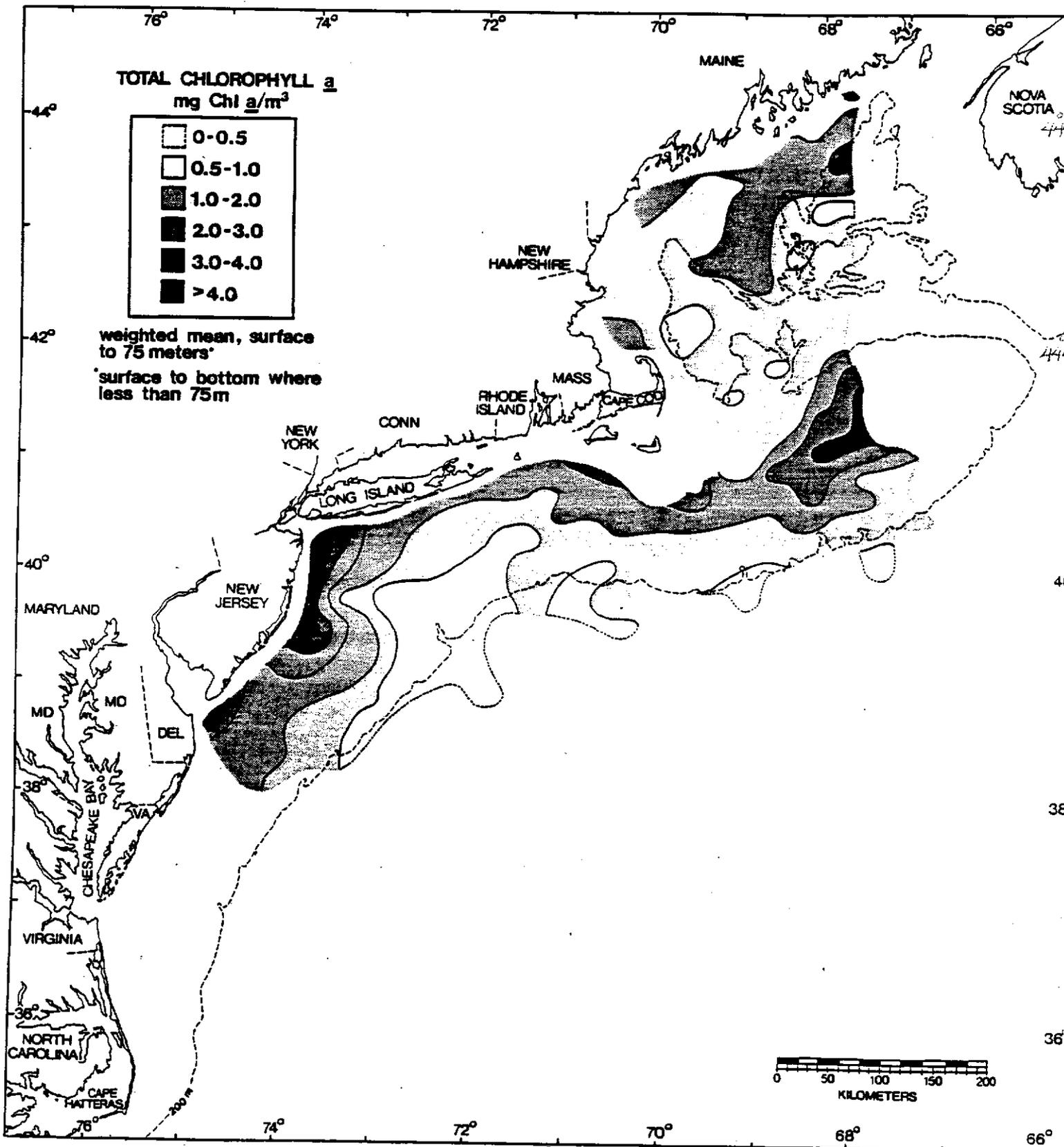


Figure 20. Distribution of chlorophyll *a* during Belogorsk 78-03, October 6- November 1, 1978.

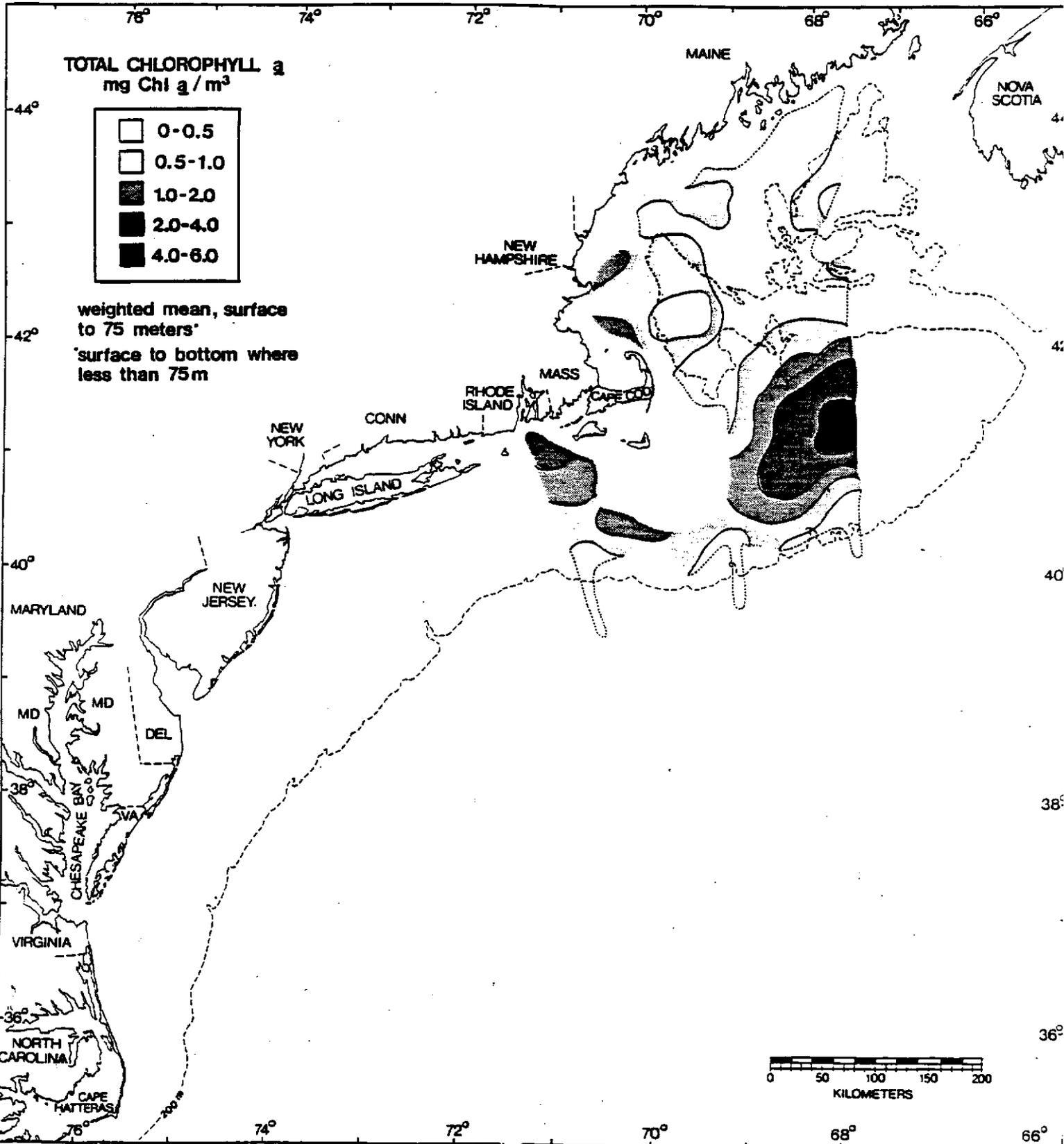


Figure 21. Distribution of chlorophyll *a* during Belogorsk 78-04, November 16-29, 1978.

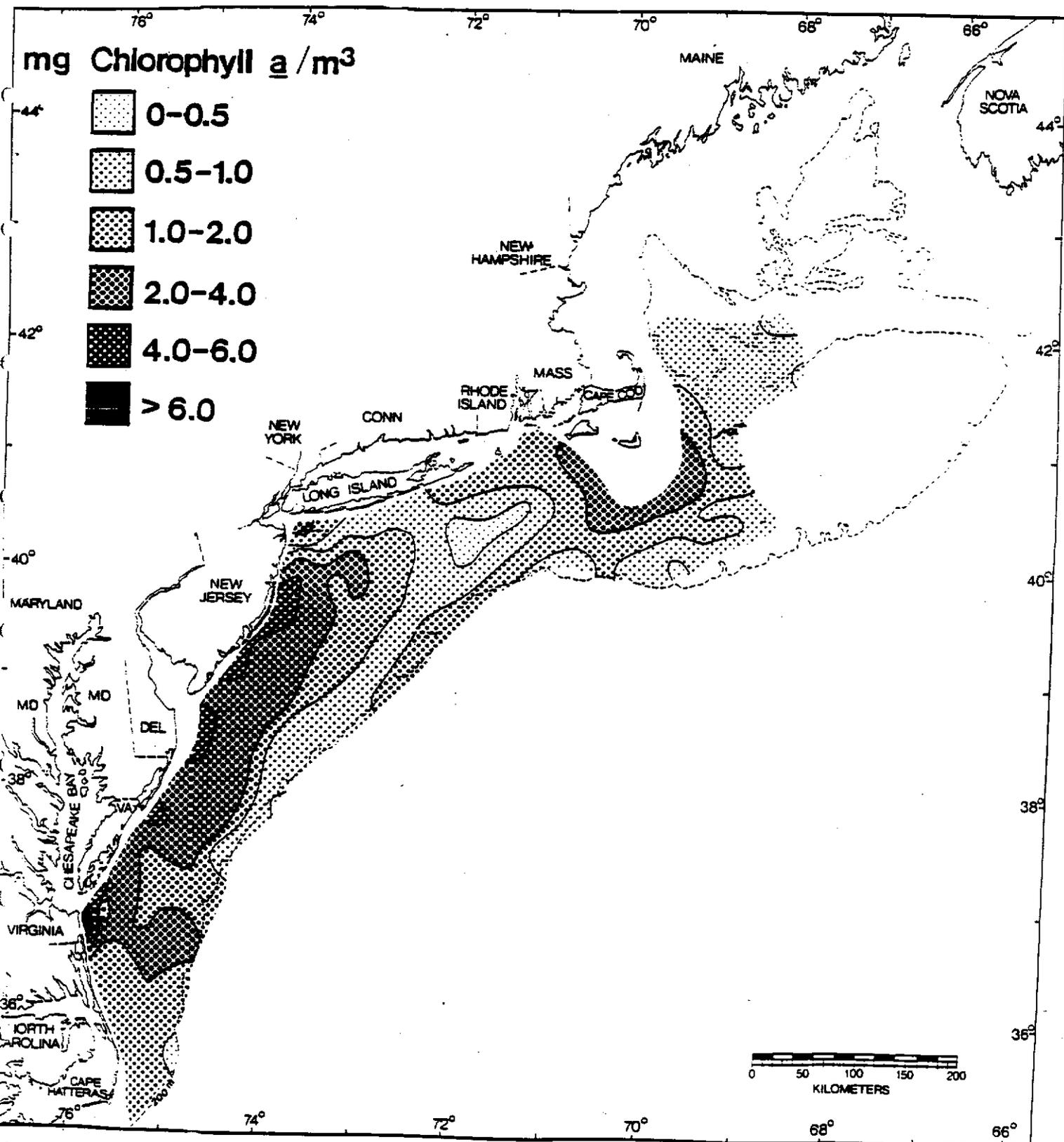


Figure 22. Distribution of chlorophyll a during Delaware II 79-03, Feb. 24-March 14, 1979.

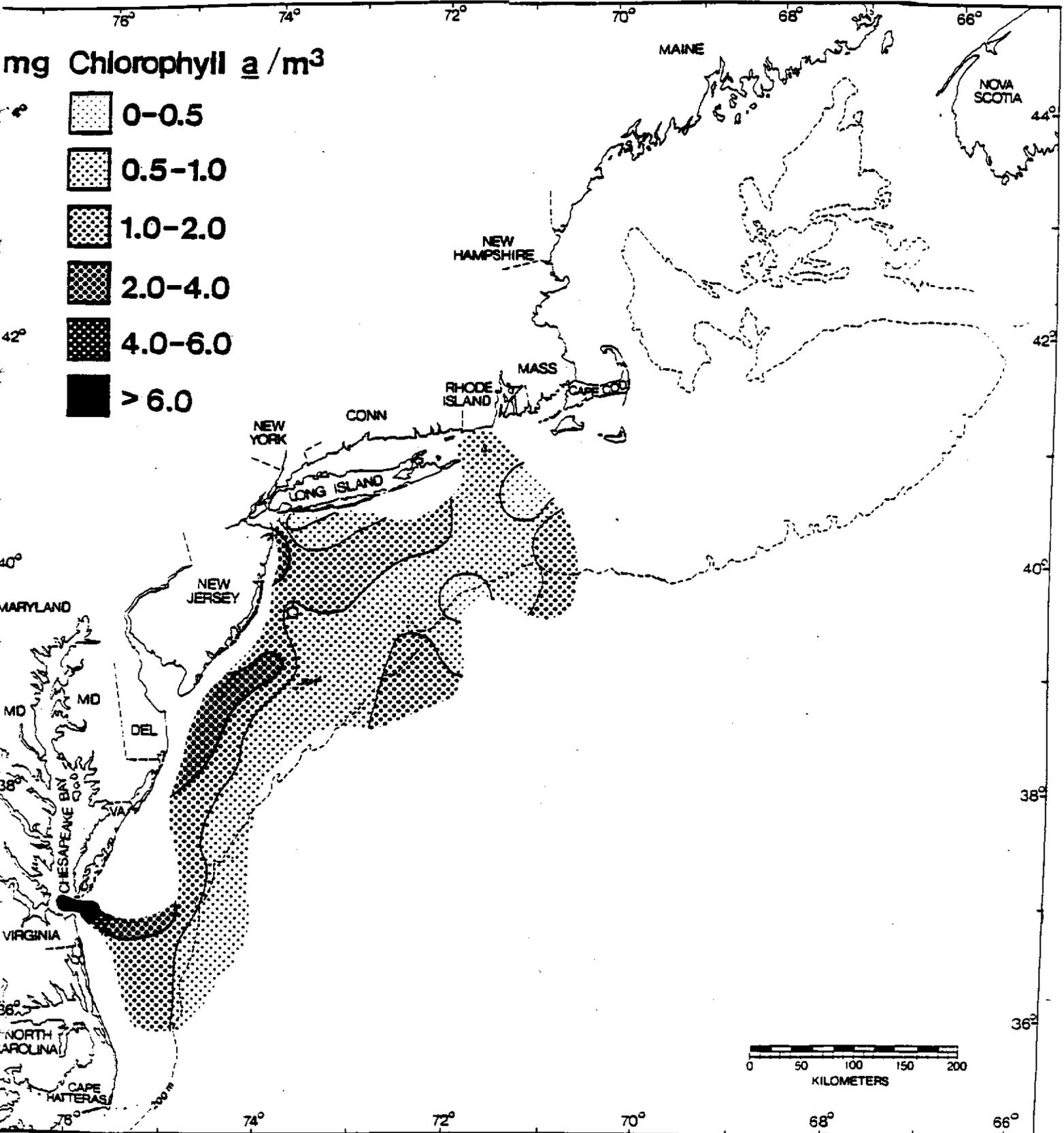


Figure 23. Distribution of chlorophyll a during Advance II 79-01, April 18-27, 1979.

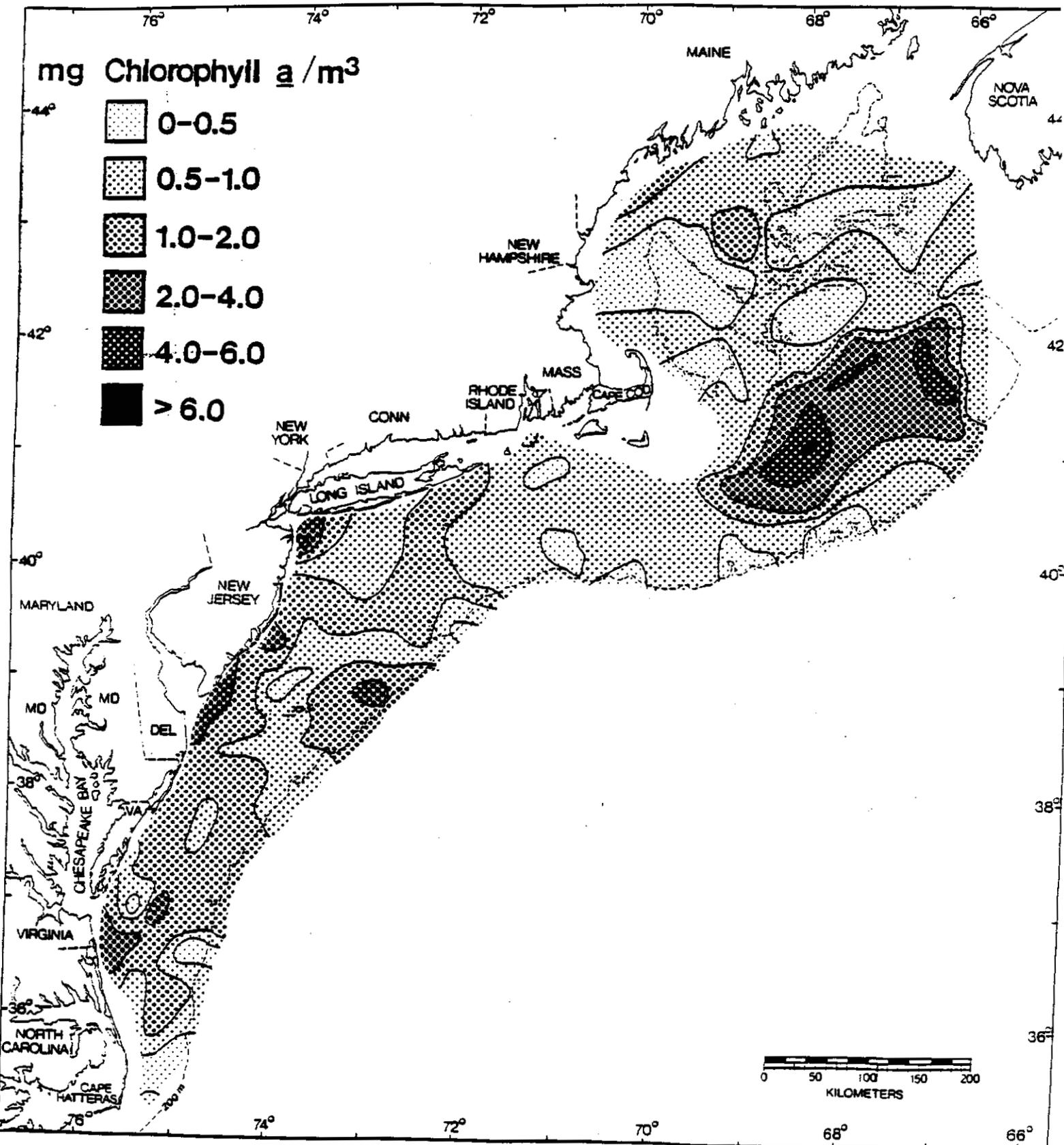


Figure 24. Distribution of chlorophyll a during Delaware II 79-05, May 5-29, 1979.

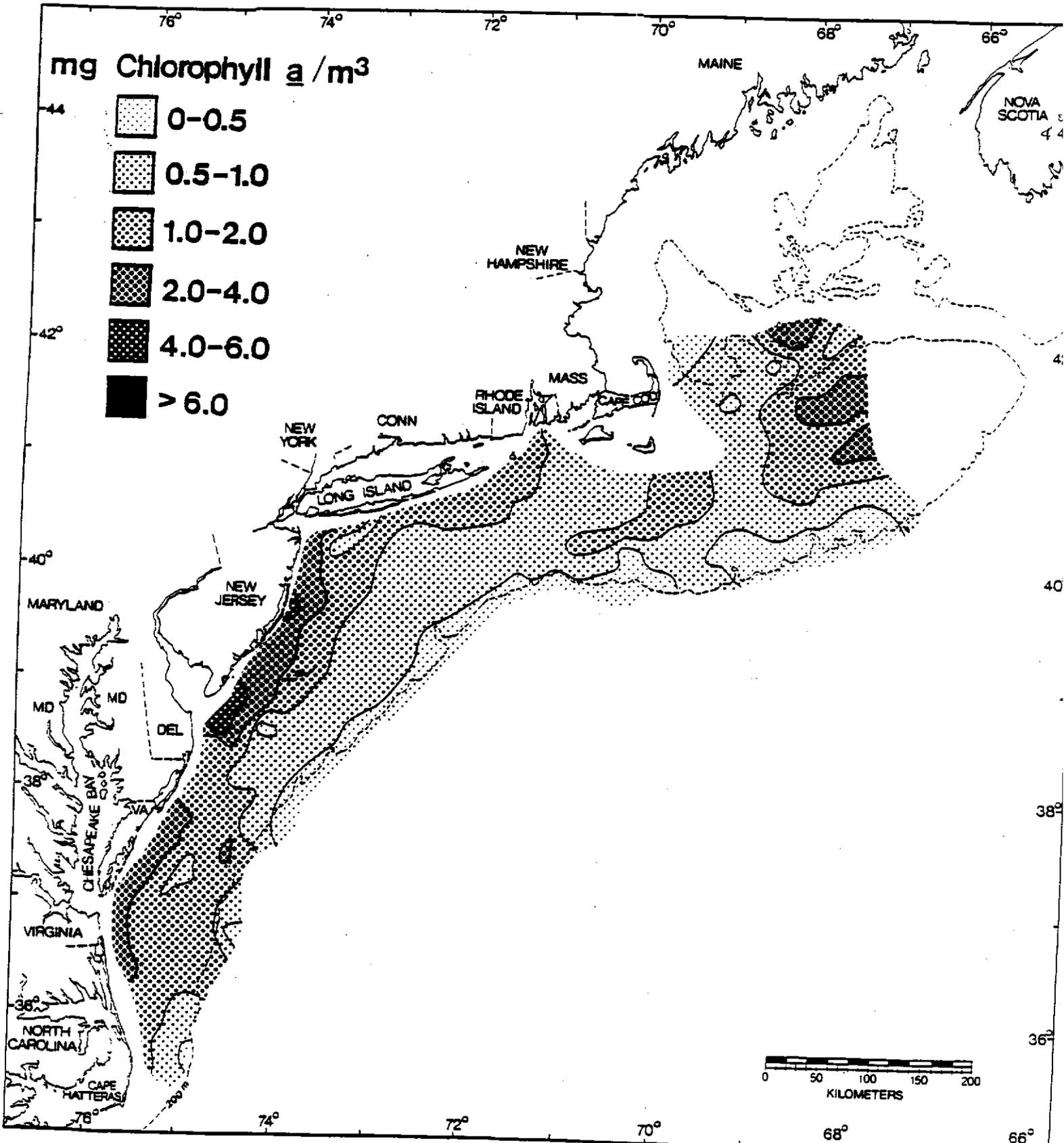


Figure 25. Distribution of chlorophyll a during Albatross IV 79-06, June 15-July 13, 1979.

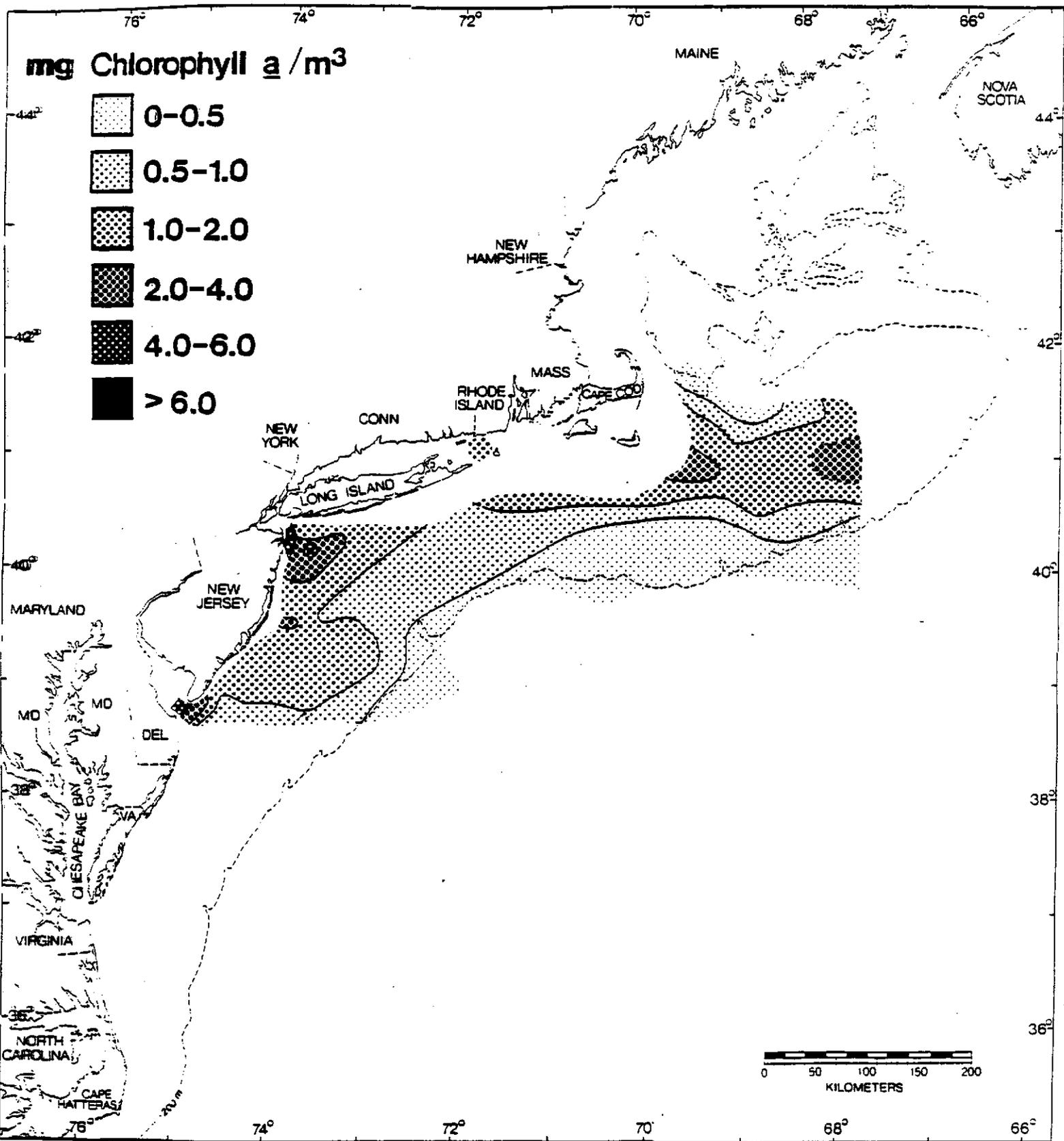


Figure 26. Distribution of chlorophyll a during Albatross IV 79-07, July 17-26, 1979.

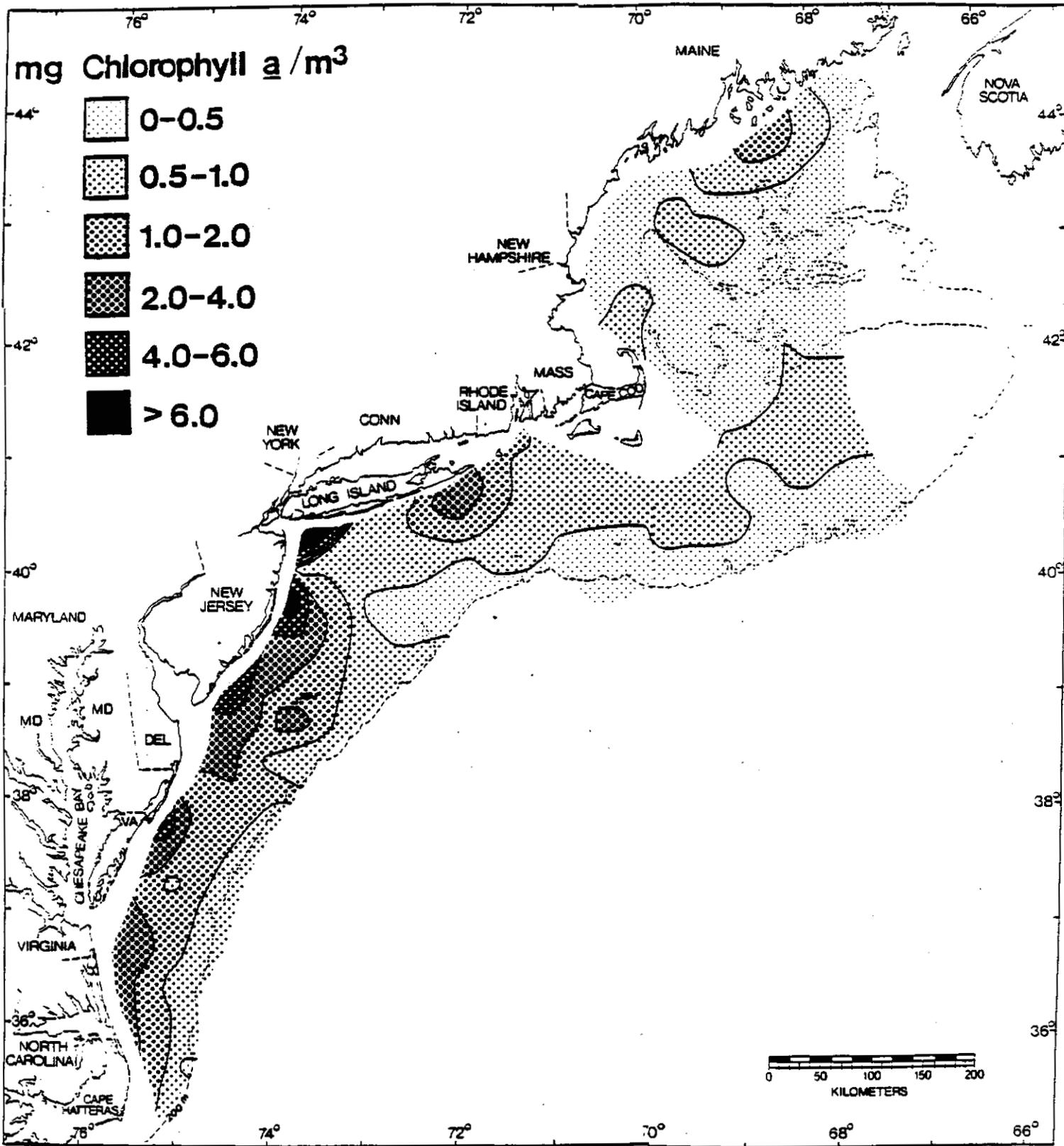


Figure 27. Distribution of chlorophyll a during Belogorsk 79-01, Aug. 11-Sept. 2, 1979.

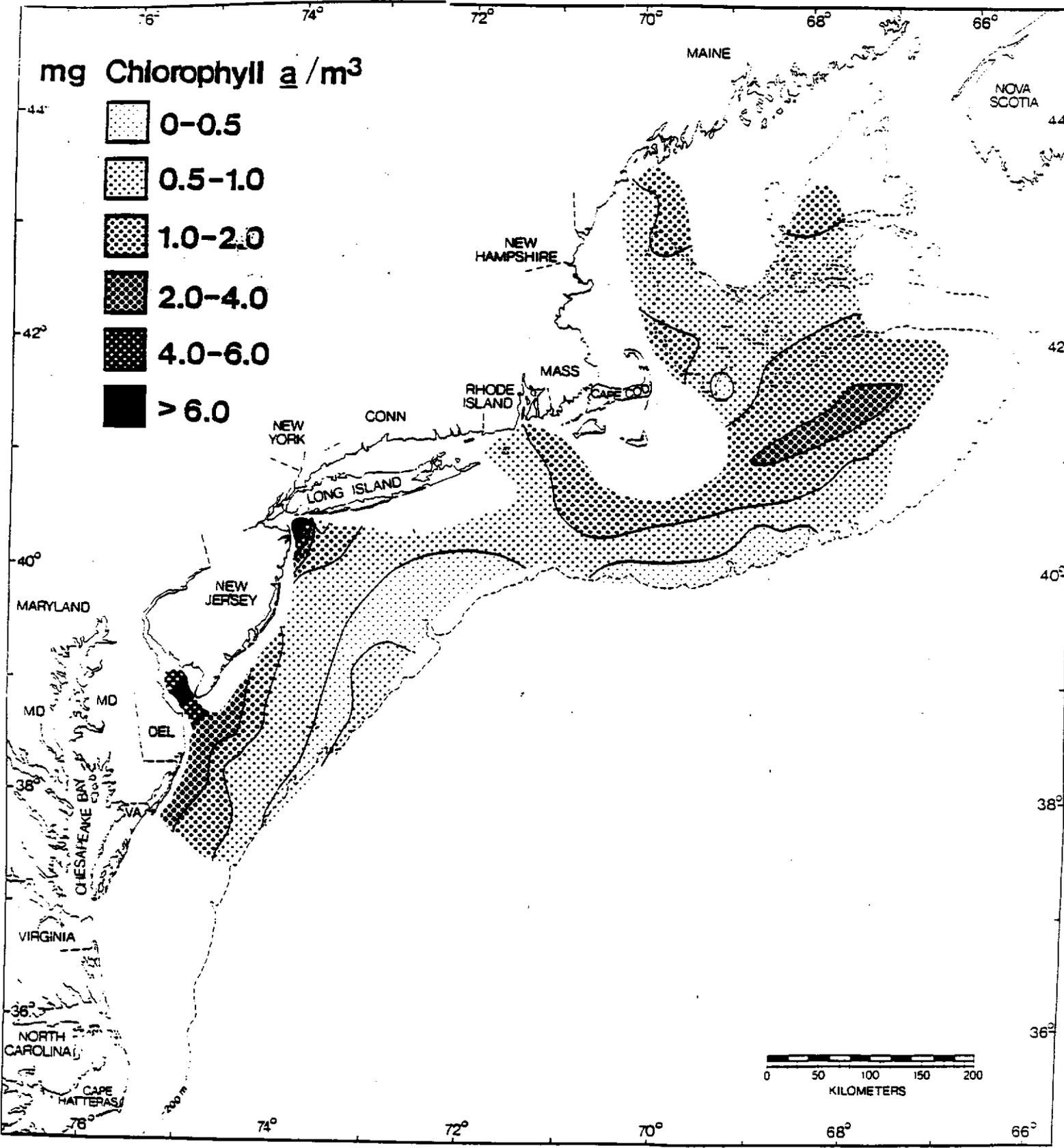


Figure 28. Distribution of chlorophyll a during Albatross IV 79-10, Sept. 12-27, 1979.

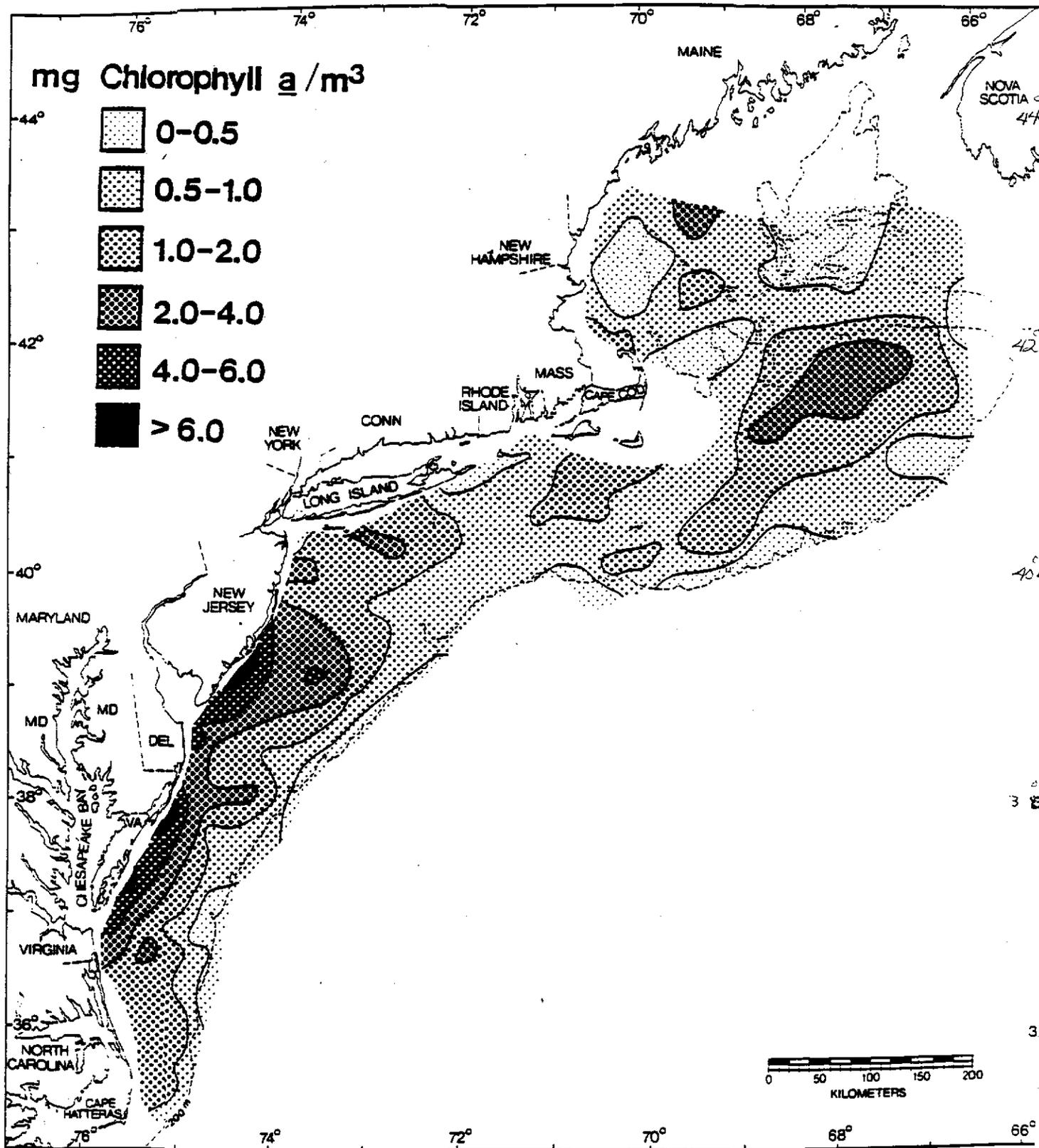


Figure 29. Distribution of chlorophyll a during Albatross IV 79-11, Oct. 4-29, 1979.

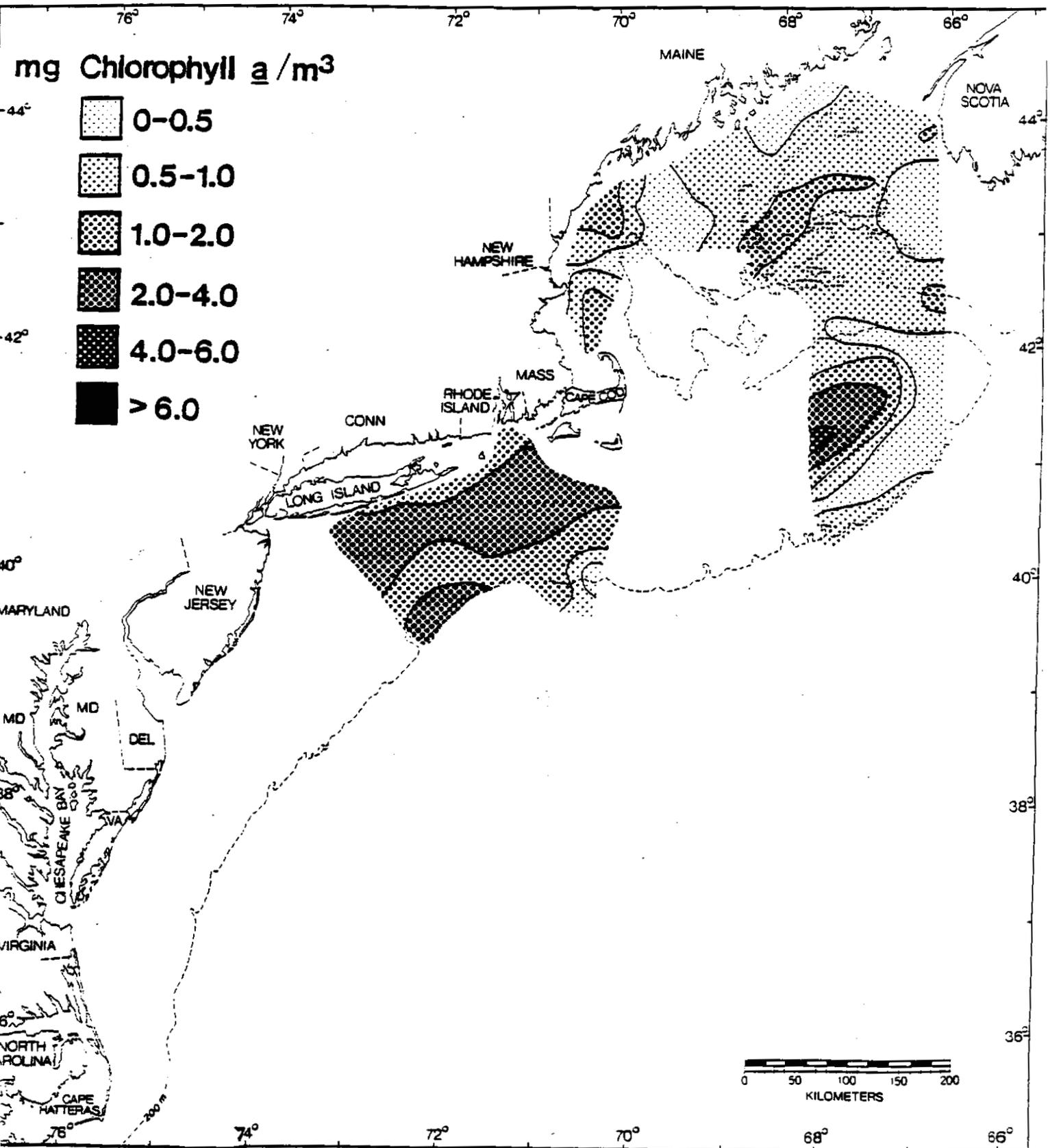


Figure 30. Distribution of chlorophyll a during Albatross IV 79-13, Nov. 15-Dec. 20, 1979.

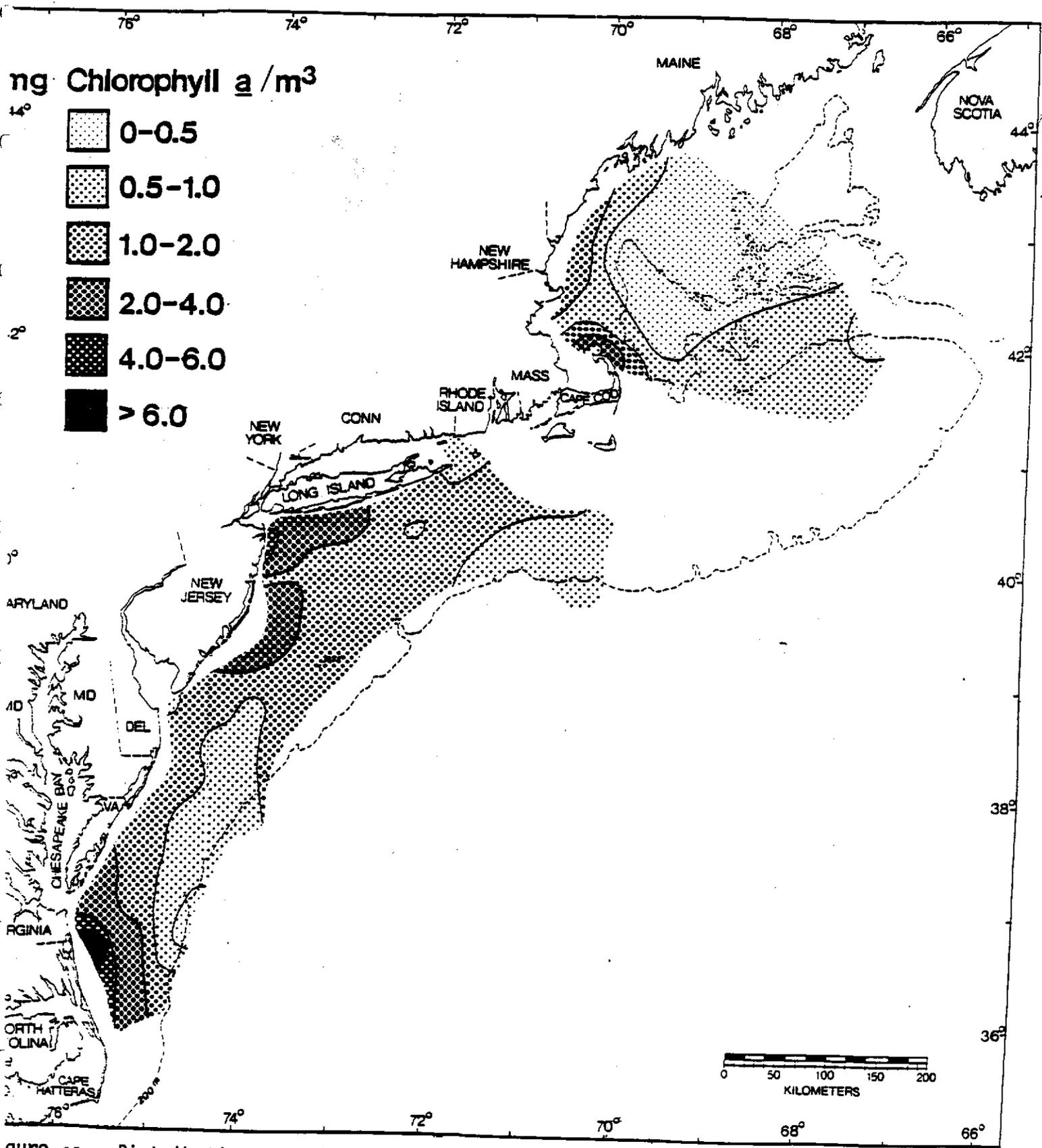


Figure 31. Distribution of chlorophyll a during Delaware II 79-11, Dec. 3-19, 1979.

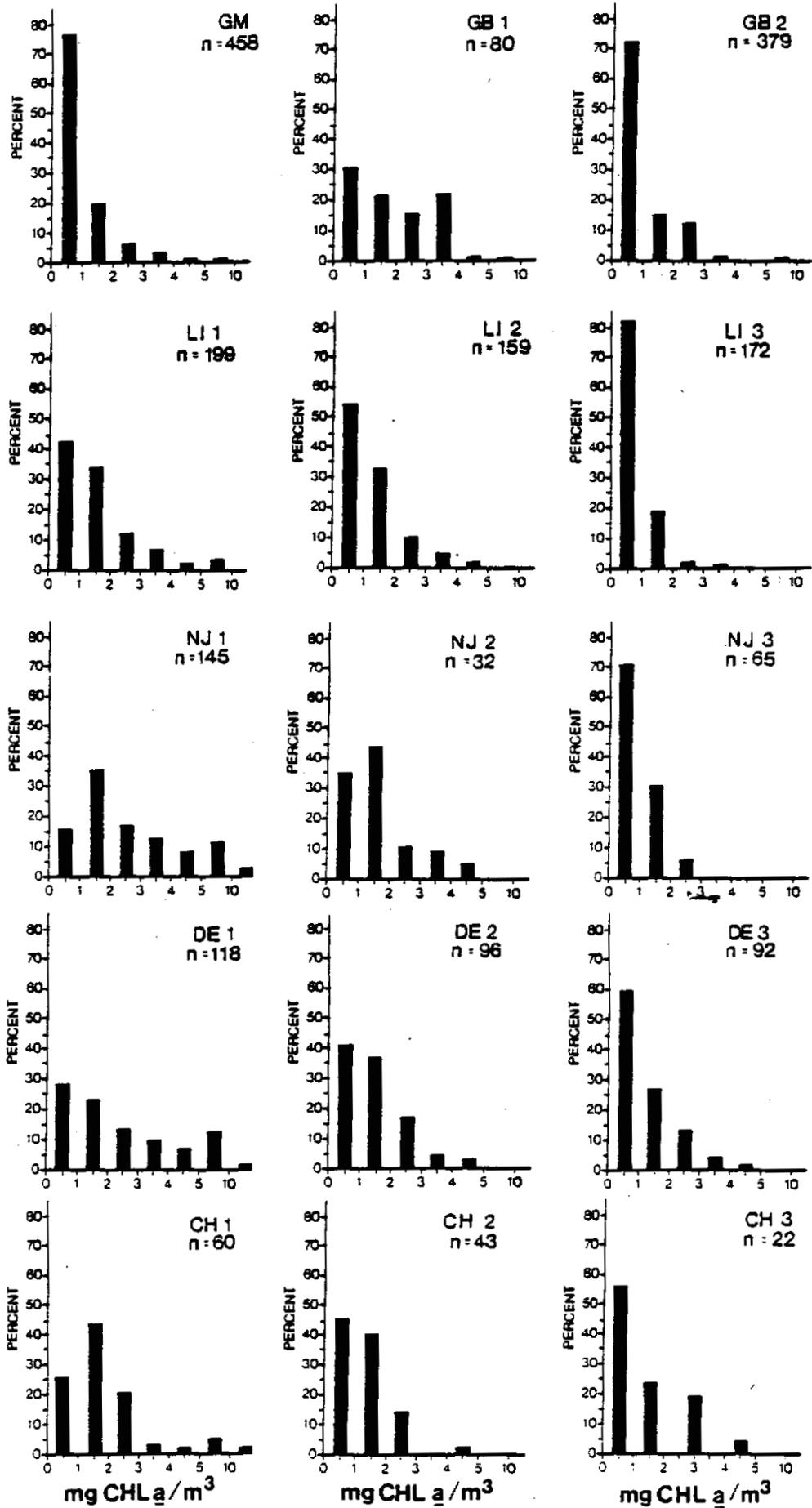


Figure 32. Frequency-percent histogram of chlorophyll a concentration (weighted water column average for each station) by shell region. Ordinate = percent of total observations within a region.

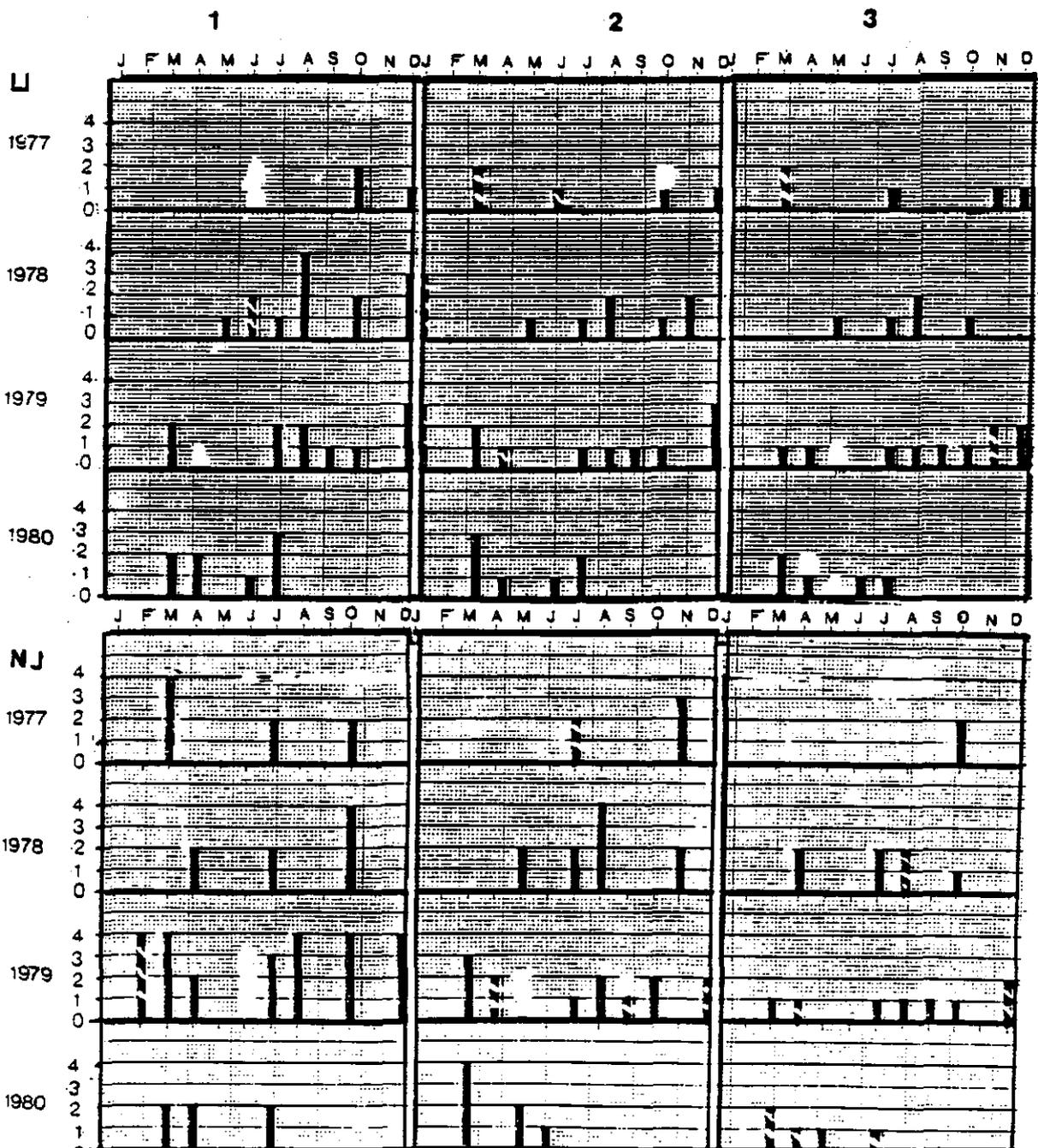
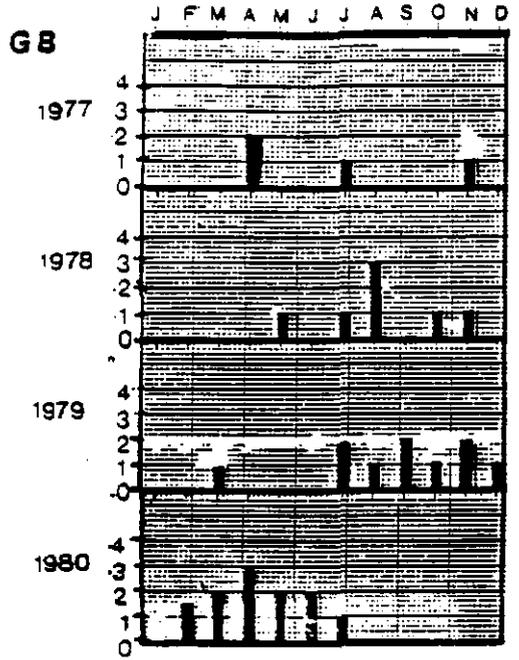
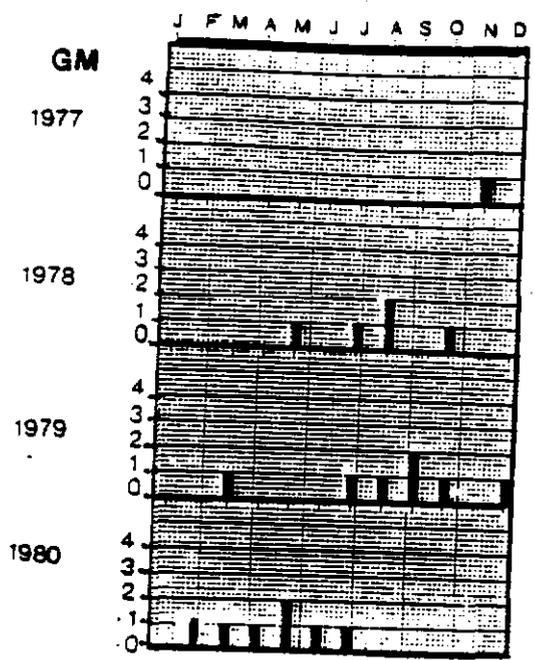


Figure 33. Weighted average water column concentration of chlorophyll versus month for each region in the shelf during 1977, 1978, 1979, 1980. See Figure 10 for map of regions.

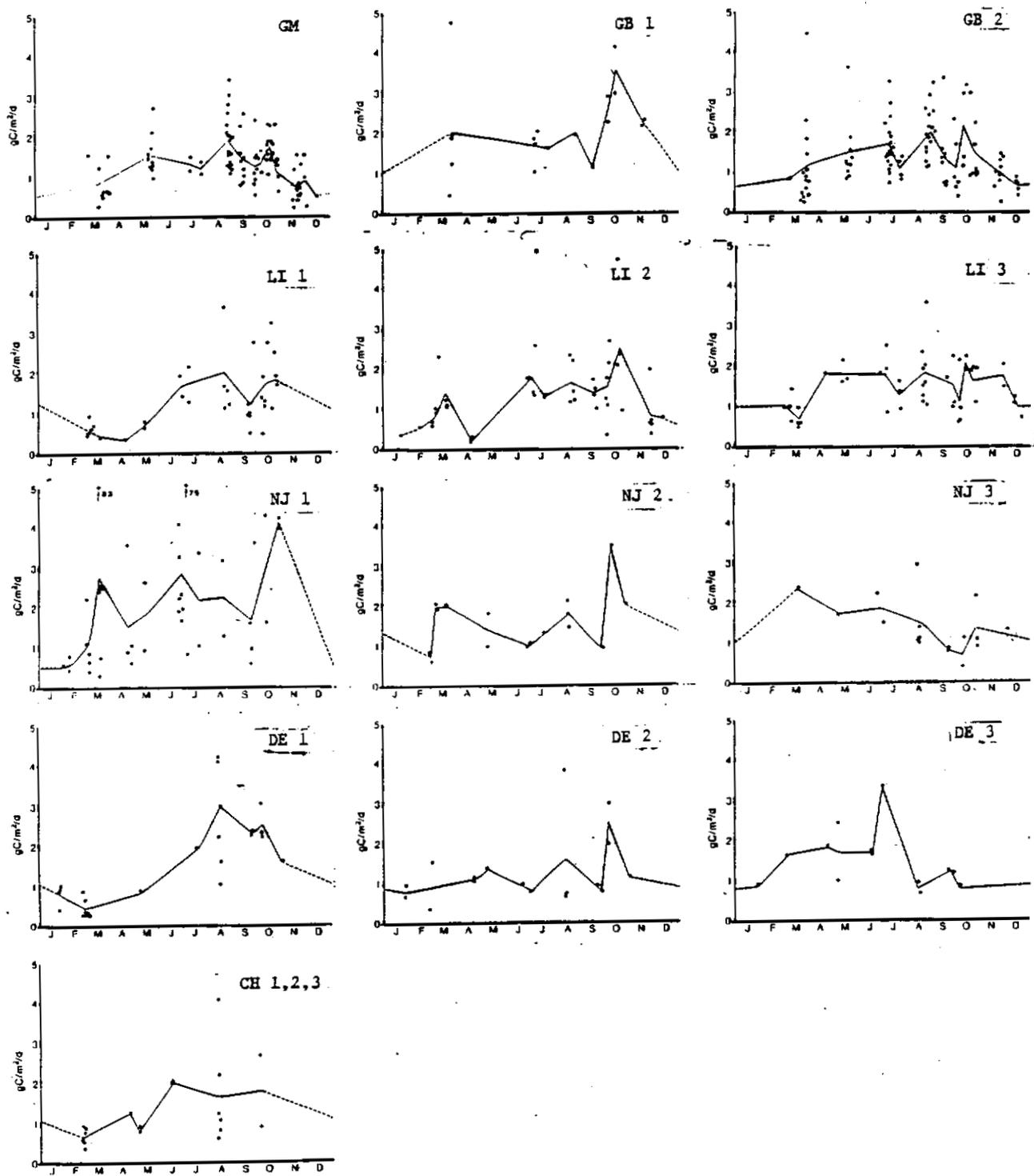


Figure 34. Daily integral phytoplankton production plotted against time for 13 regions of the Cape Hatteras-Nova Scotia Shelf.

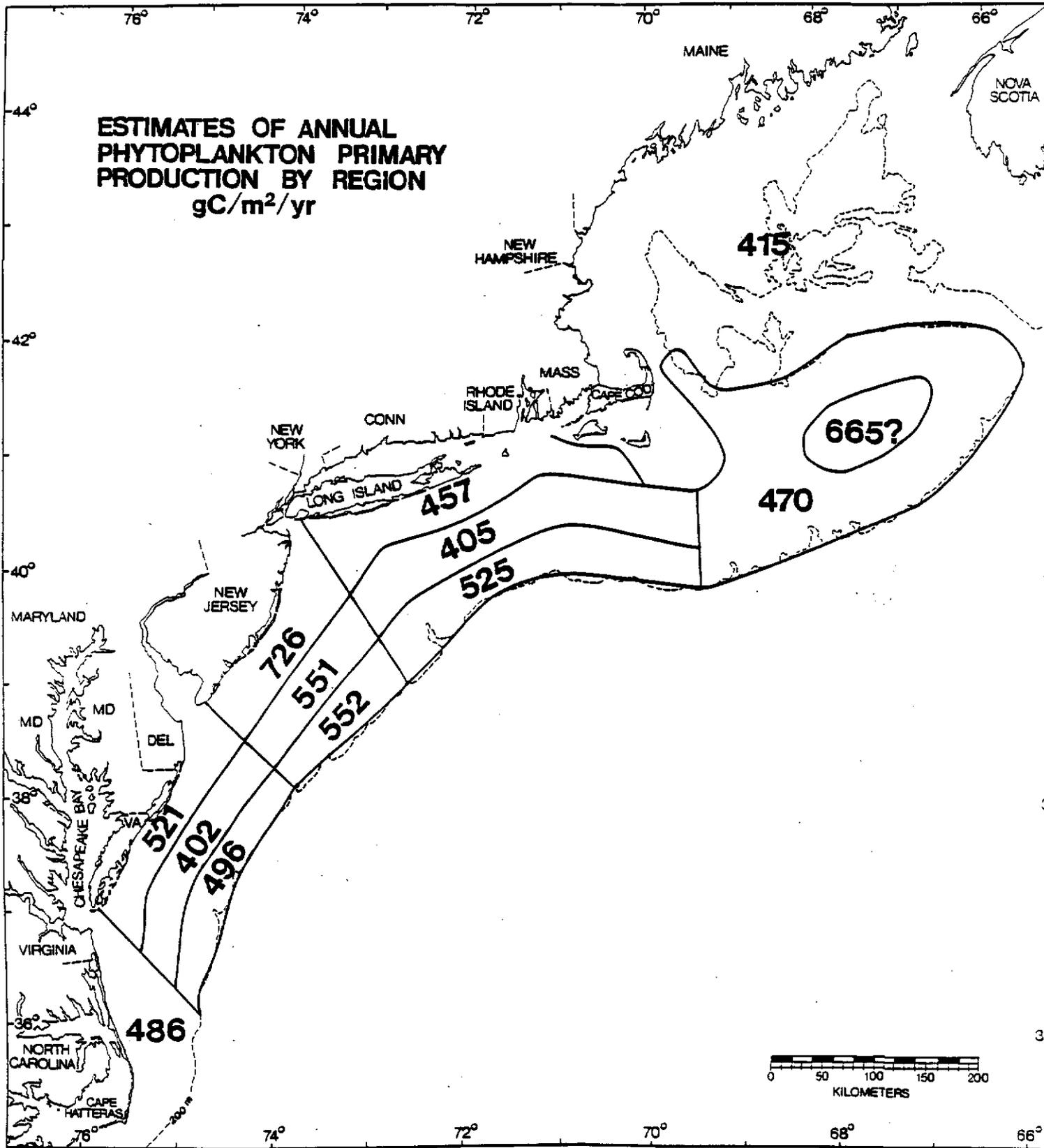


Figure 35. Annual total (particulate and dissolved) primary production by region.

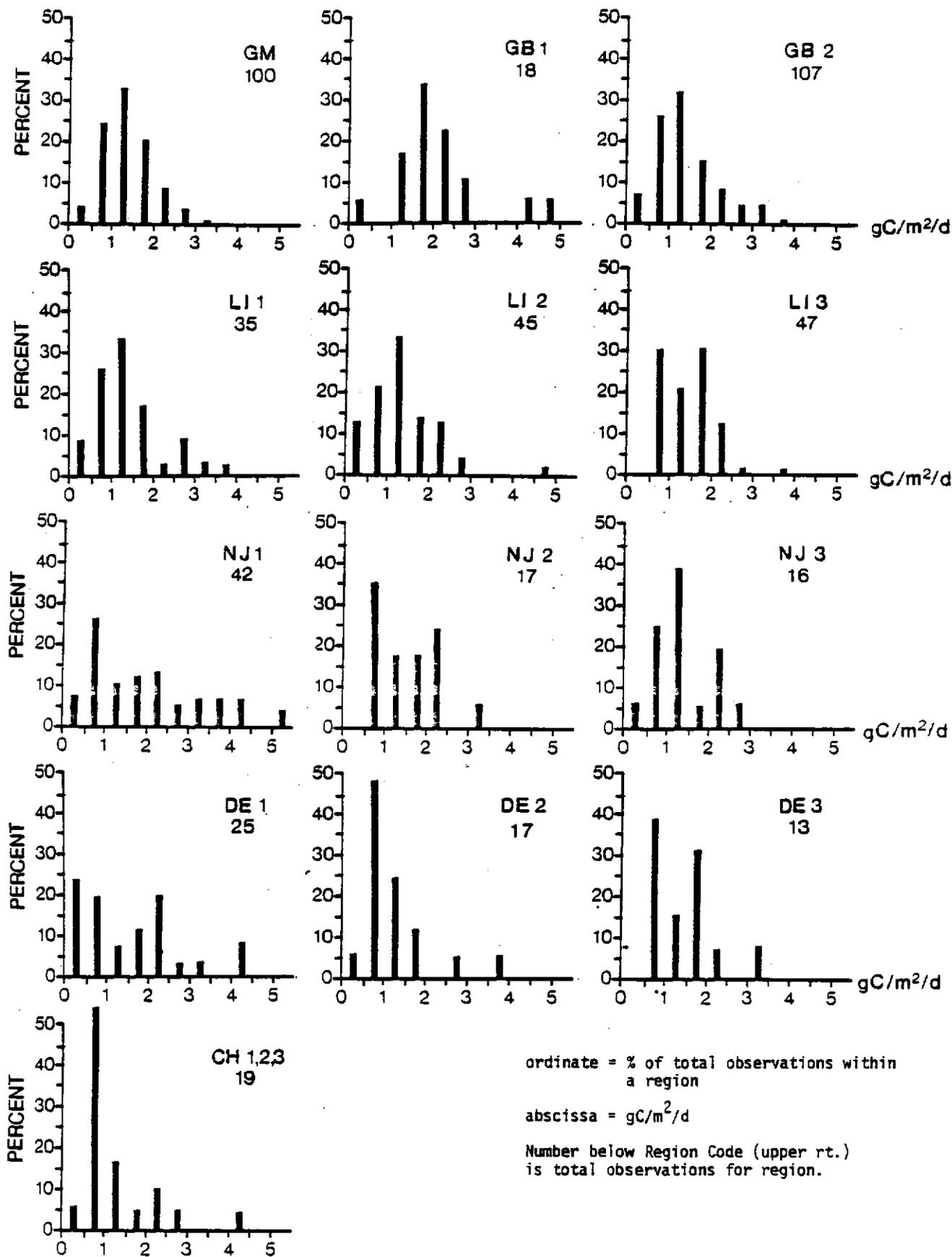


Figure 36. Frequency-percent histogram of daily integral phytoplankton production by shelf region.

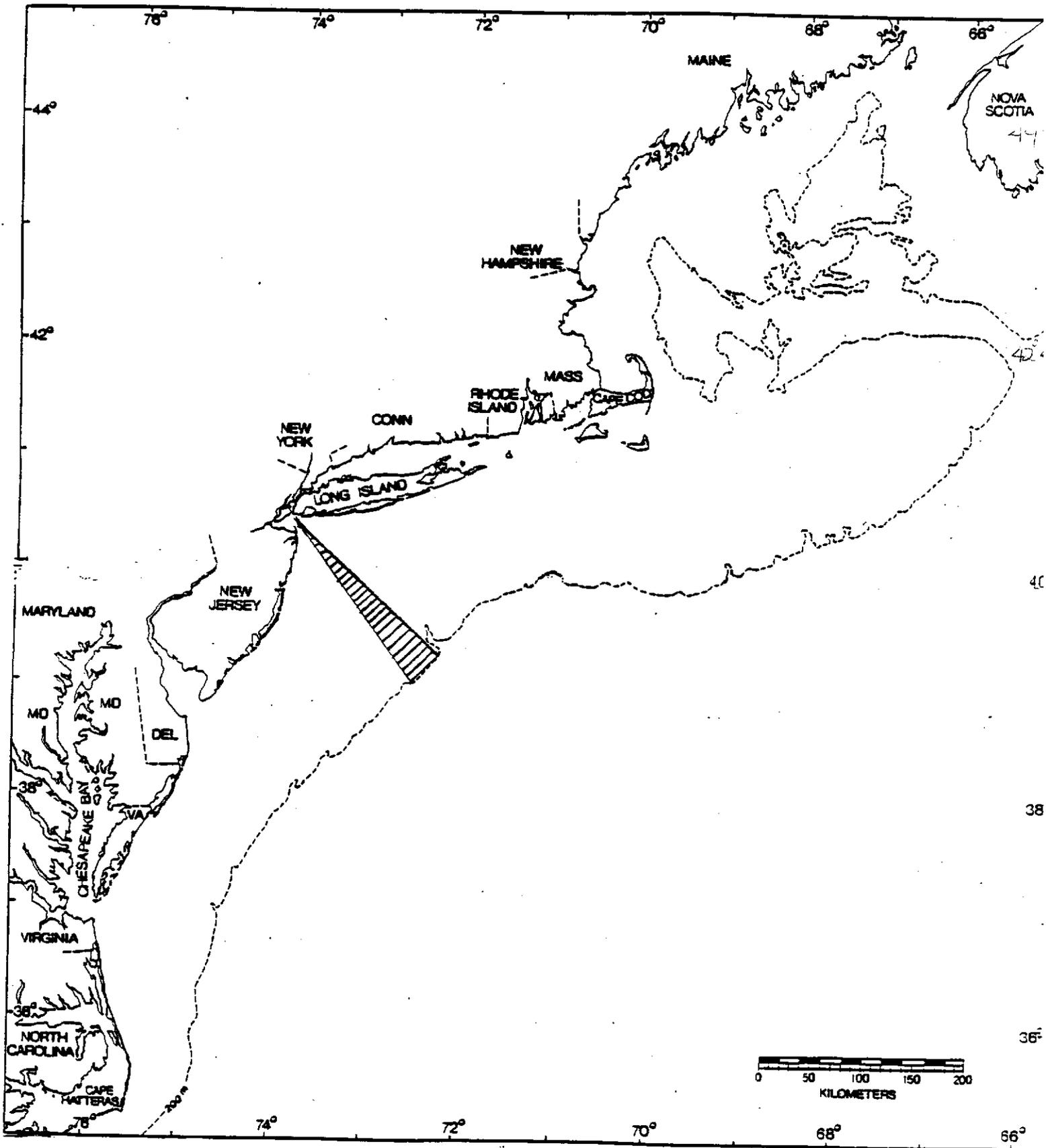


Figure 37. Map depicting the location of transects profiled for ammonium nutrient concentrations.

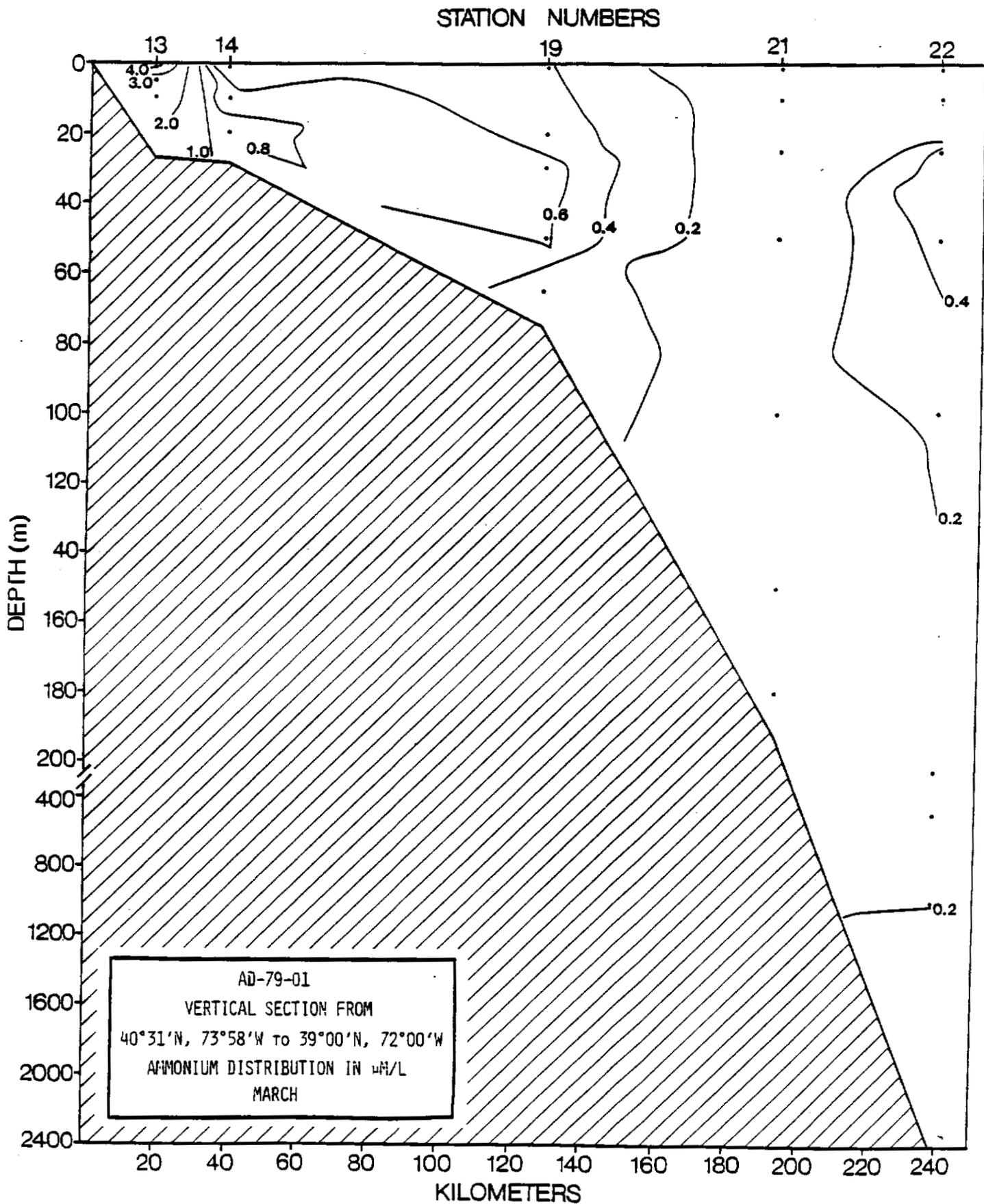


Figure 38. Cross shelf profile of ammonium in April 1979.

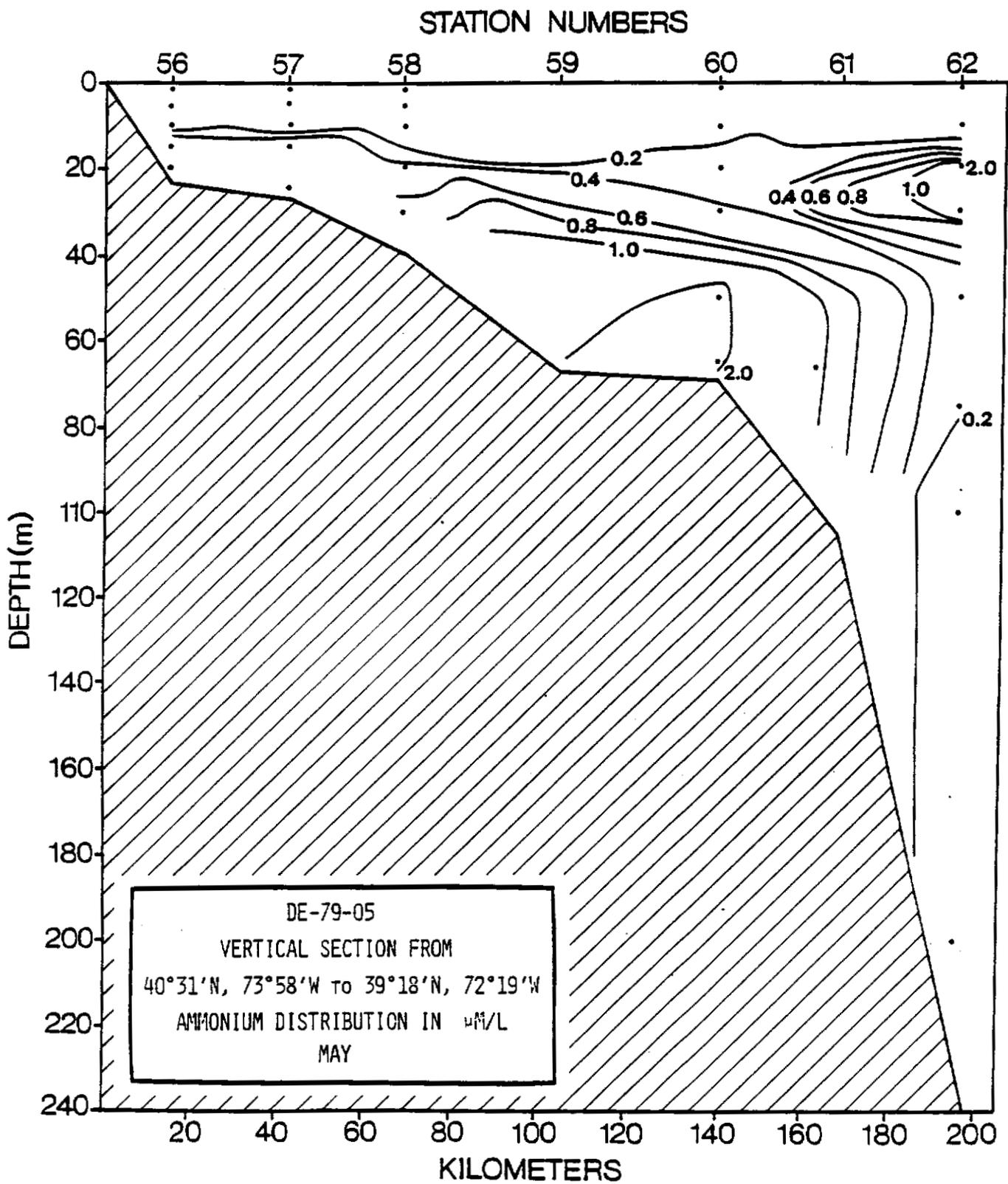


Figure 39. Cross shelf profile of ammonium in May 1979.

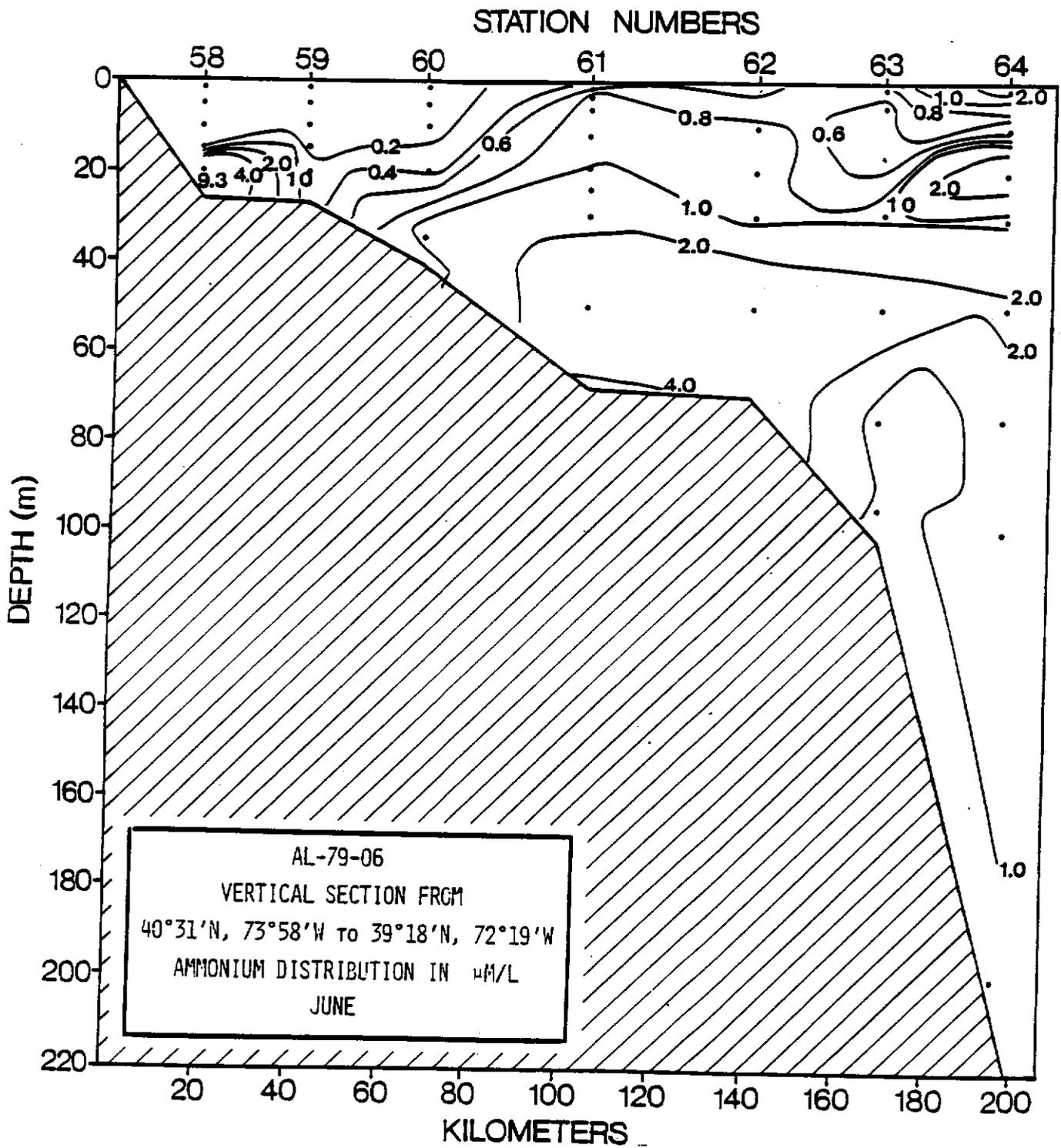


Figure 40. Cross shelf profile of ammonium in June 1979.

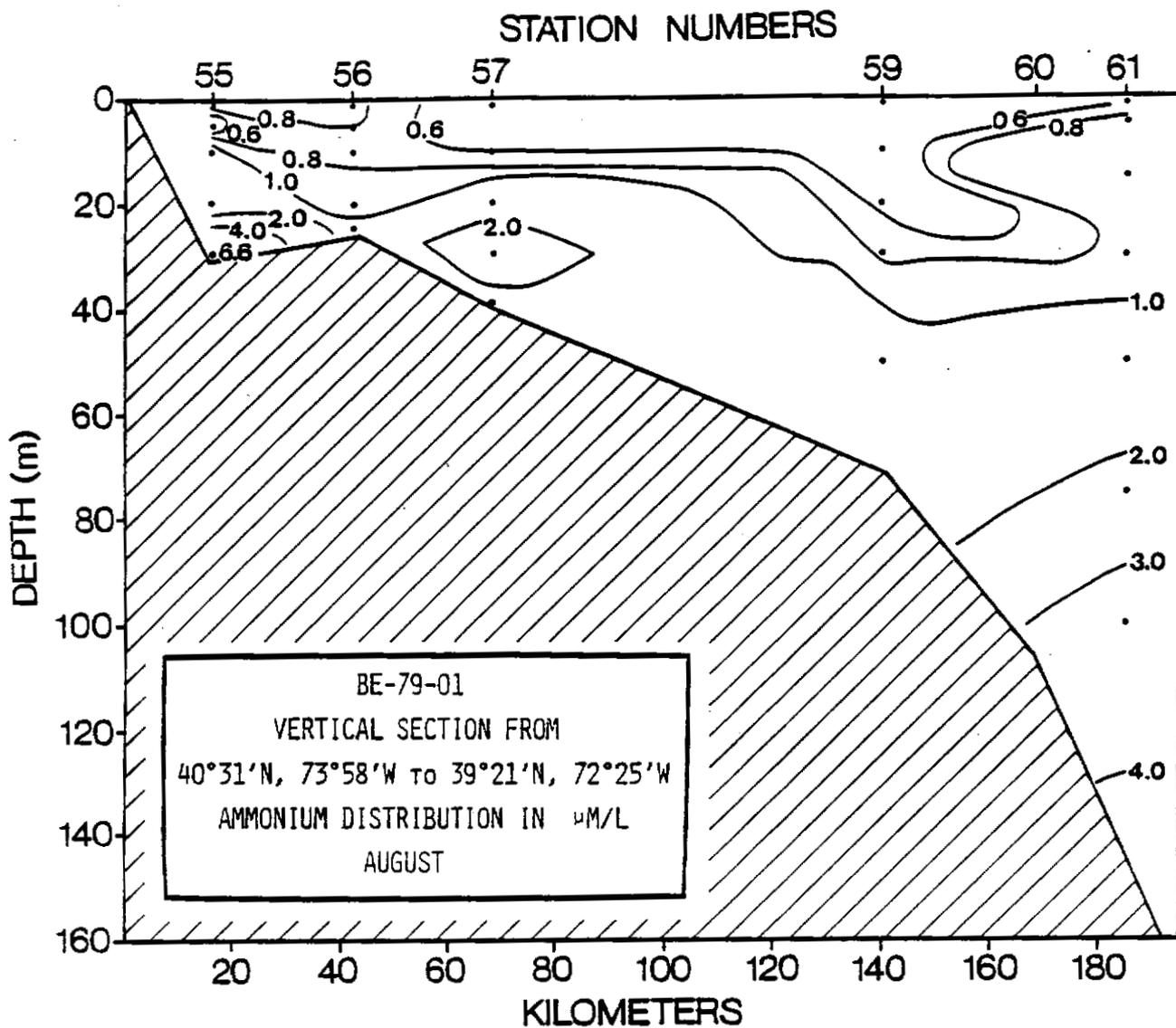


Figure 42. Cross shelf profile of ammonium in August 1979.

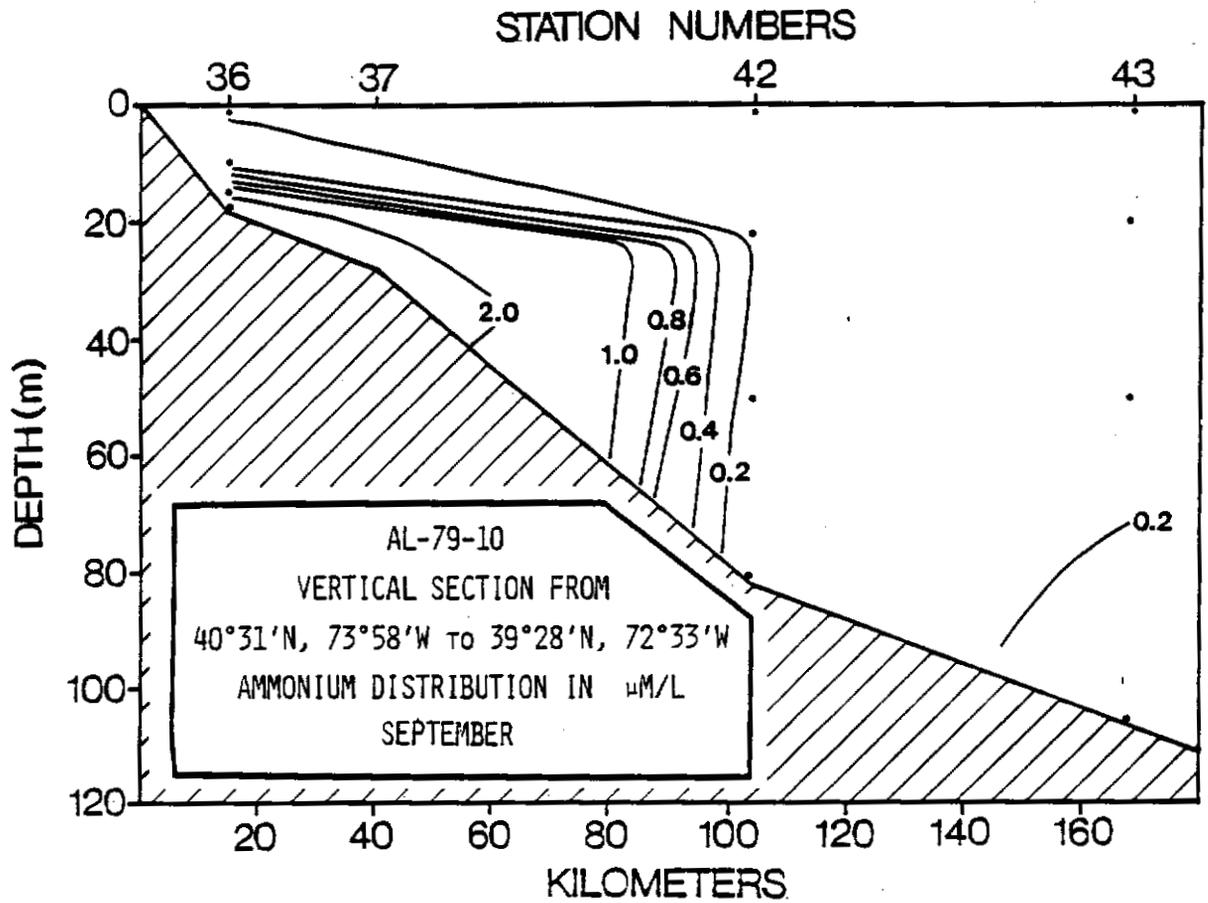


Figure 43. Cross shelf profile of ammonium in September 1979.

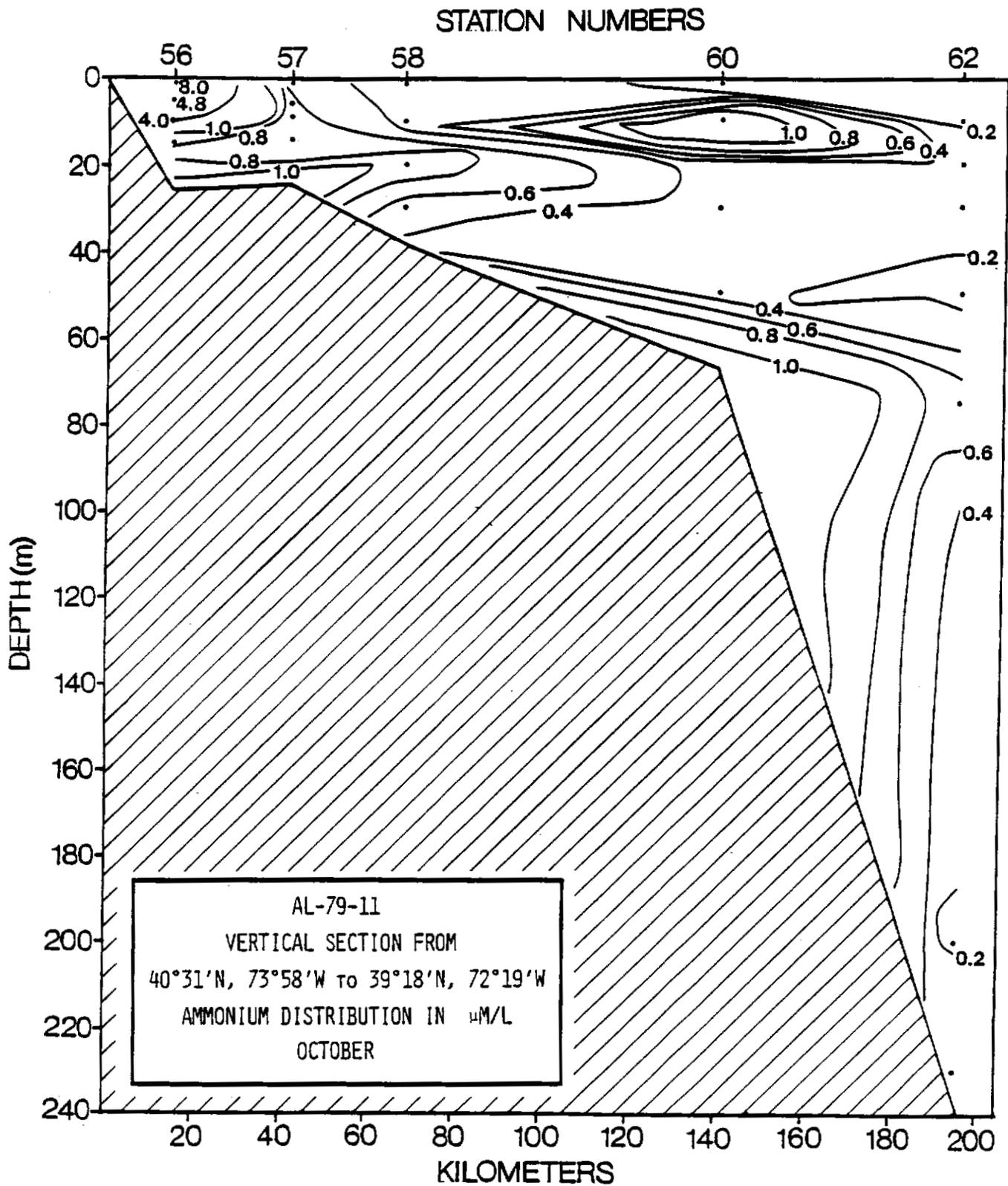


Figure 44. Cross shelf profile of ammonium in October 1979.

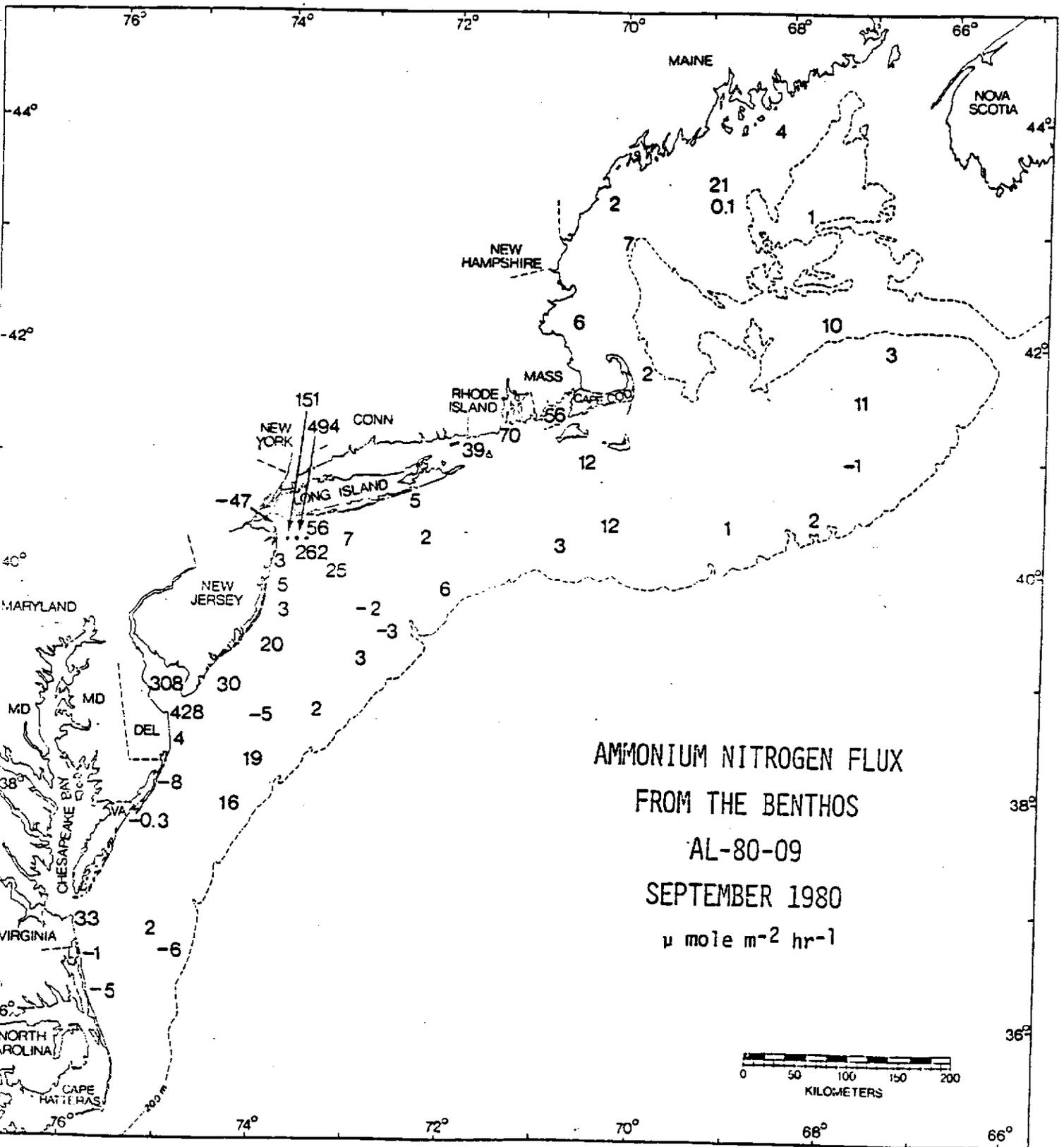


Figure 45. Shelf-wide distribution of rates of ammonium flux from the benthos. Negative values indicate flux was from water to sediment.

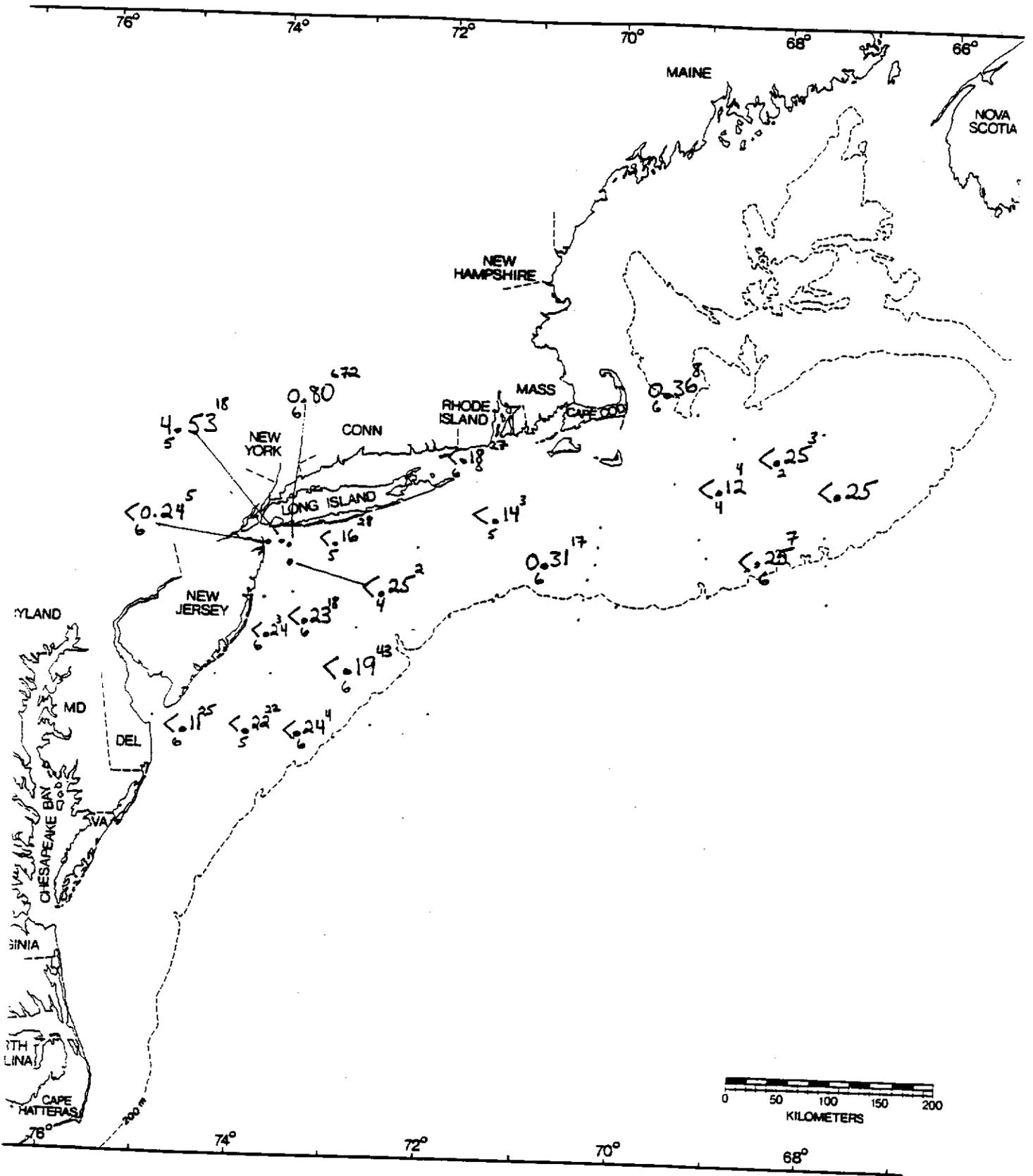


Figure 47. Distribution of cadmium (ppm, dry weight) in sediments collected during the Albatross 79-07 survey.

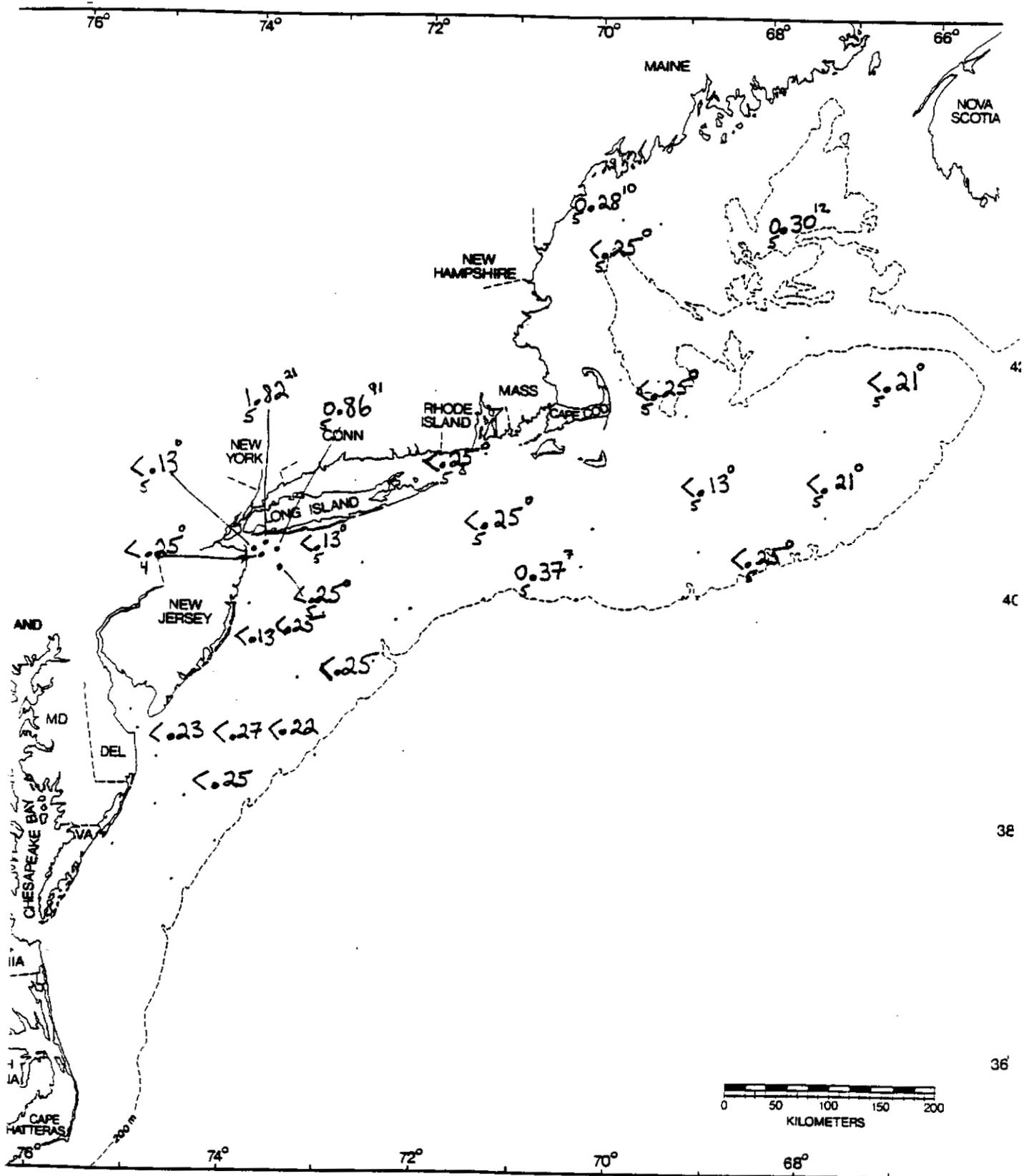


Figure 48. Distribution of cadmium (ppm, dry weight) in sediments collected during the Albatross 79-10 survey.

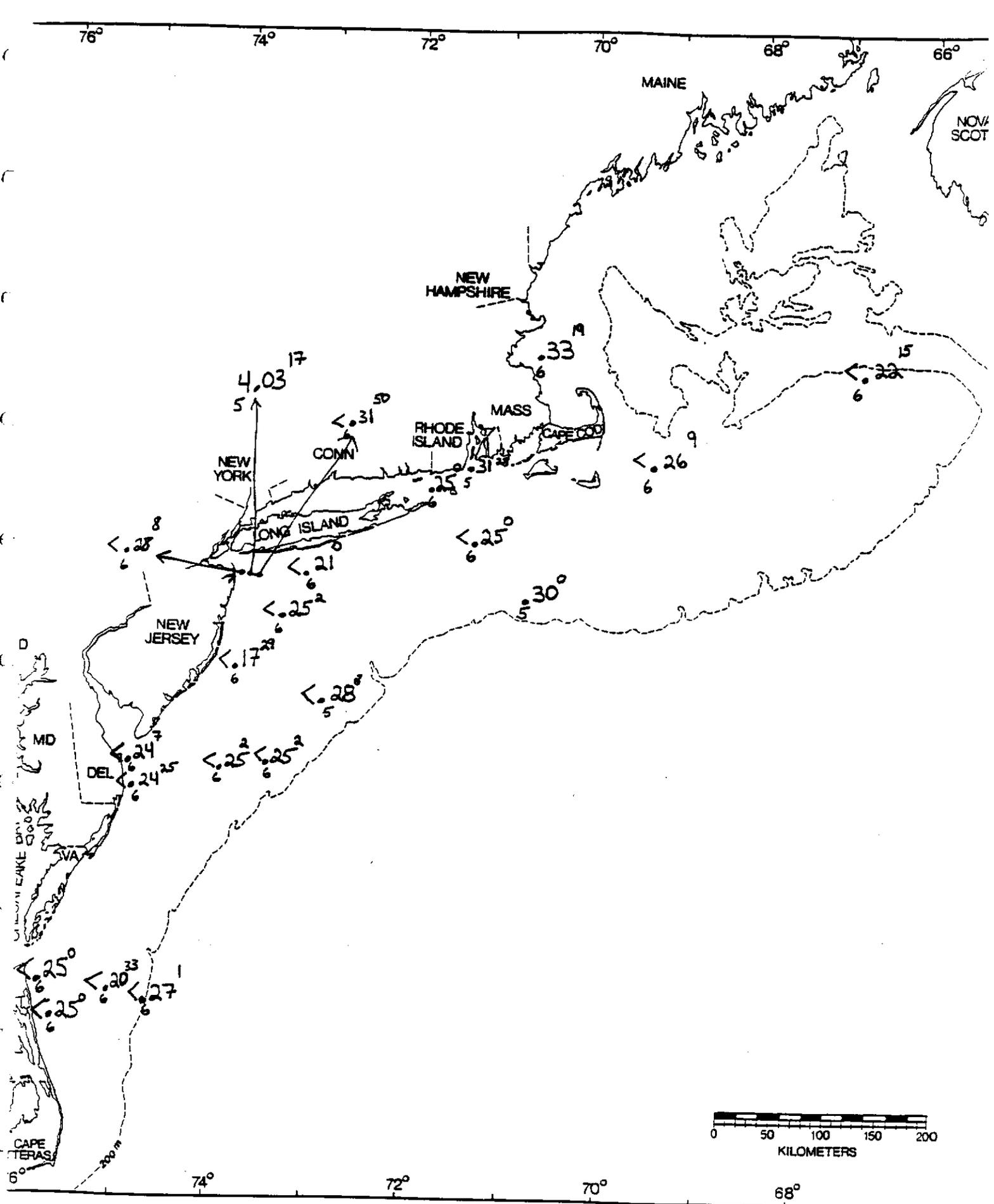


Figure 50. Distribution of cadmium (ppm, dry weight) in sediments collected during Delaware 79-11 survey.

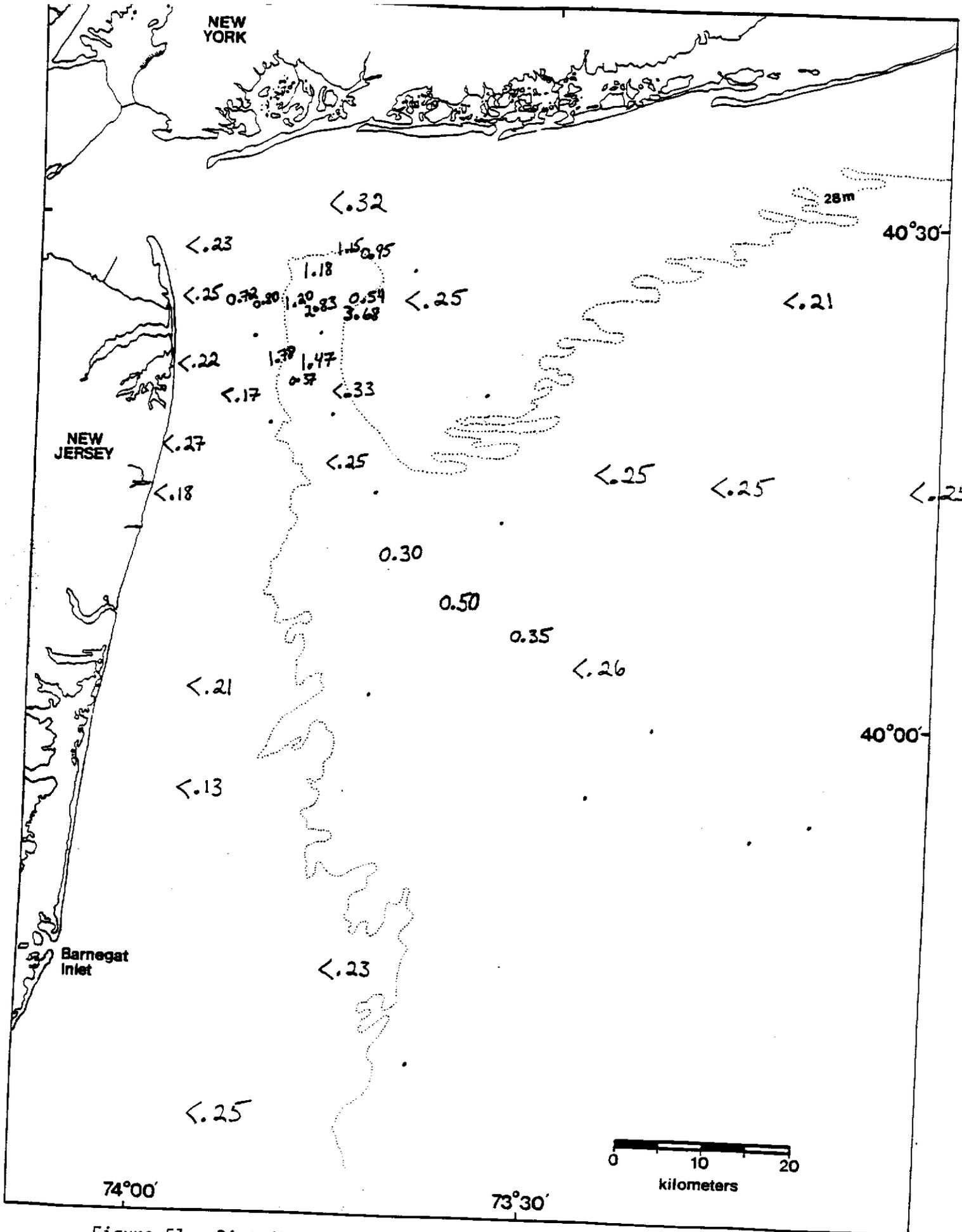


Figure 51. Distribution of cadmium (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

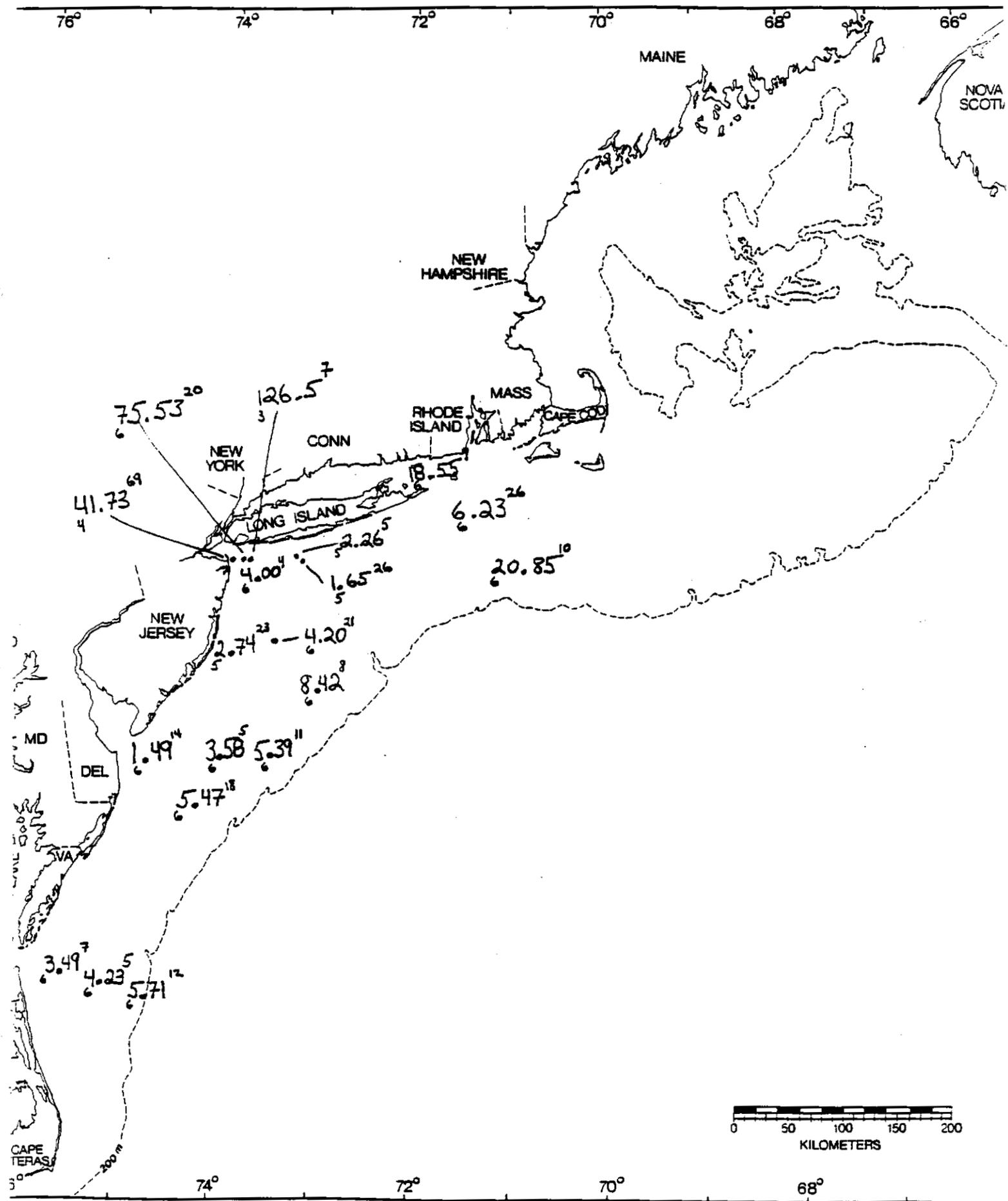


Figure 53. Distribution of chromium (ppm, dry weight) in sediments collected during the Advance 79-01 survey.

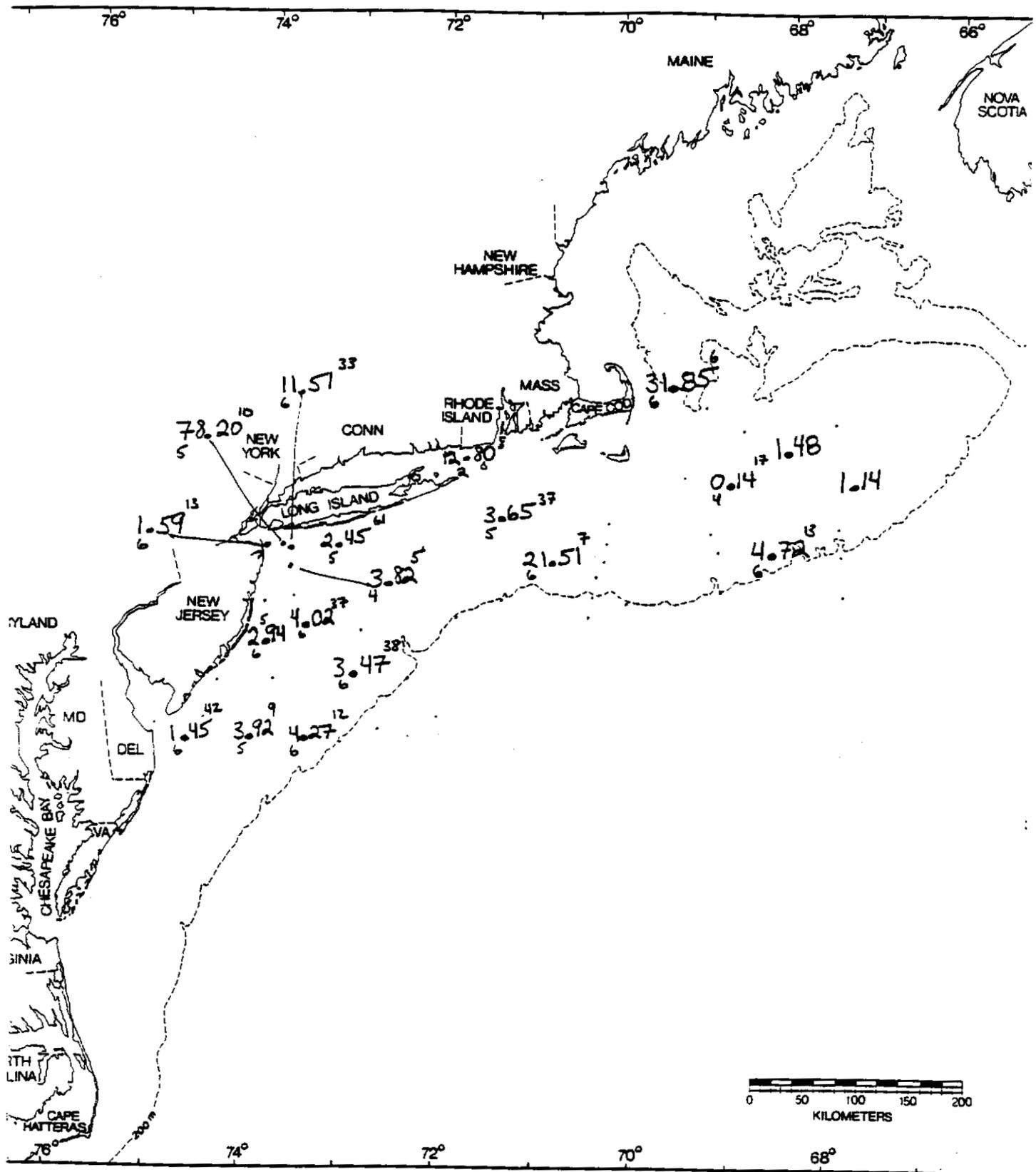


Figure 54. Distribution of chromium (ppm, dry weight) in sediments collected during the Albatross 79-07 survey.

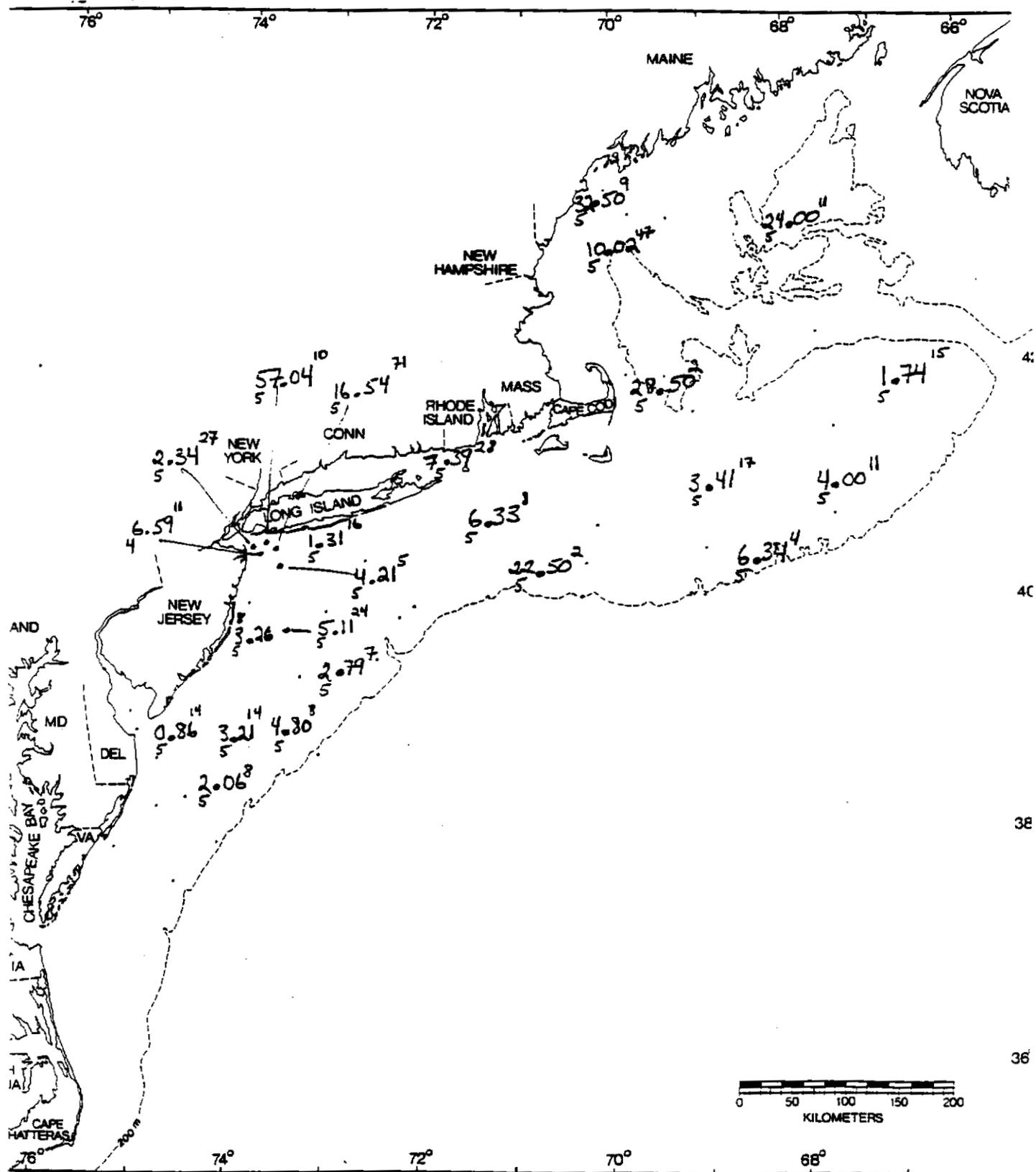


Figure 55. Distribution of chromium (ppm, dry weight) in sediments collected during the Albatross 79-10 survey.

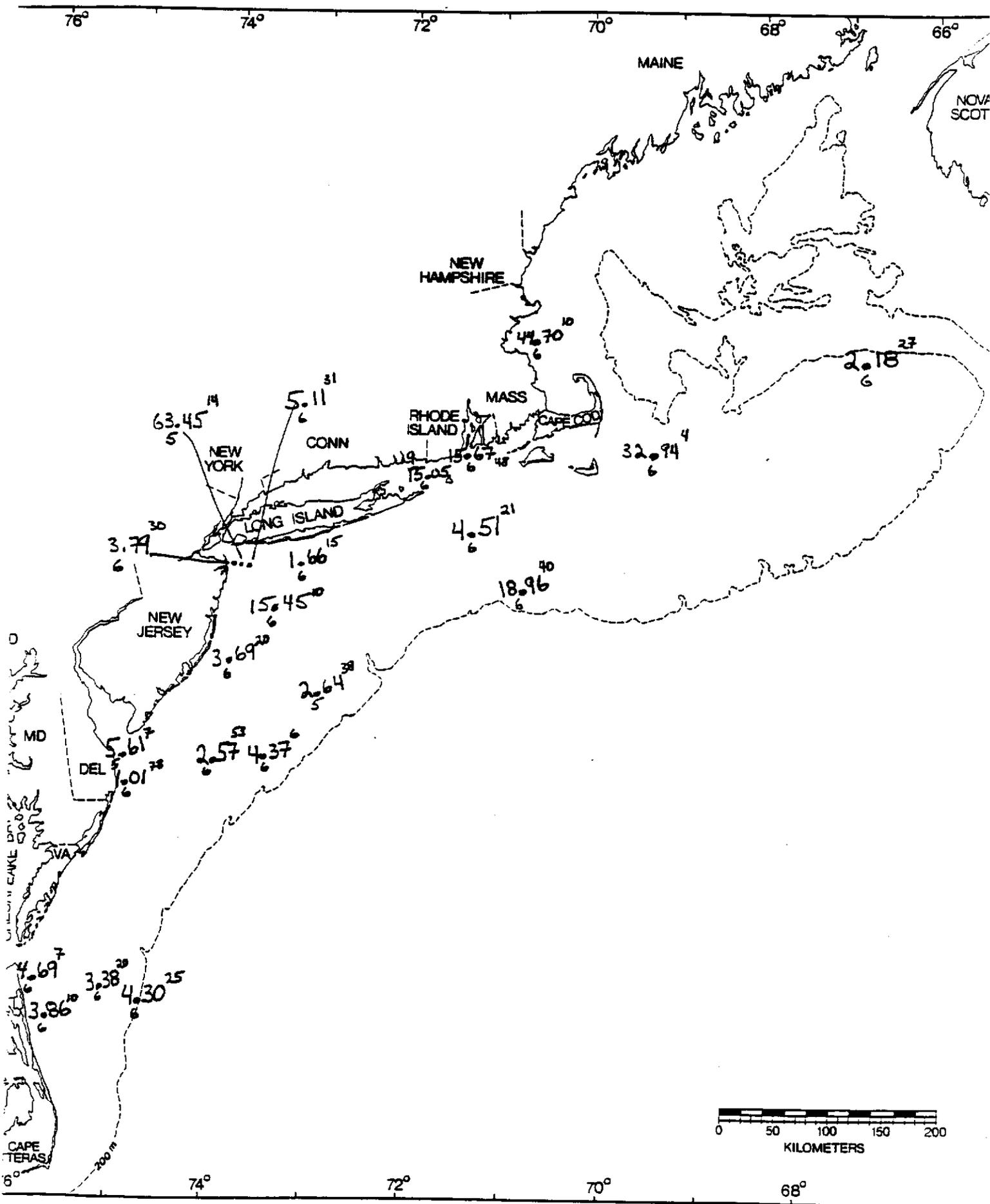


Figure 57. Distribution of chromium (ppm, dry weight) in sediments collected during the Delaware 79-11 survey.

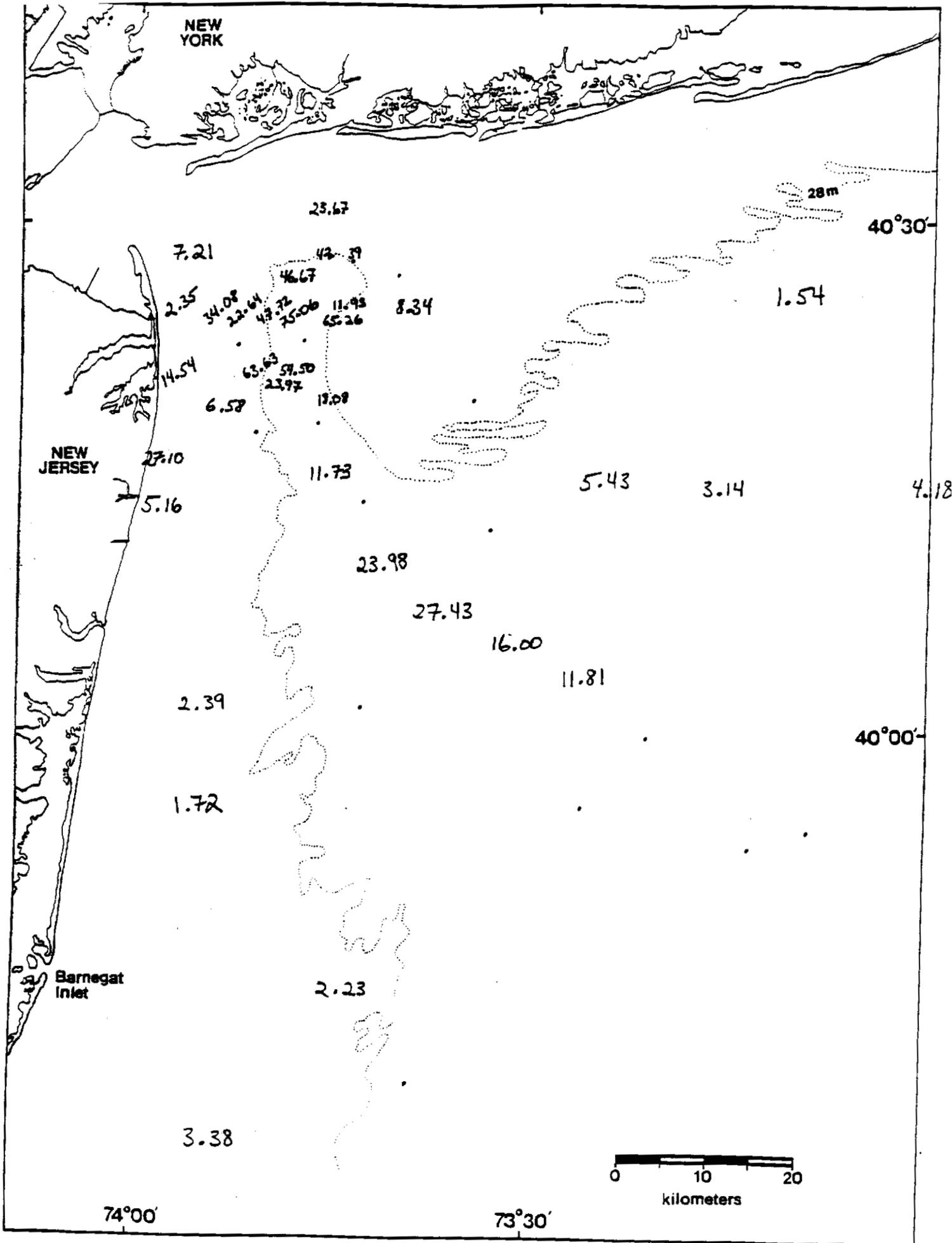


Figure 58. Distribution of chromium (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

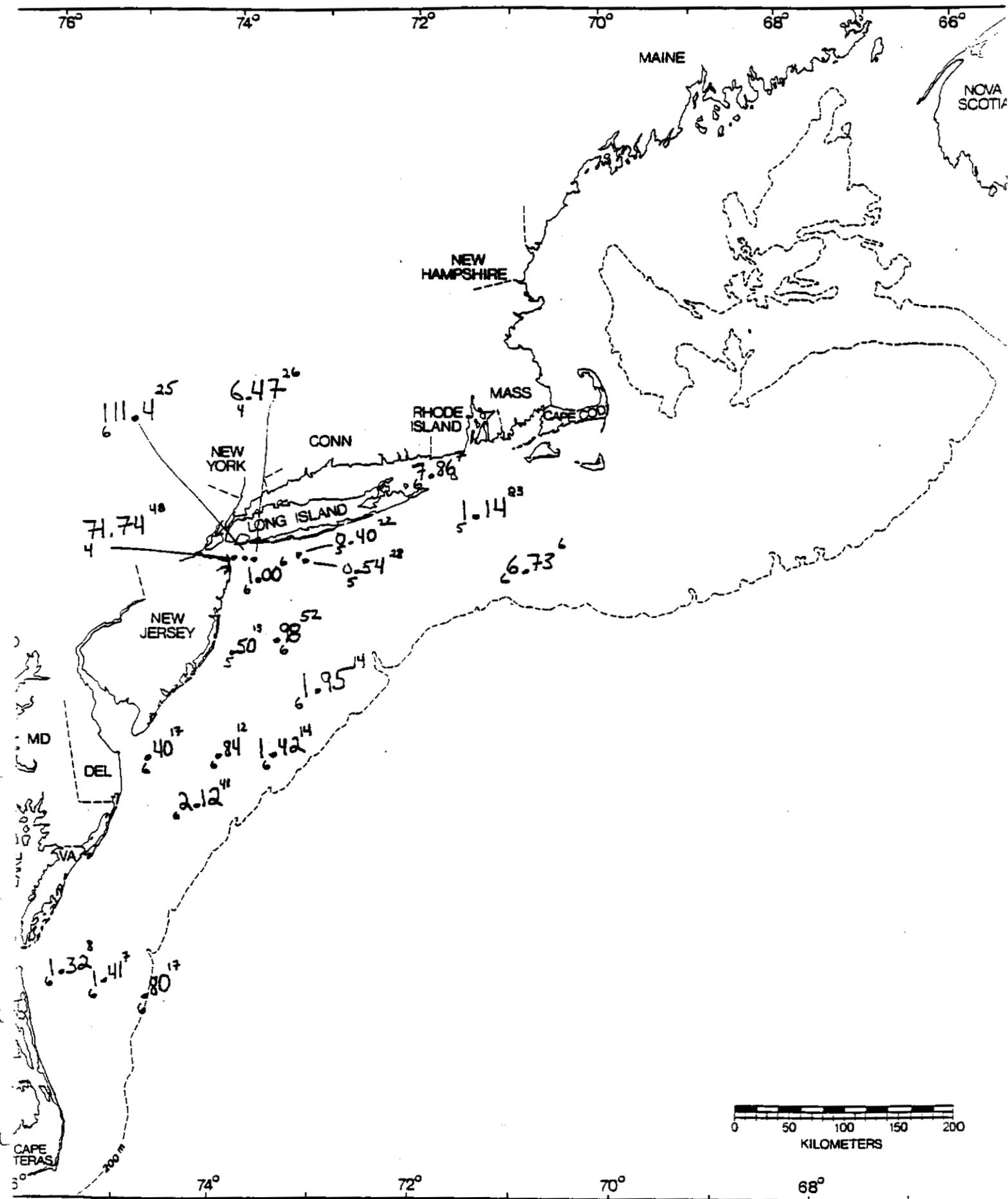


Figure 60. Distribution of copper (ppm, dry weight) in sediments collected during the Advance 79-01 survey.

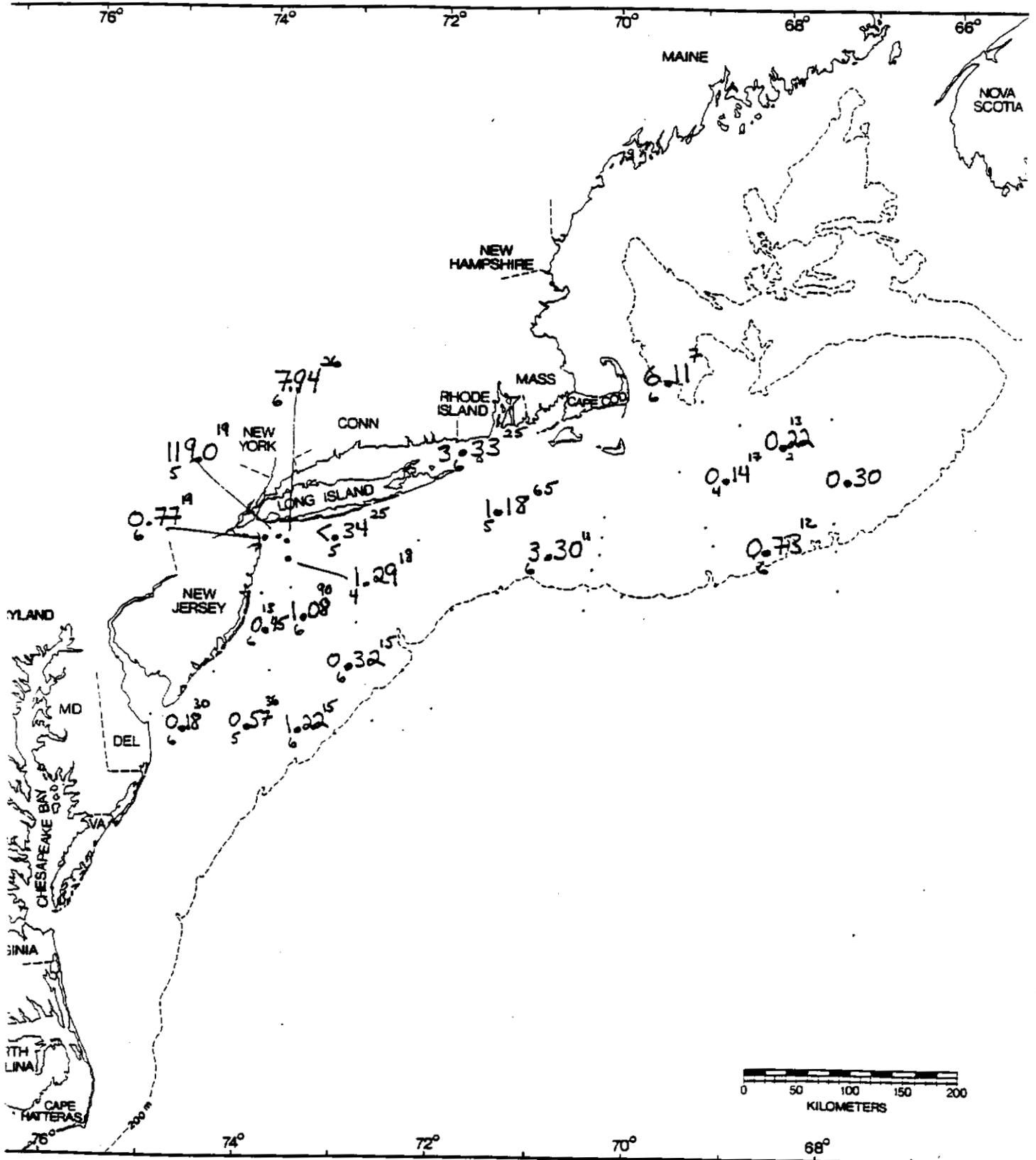


Figure 6T. Distribution of copper (ppm, dry weight) in sediments collected during the Albatross 79-07 survey.

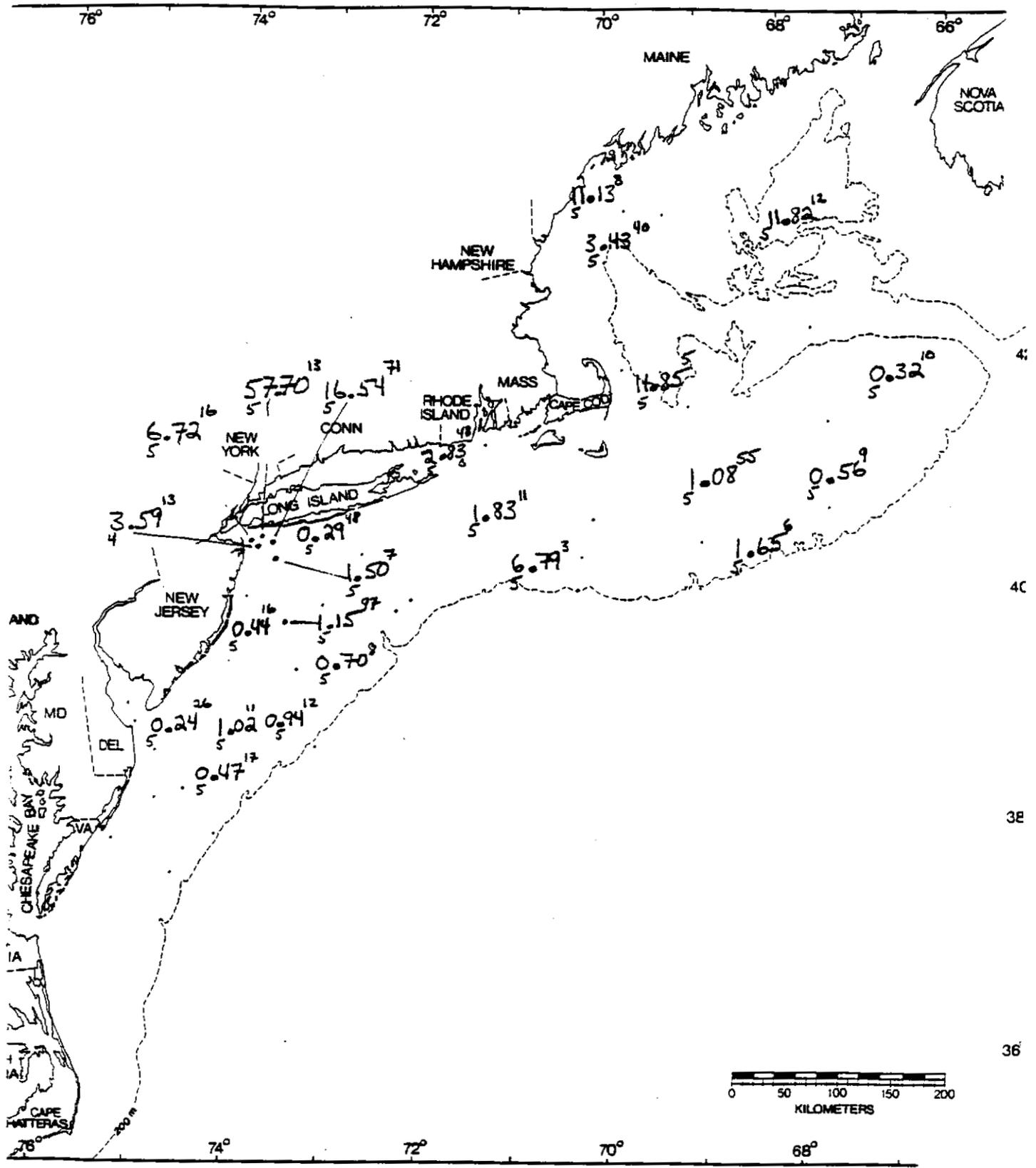


Figure 62. Distribution of copper (ppm, dry weight) in sediments collected during the Albatross 79-10 survey.

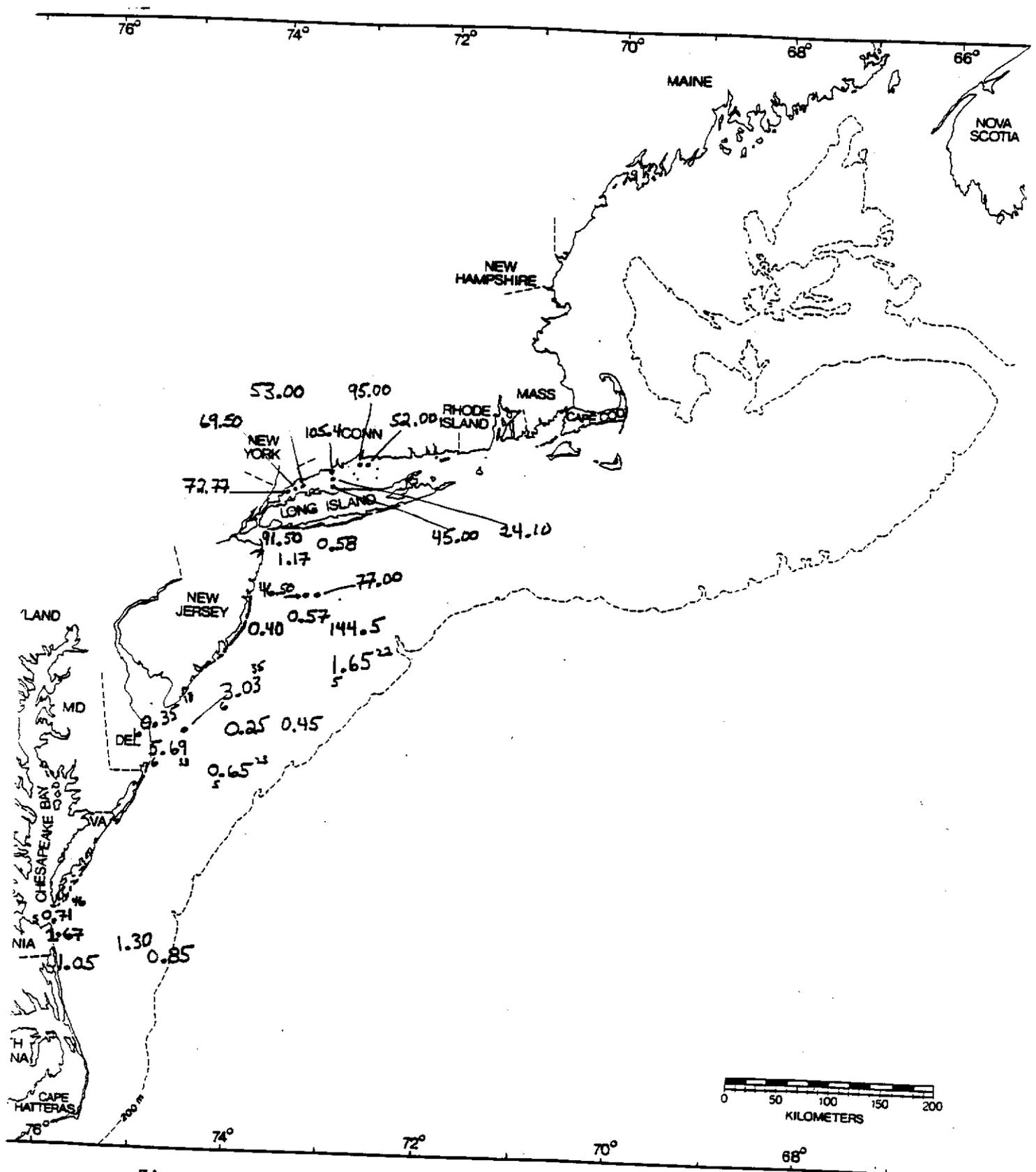


Figure 63. Distribution of copper (ppm, dry weight) in sediments collected during the Kelez 79-10 survey.

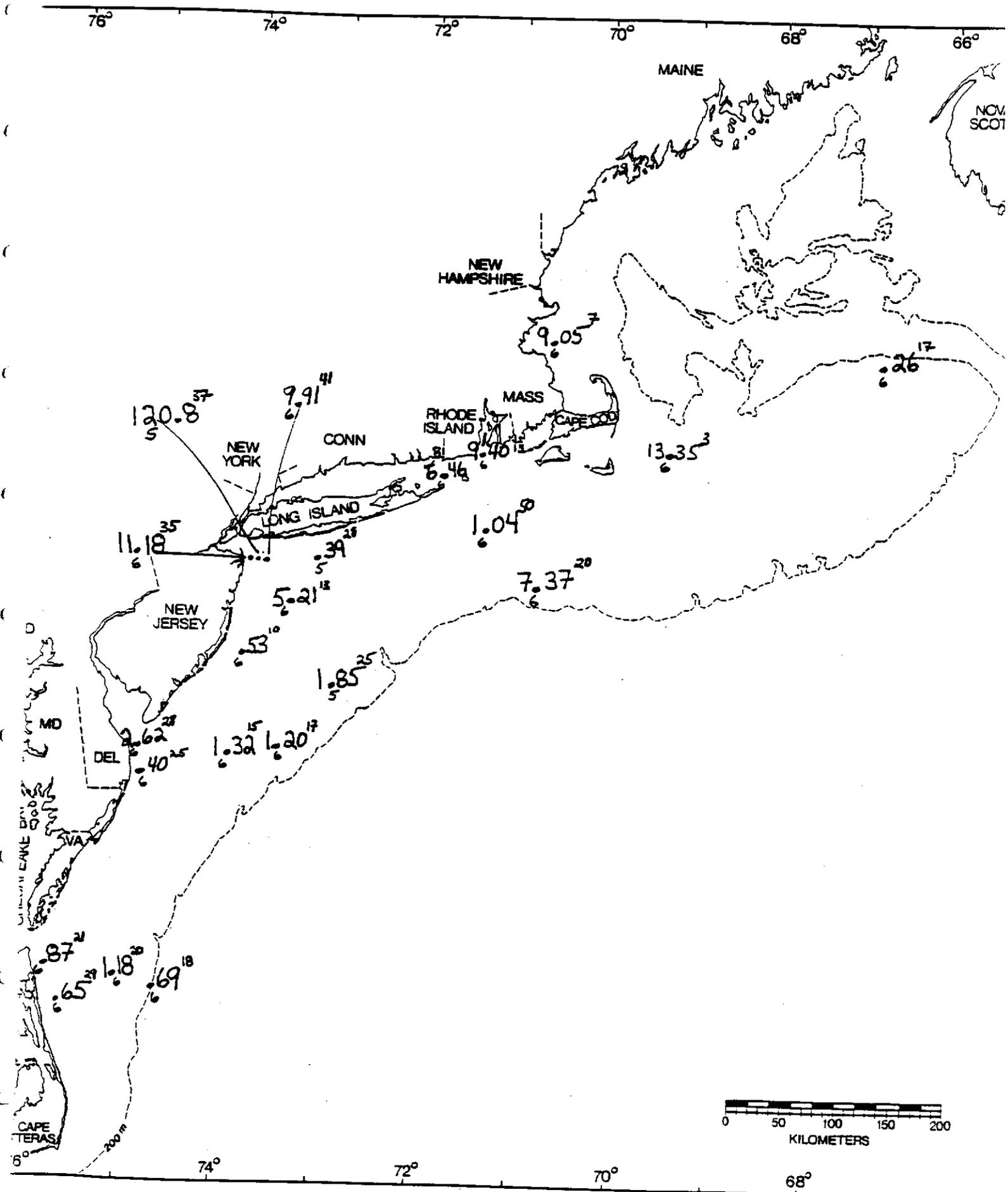


Figure 64. Distribution of copper (ppm, dry weight) in sediments collected during the Delaware 79-11 survey.

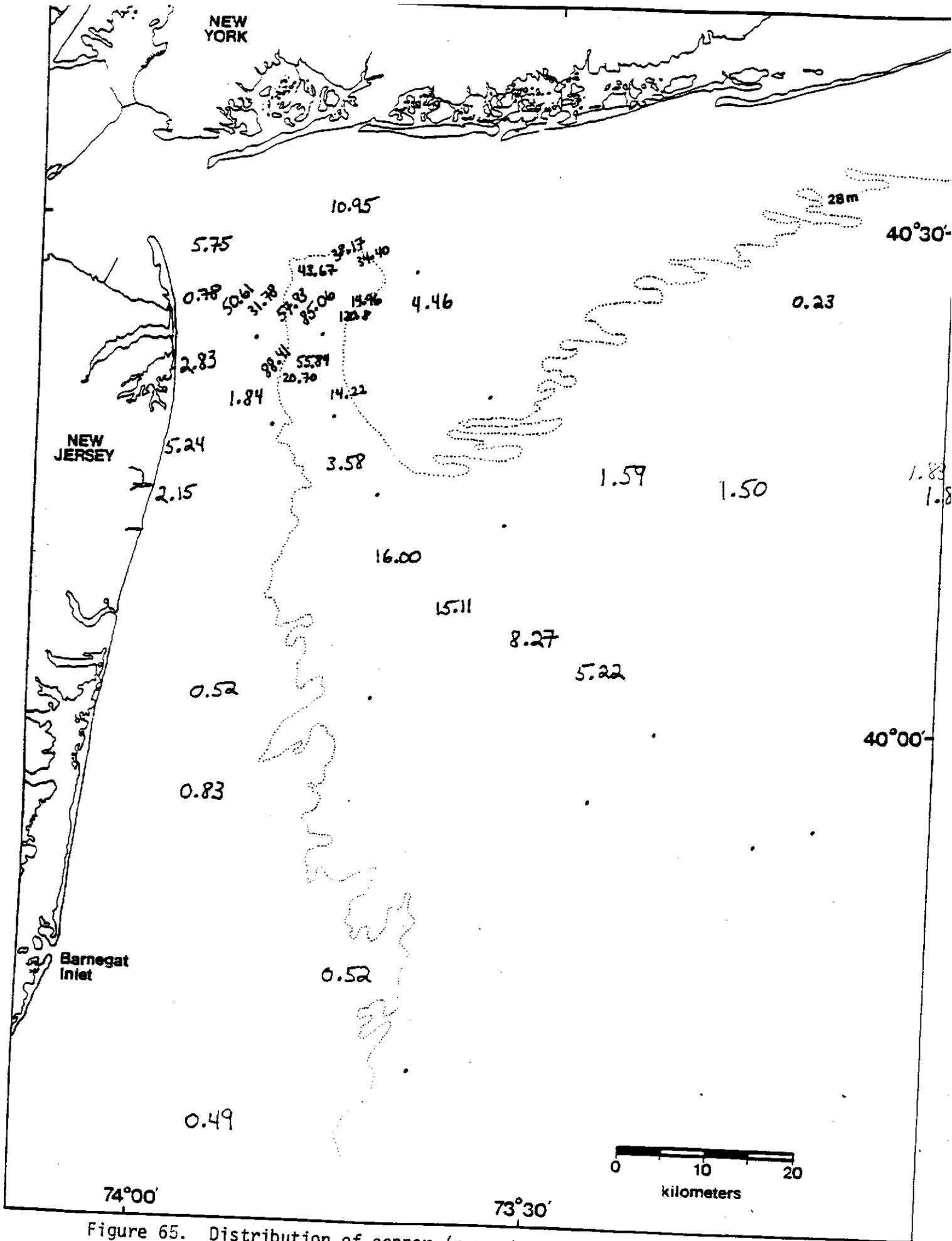


Figure 65. Distribution of copper (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

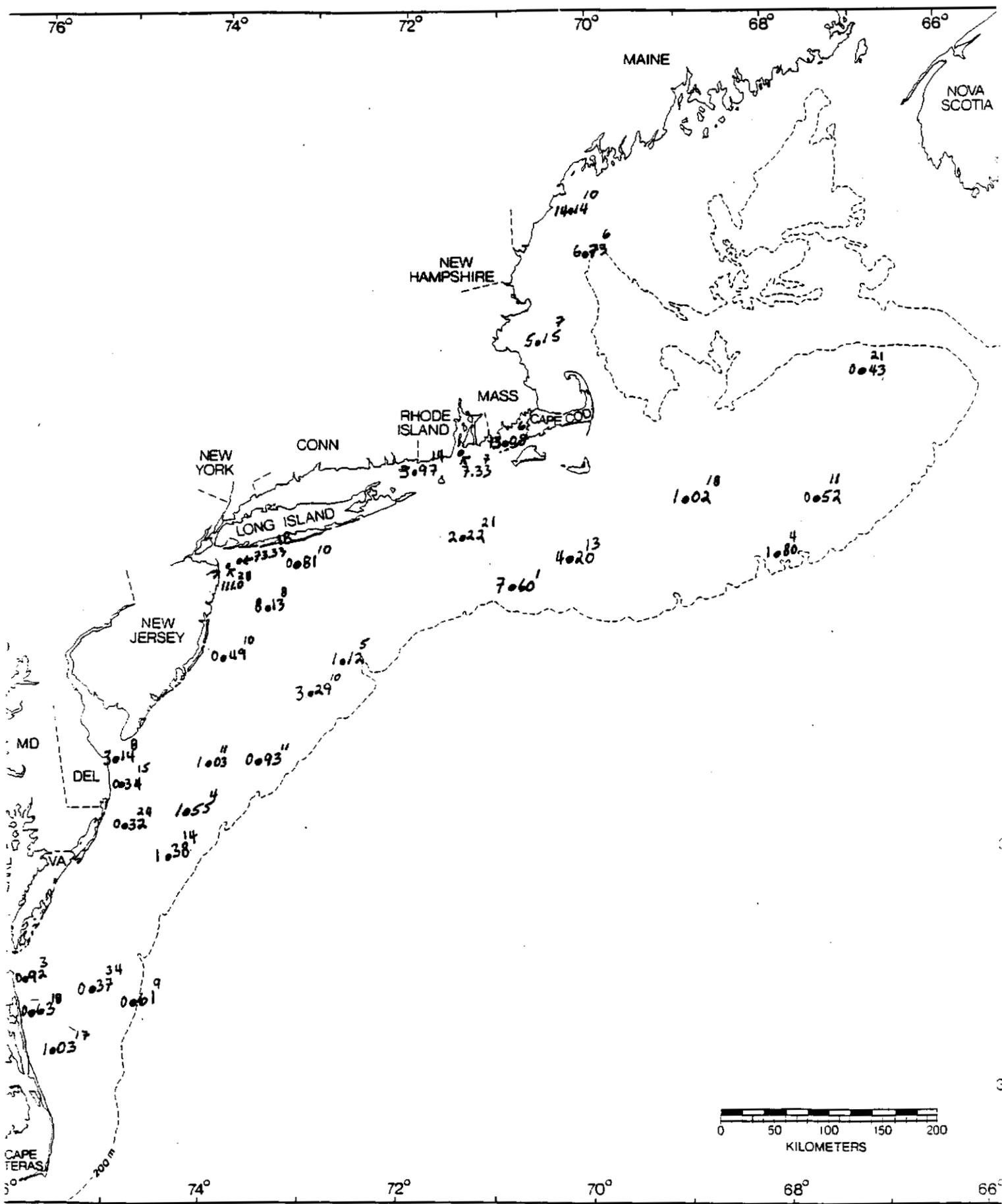


Figure 66. Distribution of copper (ppm, dry weight) in sediments collected during the Albatross 80-09 survey.

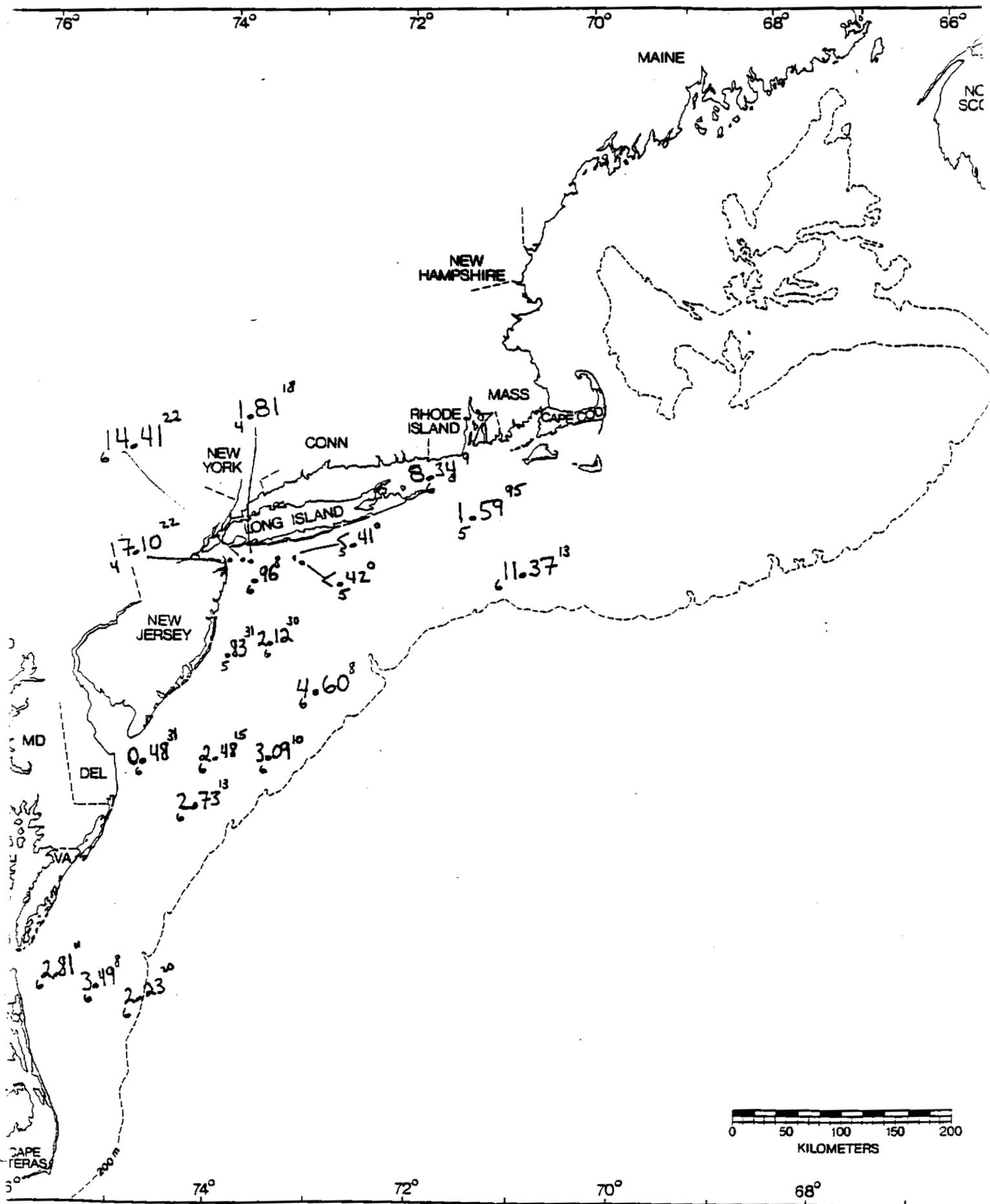


Figure 67. Distribution of nickel (ppm, dry weight) in sediments collected during the Advance 79-01 survey.

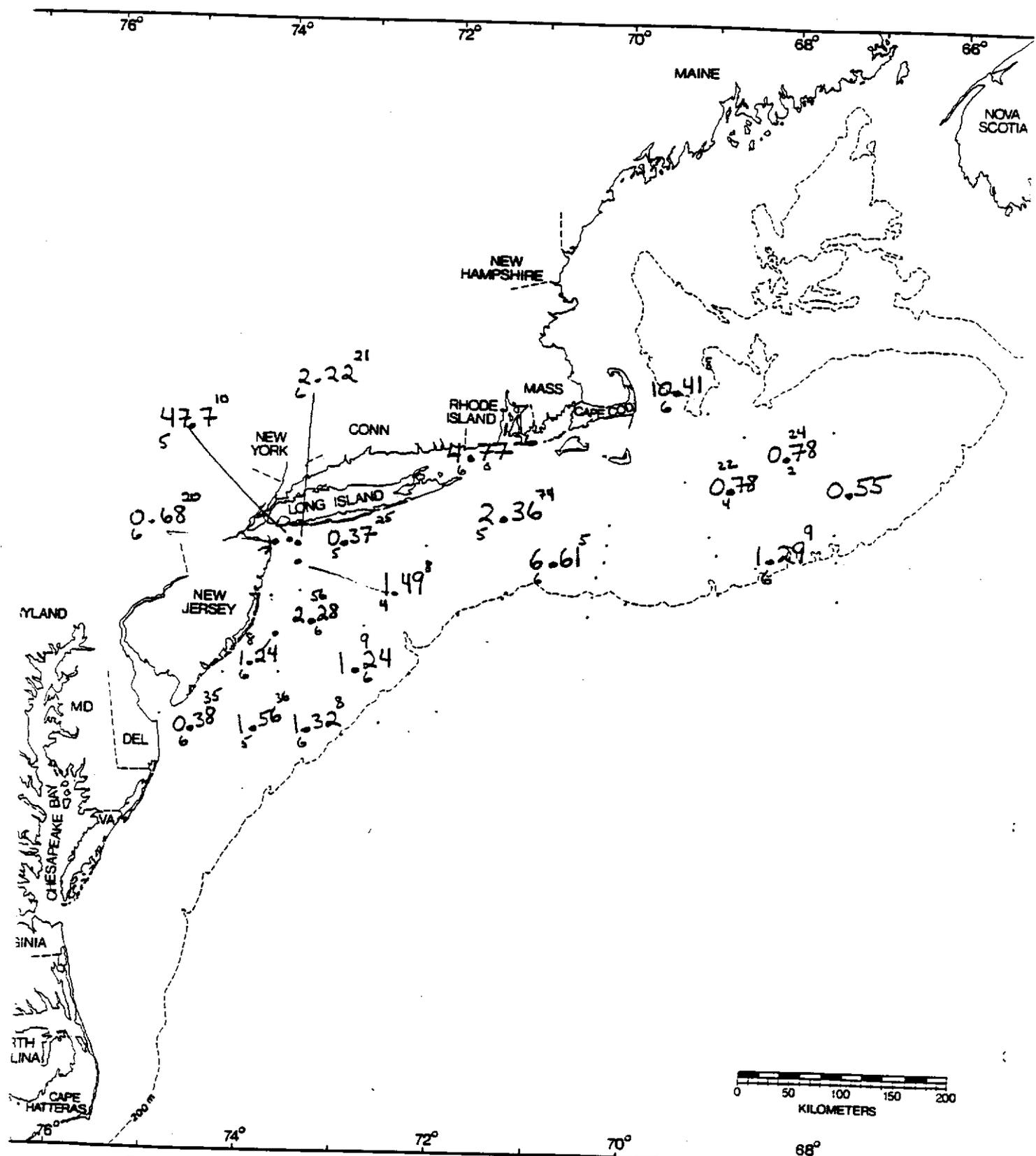


Figure 68. Distribution of nickel (ppm, dry weight) in sediments collected during the Albatross 79-07 survey.

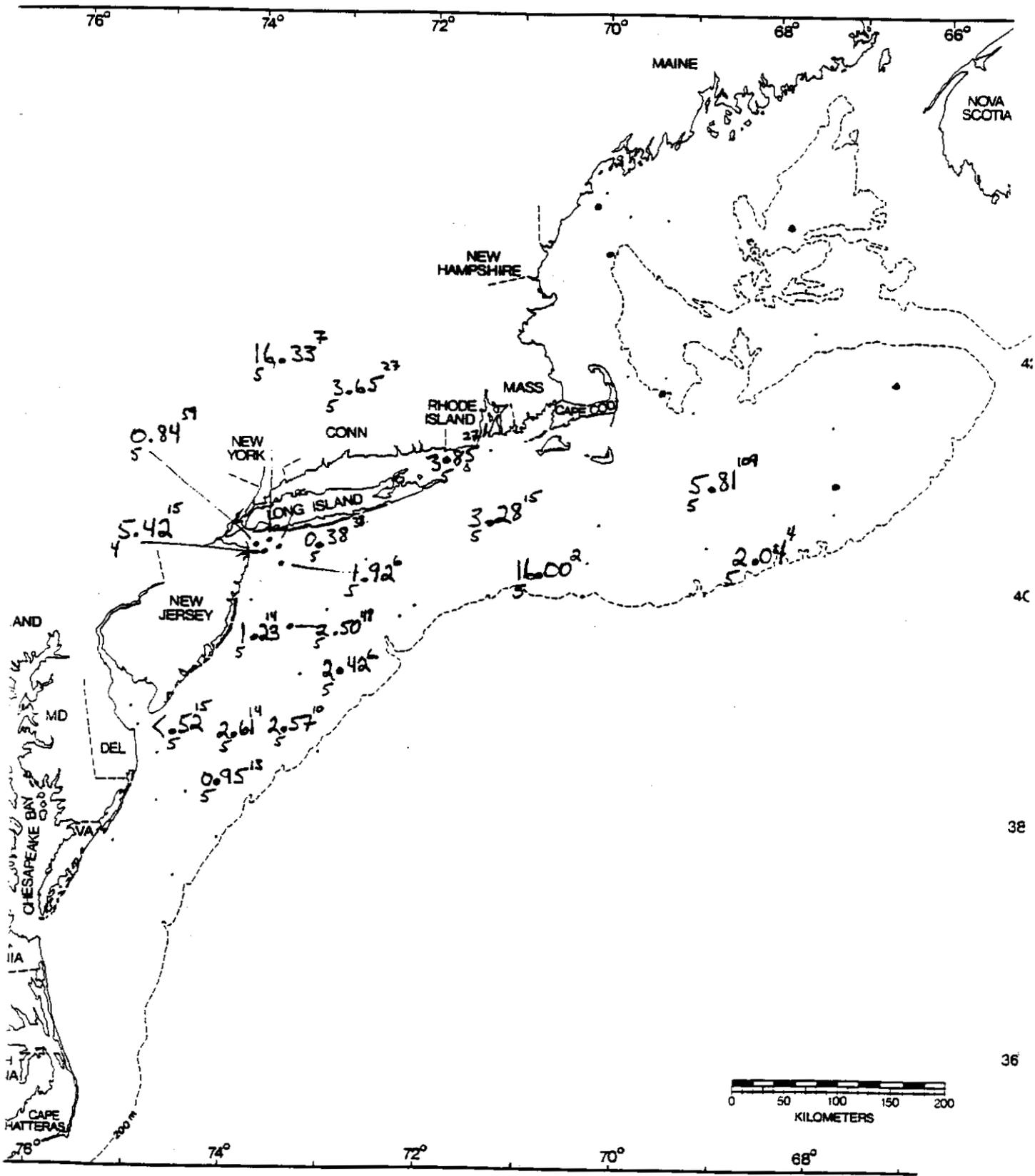


Figure 69. Distribution of nickel (ppm, dry weight) in sediments collected during the Albatross 79-10 survey.

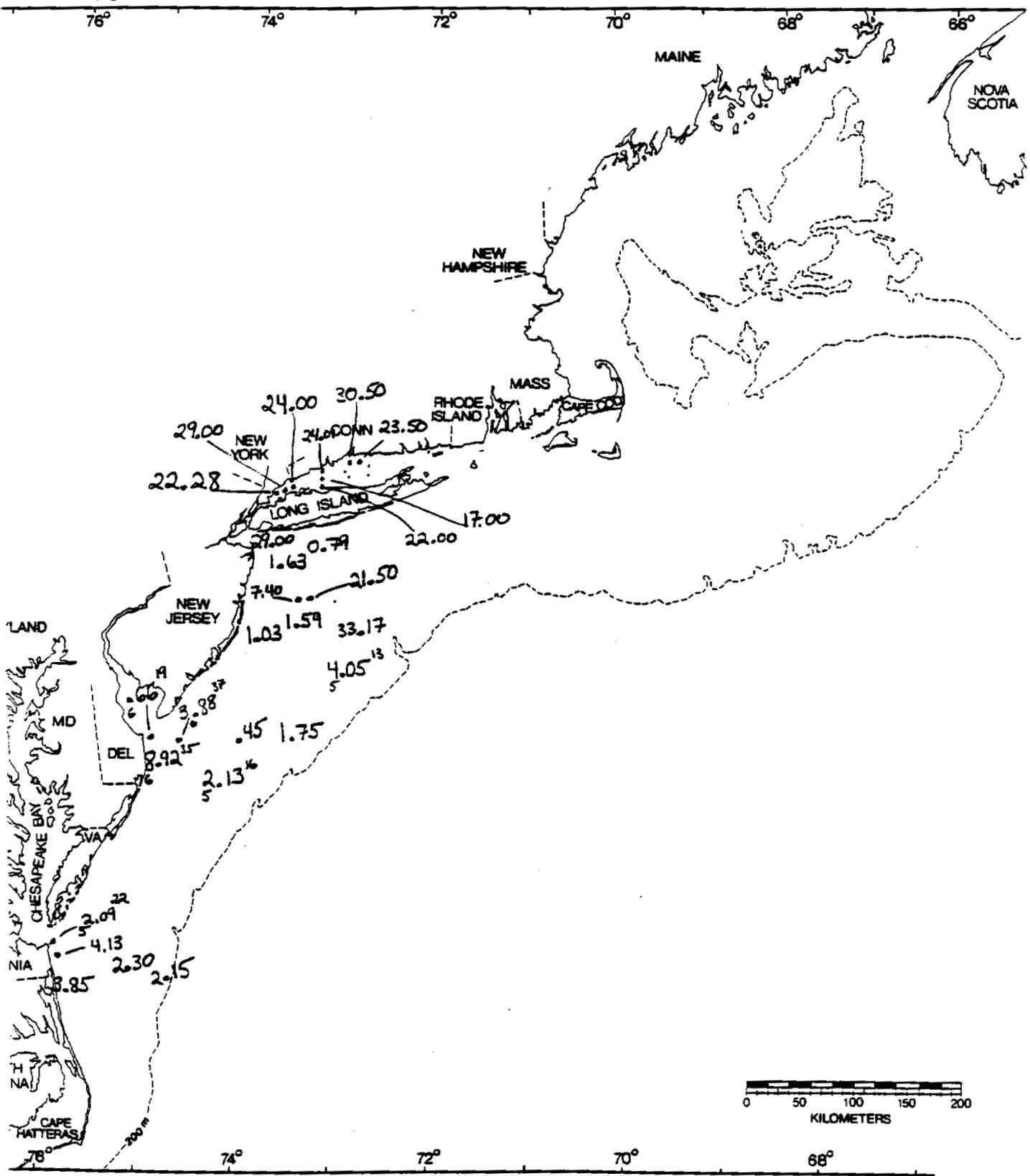


Figure 70. Distribution of nickel (ppm, dry weight) in sediments collected during the Kelez 79-10 survey.

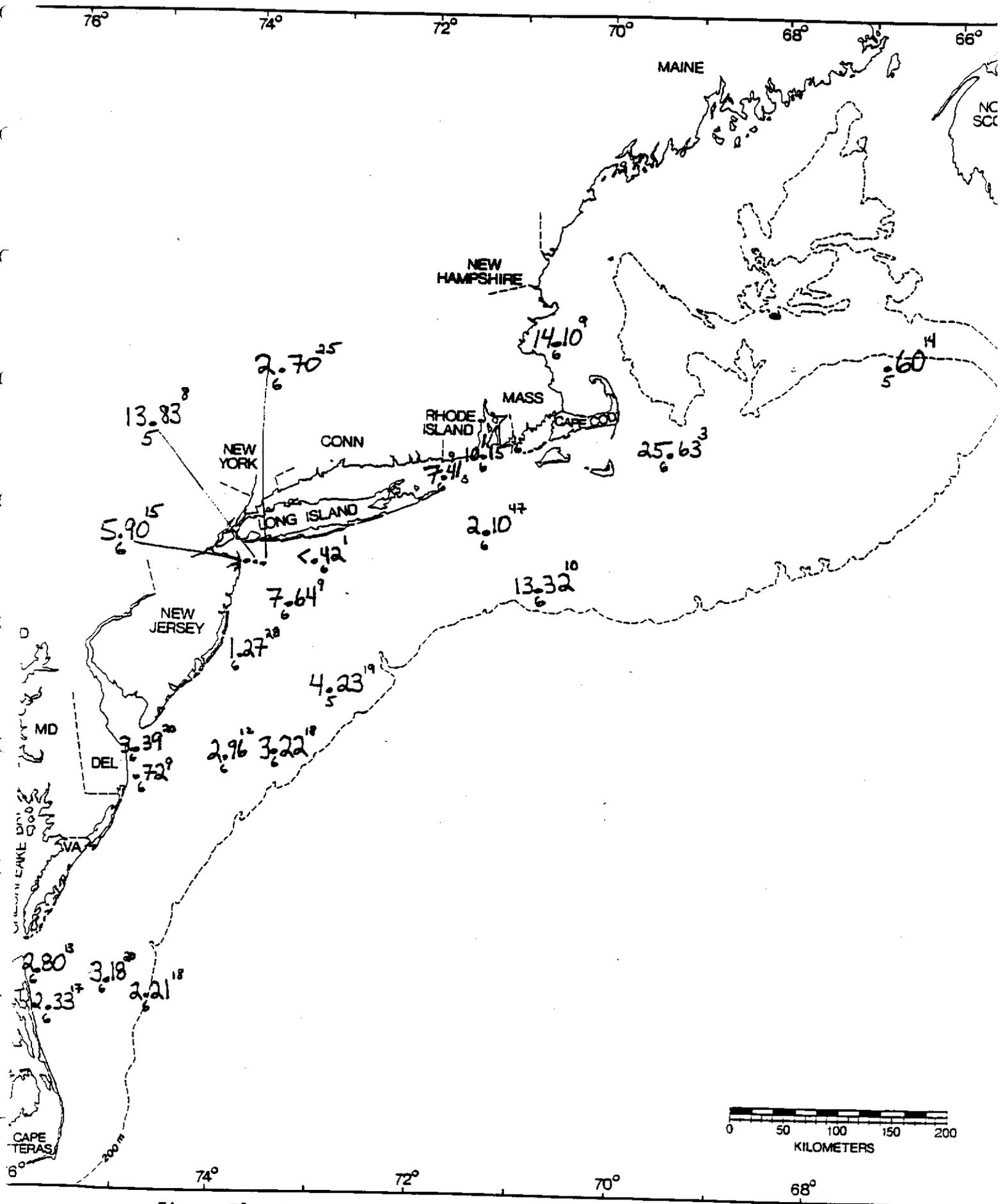


Figure 71. Distribution of nickel (ppm, dry weight) in sediments collected during the Delaware 79-11 survey.

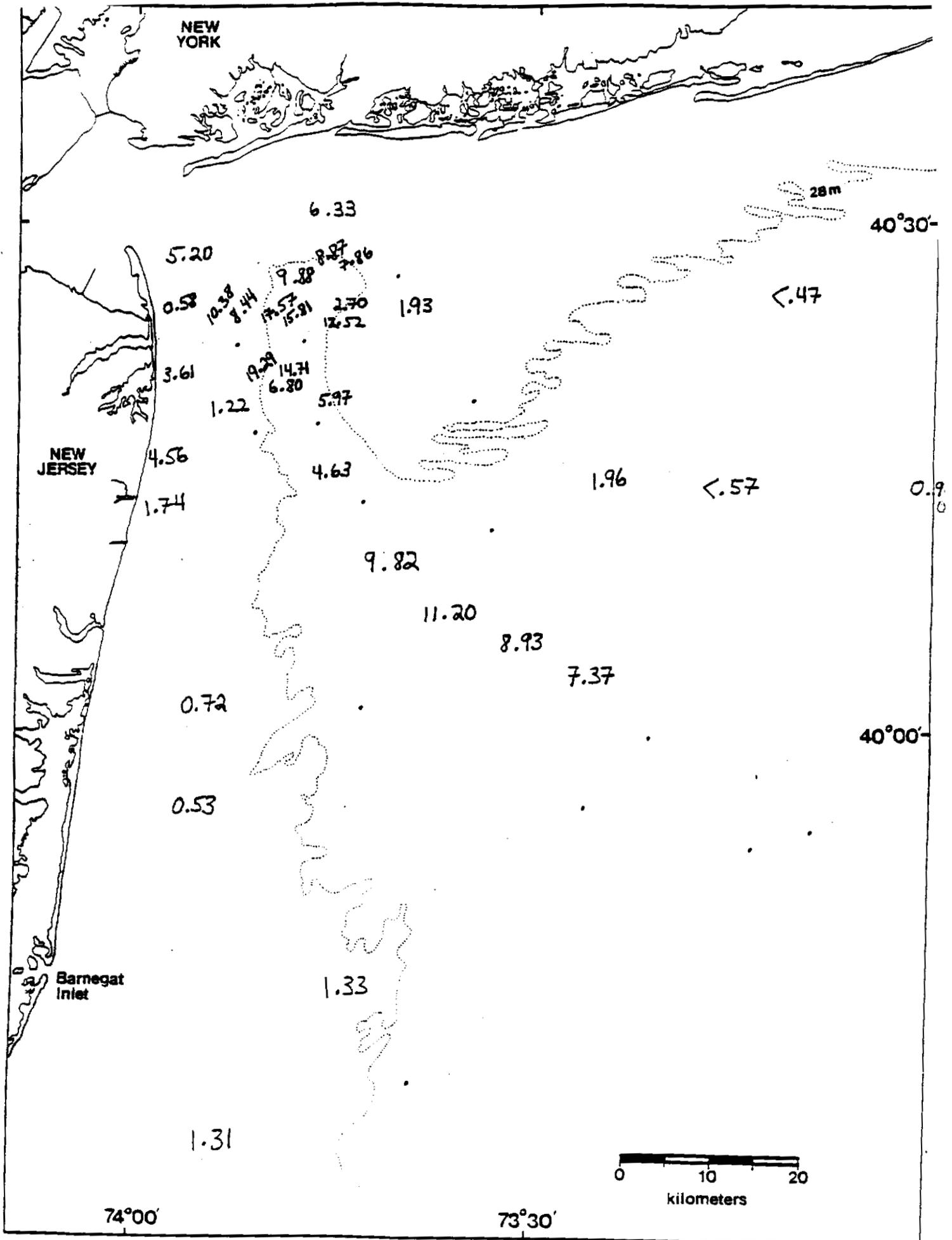


Figure 72. Distribution of nickel (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

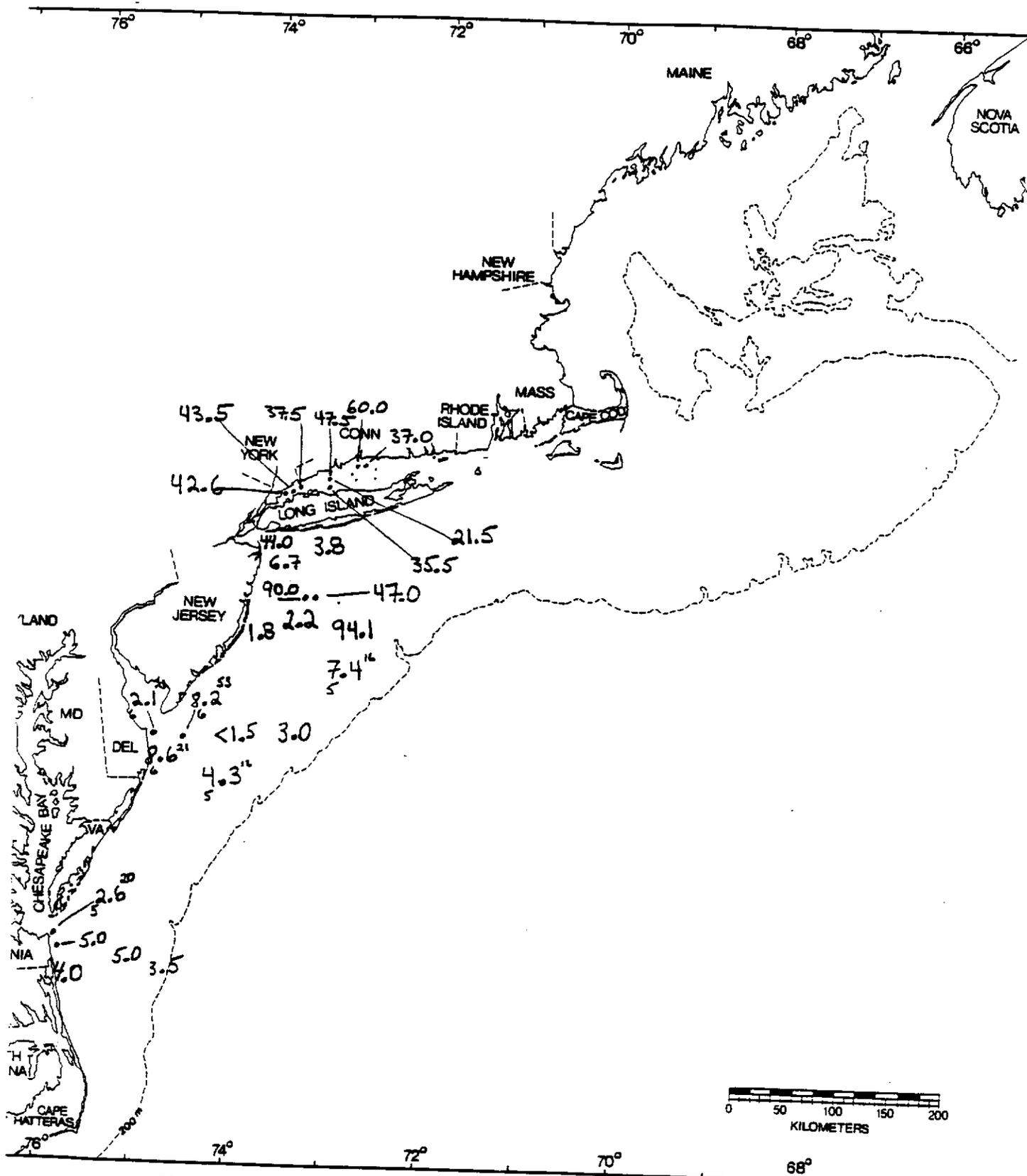


Figure 77. Distribution of lead (ppm, dry weight) in sediments collected during the Kelez 79-10 survey.

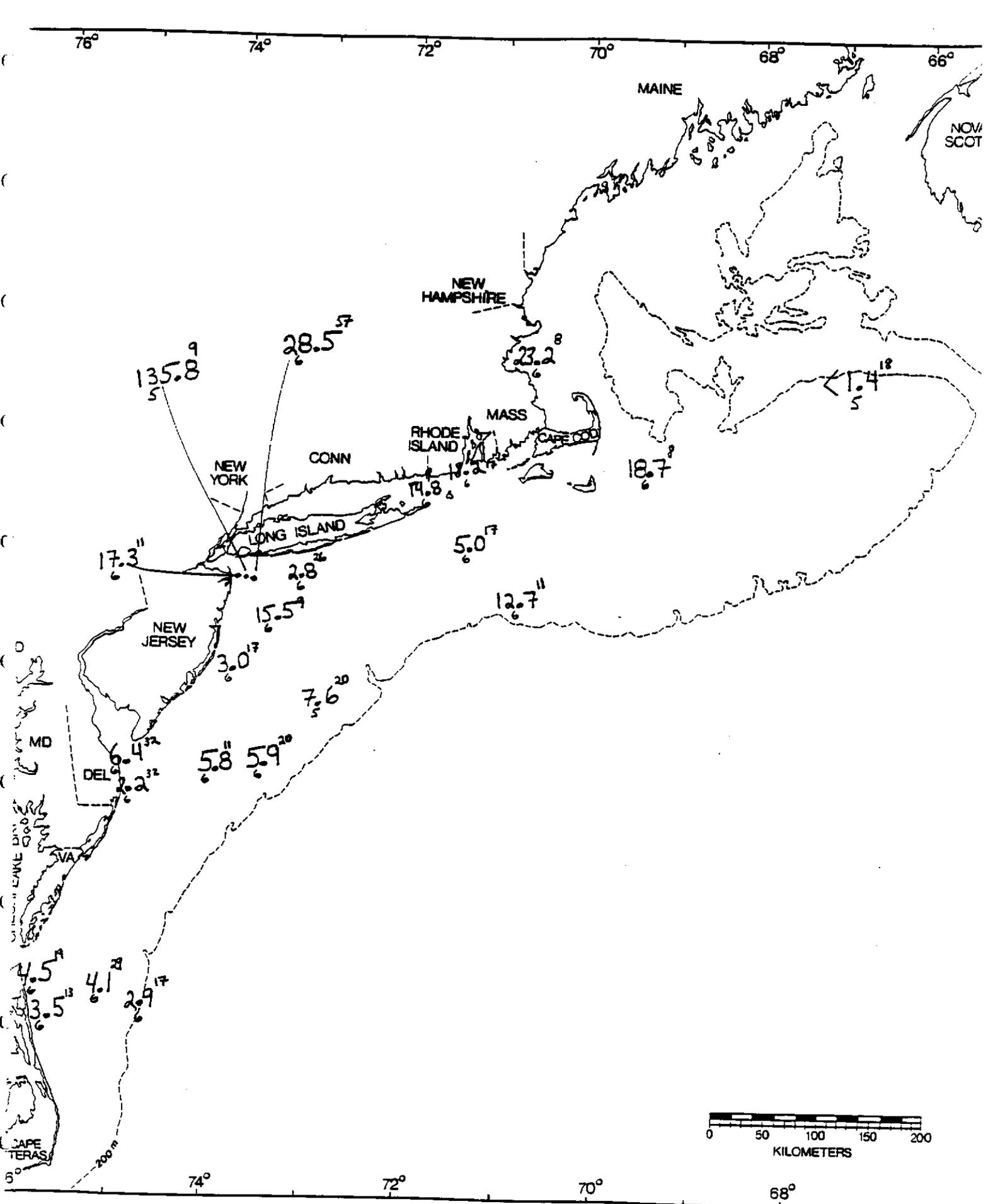


Figure 78. Distribution of lead (ppm, dry weight) in sediments collected during the Delaware 79-11 survey.

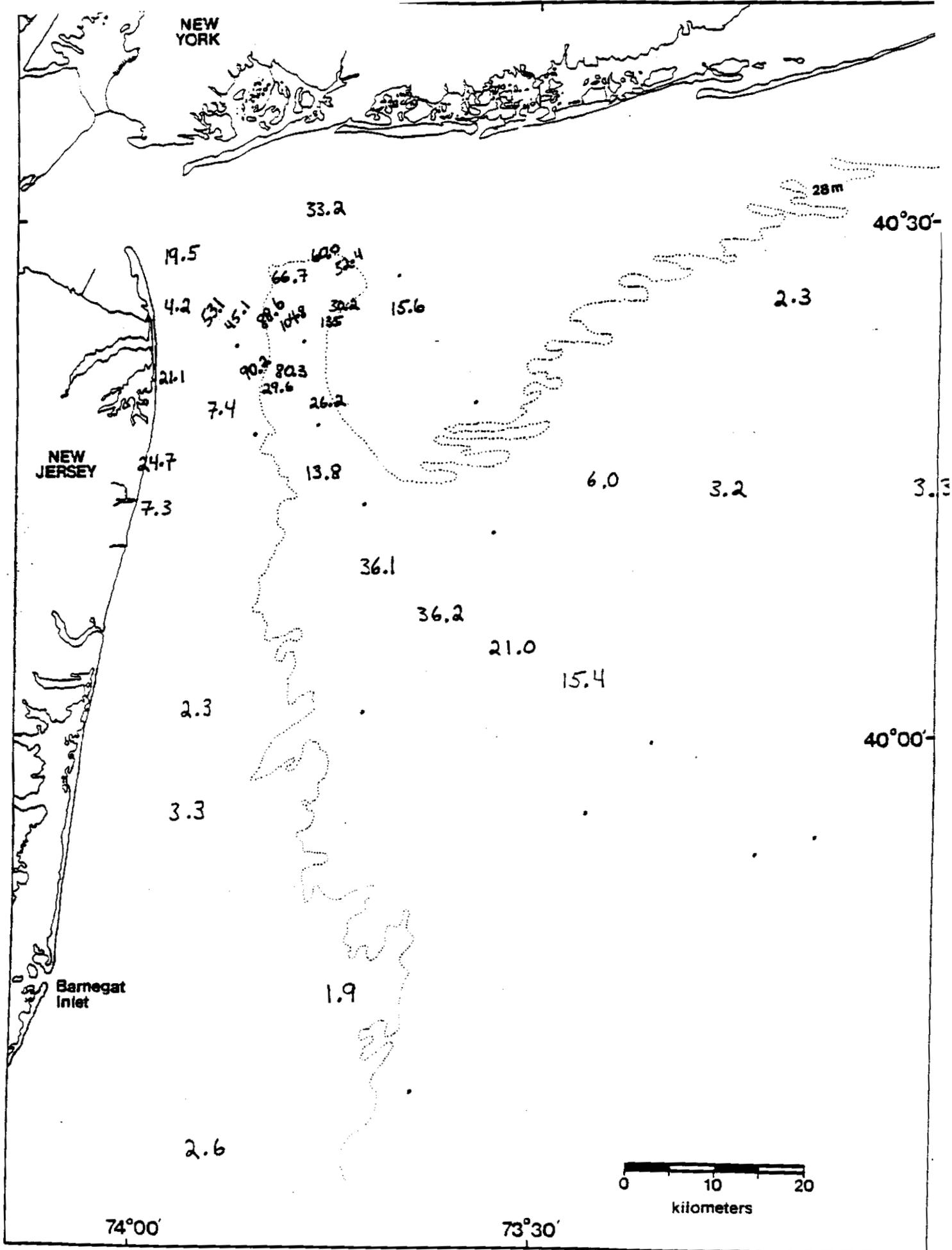


Figure 79. Distribution of lead (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

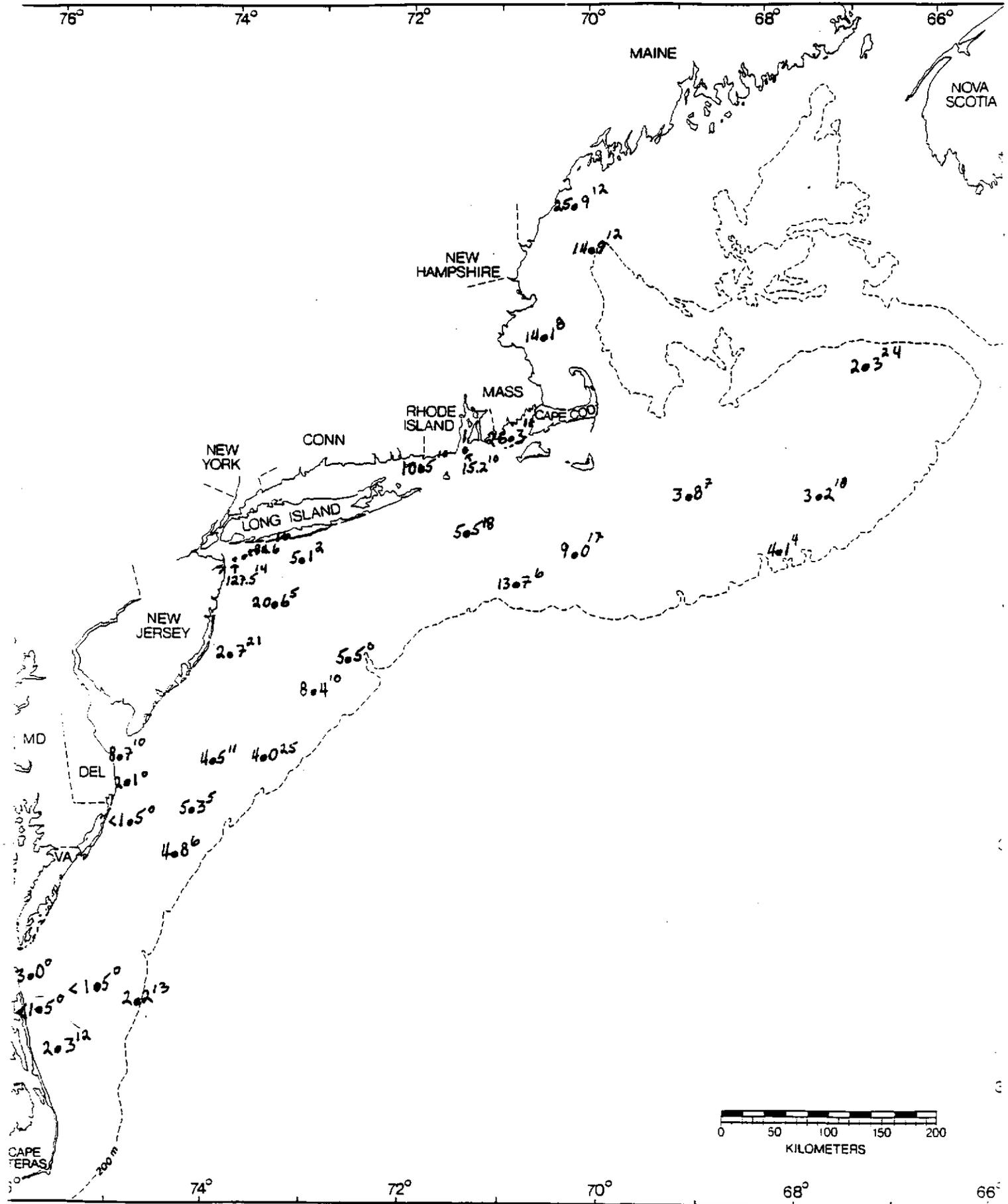


Figure 80. Distribution of lead (ppm, dry weight) in sediments collected during the Albatross 80-09 survey.

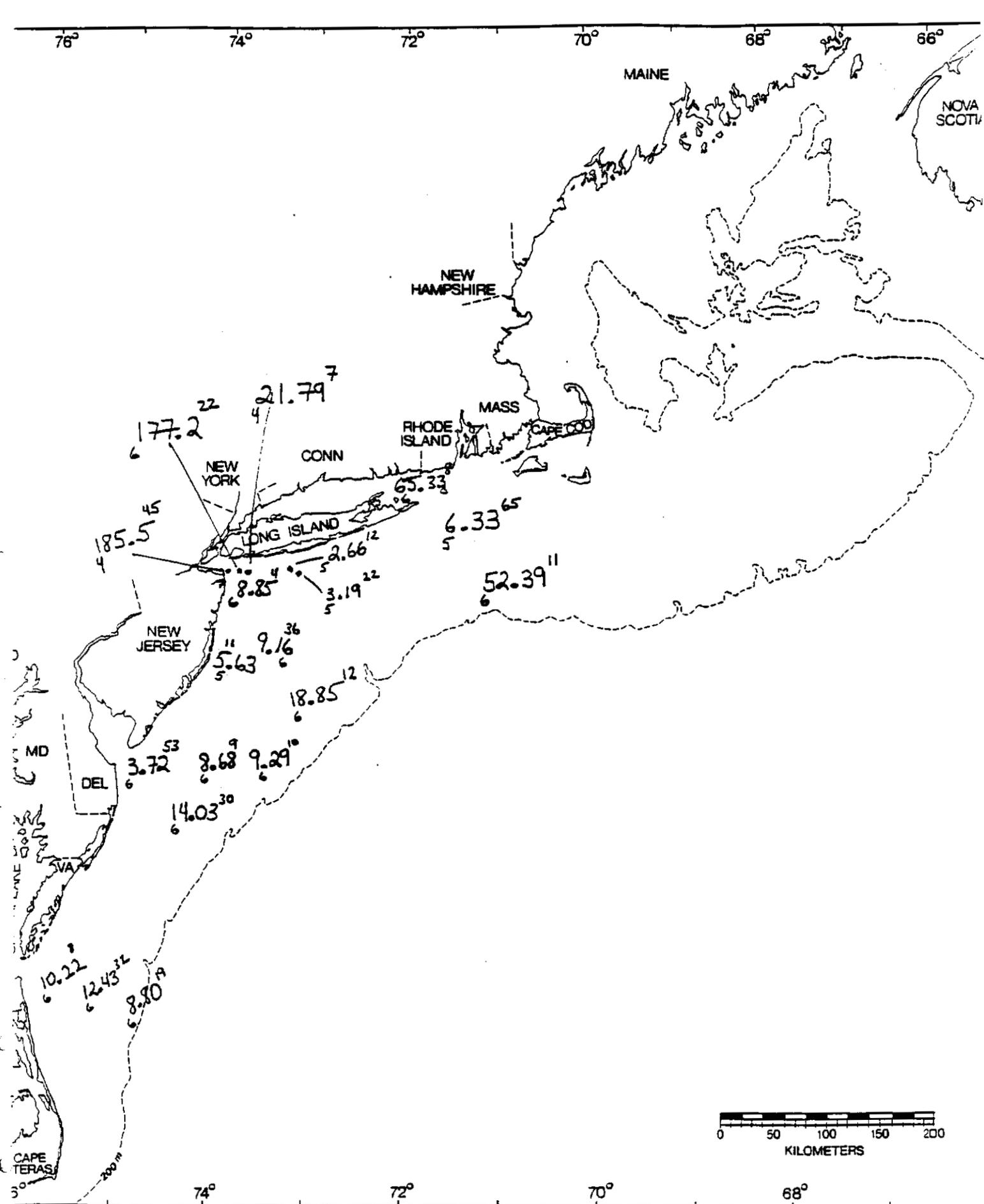


Figure 81. Distribution of zinc (ppm, dry weight) in sediments collected during the Advance 79-01 survey.

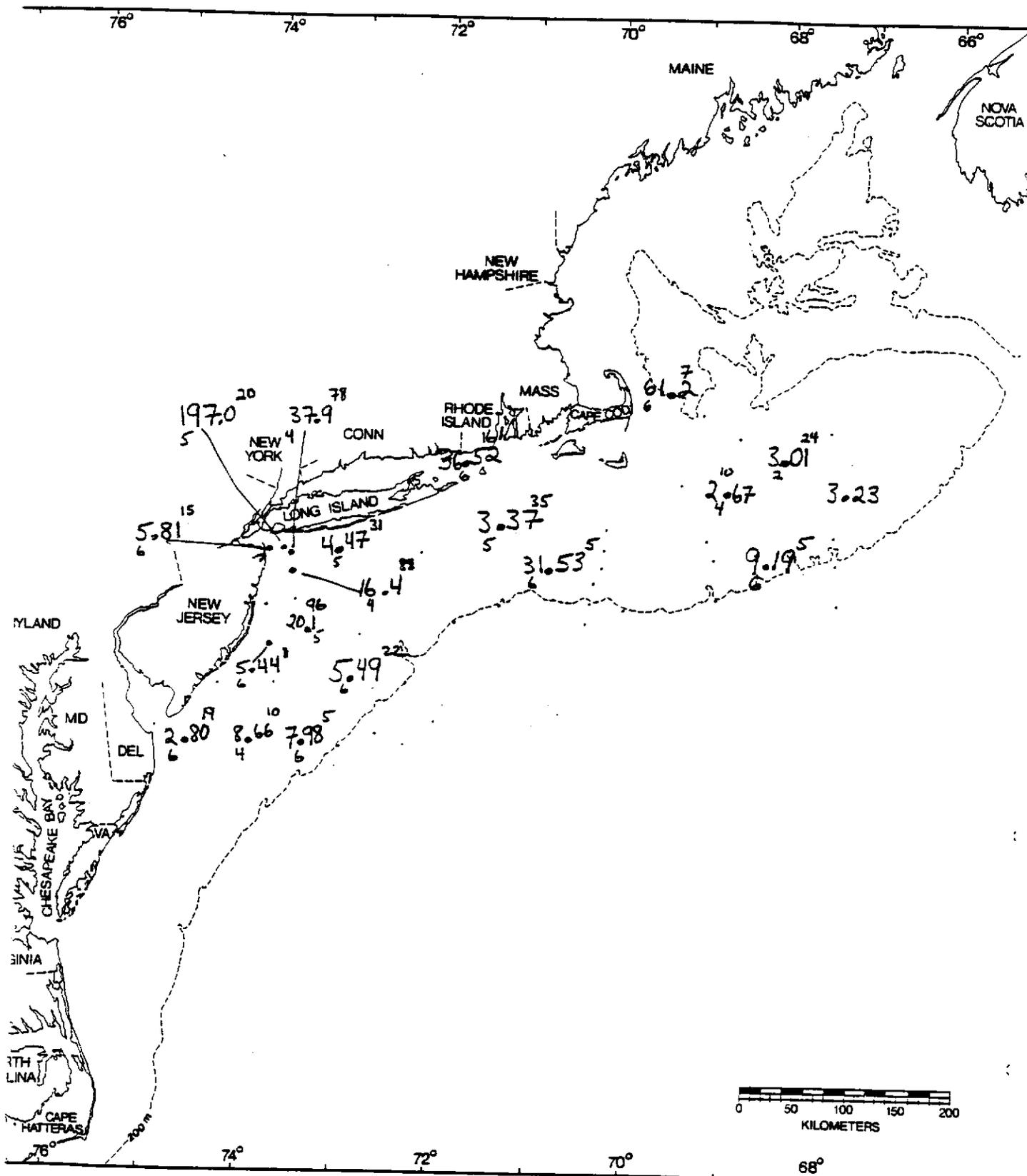


Figure 82. Distribution of zinc (ppm, dry weight) in sediments collected during the Albatross 79-07 survey.

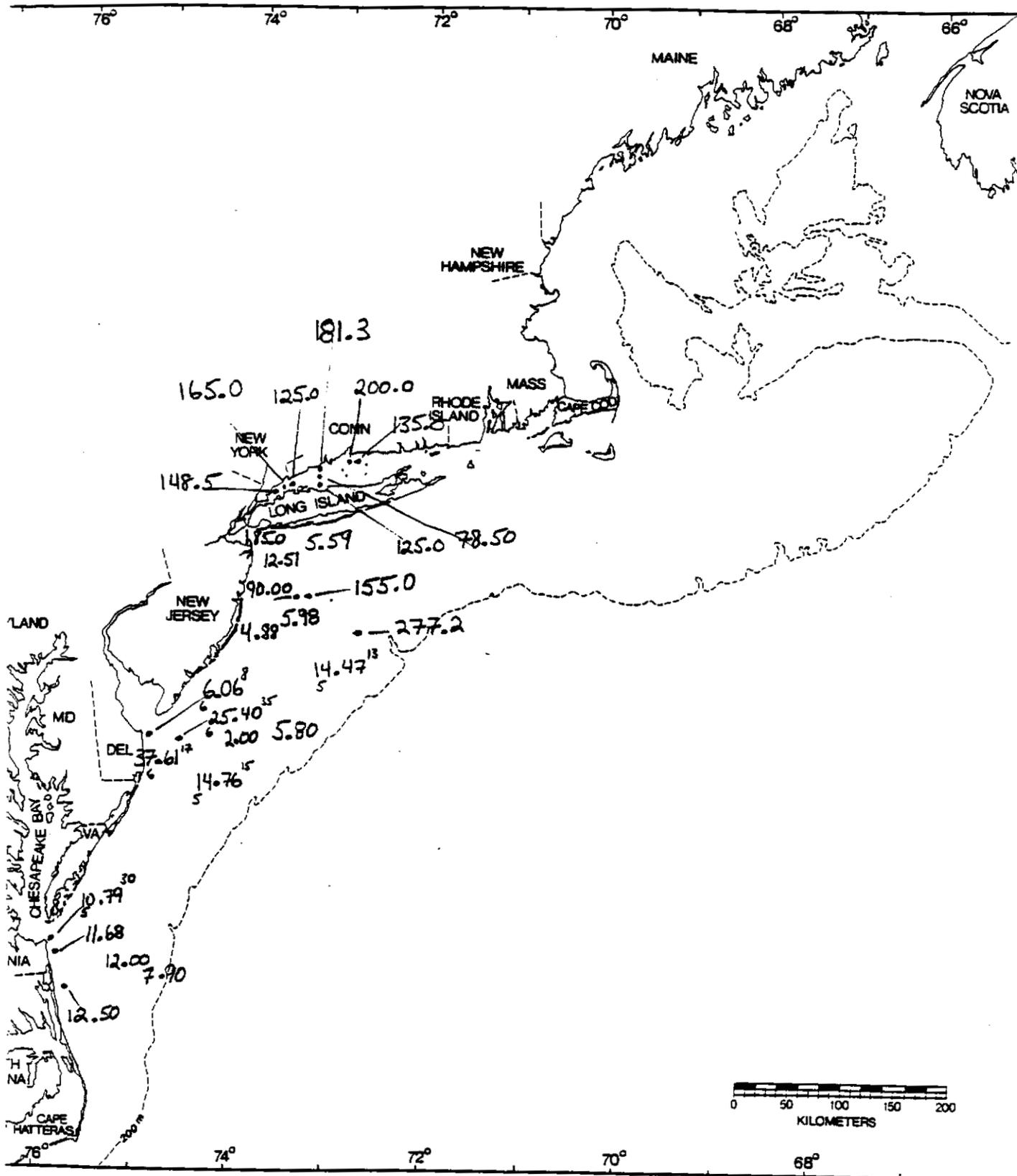


Figure 84. Distribution of zinc (ppm, dry weight) in sediments collected during the Kelez 79-10 survey.

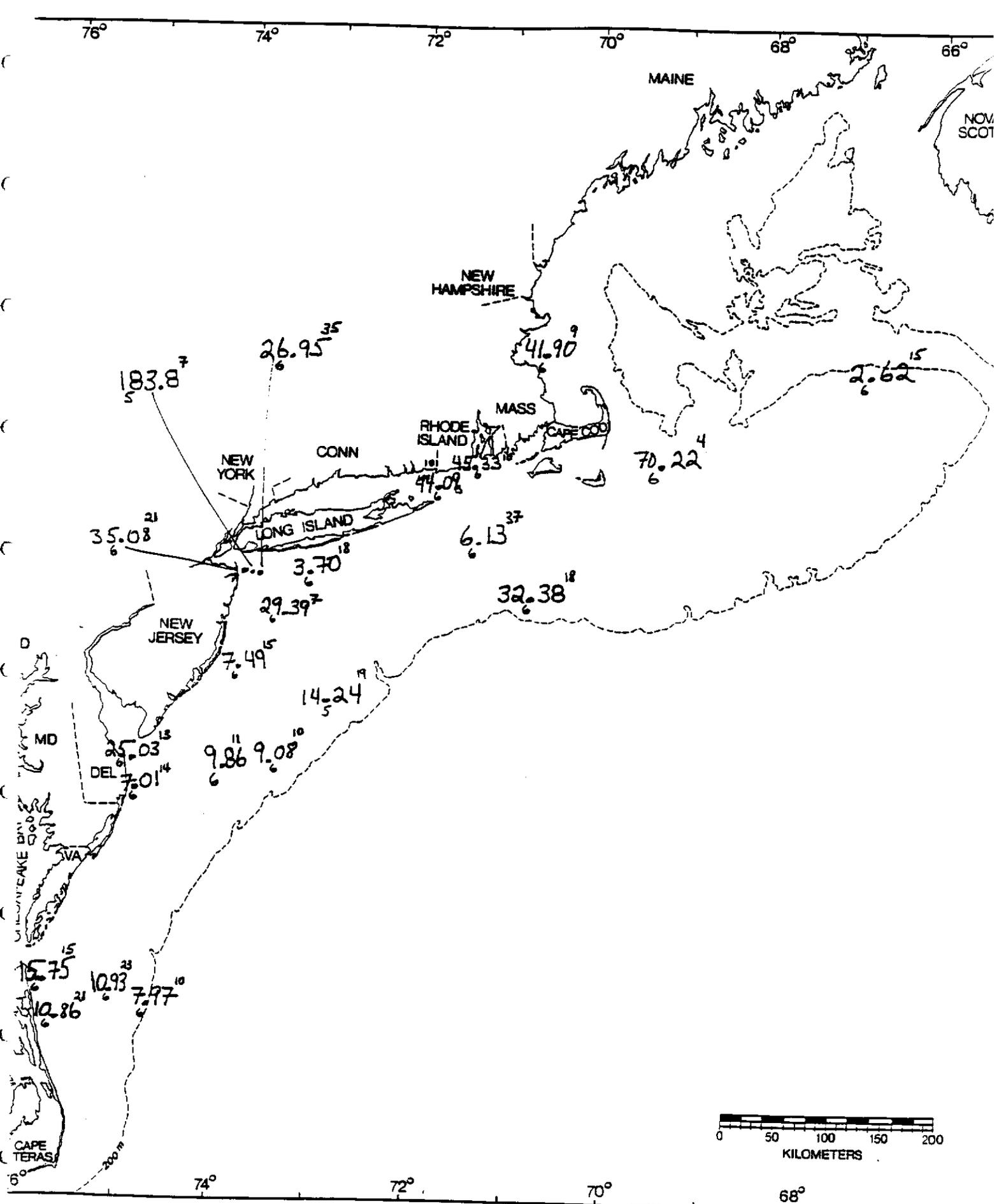


Figure 85. Distribution of zinc (ppm, dry weight) in sediments collected during the Delaware 79-11 survey.

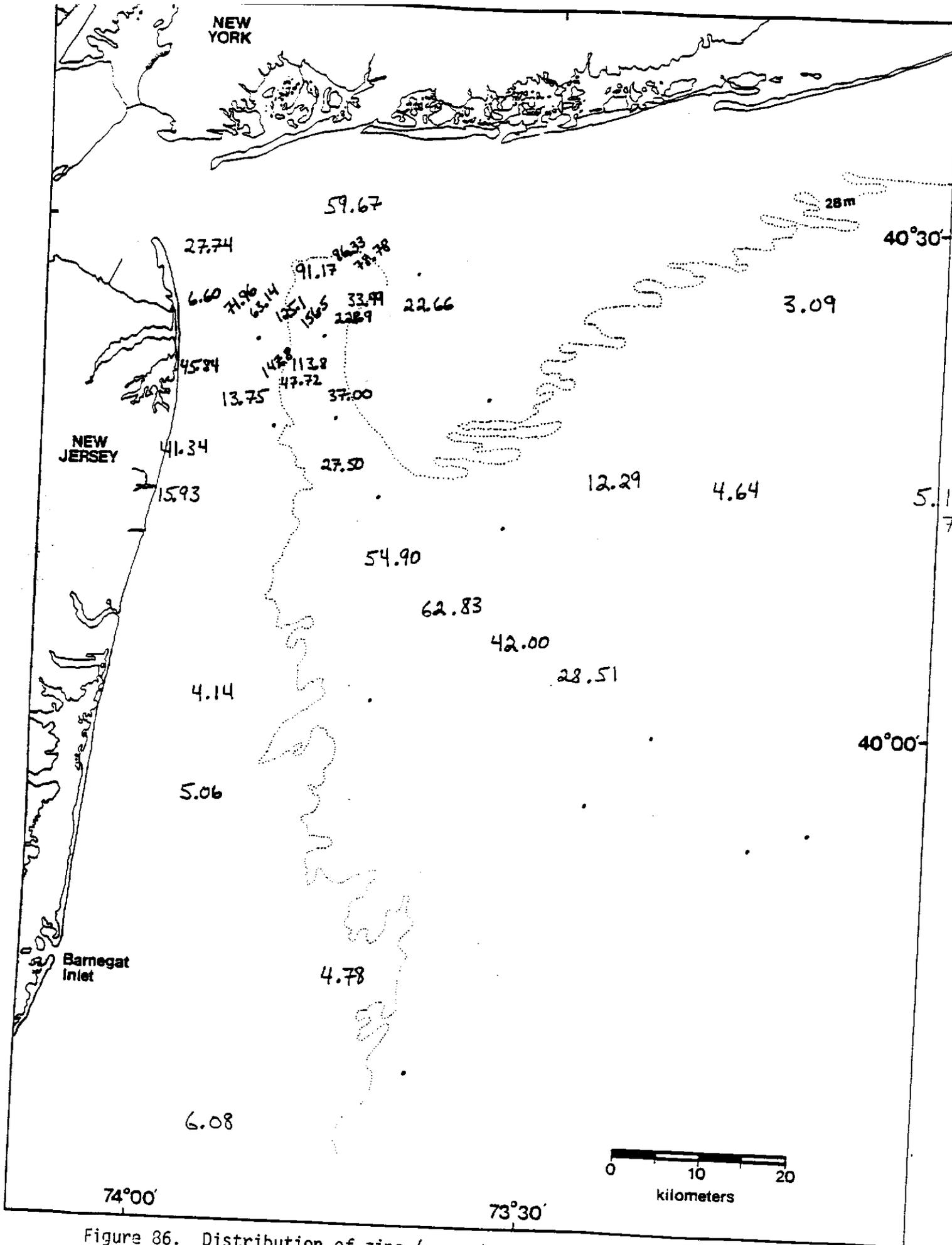


Figure 86. Distribution of zinc (ppm, dry weight) in sediments collected during the Kelez 80-07/08 survey.

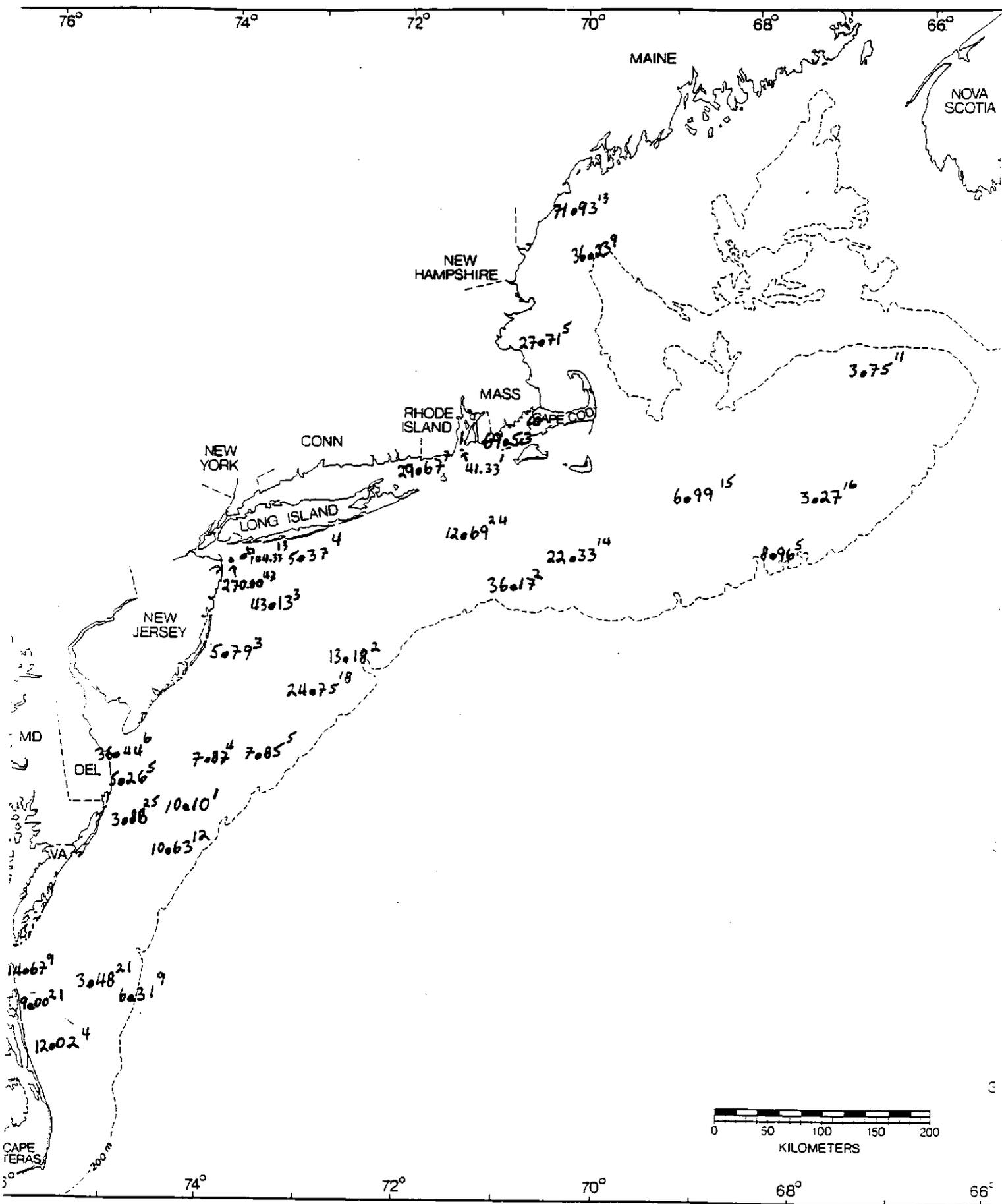


Figure 87. Distribution of zinc (ppm, dry weight) in sediments collected during the Albatross 80-09 survey.

8. Tables

Table 2. Results of nutrient field-intercalibration.

Depth (m)	PO ₄	SiO ₄	N ₂ + NO ₃	NO ₂	NH ₄
Brookhaven - Kelez - MESA station B4 (39°37'N, 72°03.5'W)					
2	.17	2.22	.16	.03	.00
10	.13	1.58	.07	.01	.24
20	.11	1.29	.08	.01	.12
30	.16	1.49	.03	.02	.09
40	.56	4.25	5.65	.19	.07
61	.70	5.43	9.49	.03	.19
81	.77	7.78	10.92	.03	.10
106	.82	9.40	11.69	.05	.25
Sandy Hook - Albatross 80-07 - station 28 (39°37'N, 72°03'W)					
1	.17	1.79	.00	.06	.17
10	.14	1.21	.00	.07	.38
19	.17	1.04	.00	.00	.09
29	.19	1.04	.06	.03	.22
49	.12	1.77	.00	.03	.17
58	.43	3.92	4.65	.03	.16
68	.75	4.27	6.04	.06	.10
90	.61	4.42	6.49	.06	.06
120	.83	9.36	8.23	.06	.10

Table 4. Frequency of daily rates of phytoplankton production (gC/m²/d) by region and by production intervals.¹

Frequency of daily rates of phytoplankton production (gC/m²/d) by region and by production intervals¹.

Region Code ²	0-.5	.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	>5
GM	5 ³	25	34	21	9	4	2				
GB1	1	0	3	6	4	2	0	0	1	1	
GB2	7	28	33	17	10	5	5	1	1		
LI1	3	9	11	6	1	3	1	1			
LI2	6	9	15	6	6	2	0	0	0	1	
LI3	1	14	10	14	6	1	0	1			
NJ1	3	11	4	5	6	2	3	3	3	0	2
NJ2	0	6	3	3	4	0	1				
NJ3	1	4	6	1	3	1					
DE1	6	5	2	3	5	1	1	0	2		
DE2	1	8	4	2	0	1	0	1			
DE3	0	5	2	4	1	0	1				
CH1,2,3	1	10	3	1	2	1	0	0	1		

¹ See Table 1 for list of surveys used to generate this table.

² See Figure 12 for region codes and region locations.

³ Number of observations.

Table 5.

Cruise	Month	Ammonium Nitrogen			Inorganic Nutrients		
		Samples Analyzed	Data Reduced	Report/Data Available	Samples Analyzed	Data Reduced	Report/Data Available
AD-77-01	March	✓			✓		
AL-77-05	June	✓			✓		
BE-78-04	November	✓	✓	✓	✓	✓	✓
AD-79-01	April	✓	✓		✓		
DE-79-05	May	✓	✓		✓		
FRC-05-06	May	✓	✓	✓	✓	✓	✓
AL-79-06	June/July	✓	✓		✓	✓	
AL-79-07	July	✓	✓		✓	✓	
BE-79-01	August	✓	✓	✓	✓		
AL-79-09	September	✓	✓		✓	✓	
BE-79-03	September/October	✓	✓	✓			
AL-79-10	September	✓	✓				
AL-79-11	October	✓	✓				
BE-79-05	November	✓	✓	✓			
AL-79-13	November/December	✓	✓				
DE-79-11	December	✓	✓				
AL-80-02	March	✓	✓				
AL-80-04	April	✓	✓		✓	✓	
EV-80-01	May	✓	✓	✓			
DE-80-03	May/June	✓	✓	✓			
EV-80-04	May/June	✓	✓	✓			
AL-80-07	July	✓	✓		✓		
EV-80-06	July/August	✓	✓				
AL-80-09	September	✓	✓				
AL-80-10	October	✓	✓				

Table 5. Status of inorganic nutrient analyses.

Table 6. Ranges of metal levels.

Values in ppm, dry weight

	<u>Low</u>	<u>Medium</u>	<u>High</u>
Cd	<0.25	0.25-1.00	>1.00
Cr	0-10	10-50	>50
Cu	0-5	5-10	>10
Ni	0-5	5-20	>20
Pb	0-10	10-20	>20
Zn	0-25	25-100	>100

Table 7.
Comparison of trace metals (ppm) in sediments of the New York Bight Apex, 1973-1974-1980.

A7301 August, 1973				A7401 August, 1974				KE 80-07/08 July-August, 1980									
								(stations correspond to SYMAP station numbers)									
SYMAP STA. #	Cr	Cu	Ni	Pb	Zn	SYMAP STA. #	Cr	Cu	Ni	Pb	Zn	KELEZ STA. #	Cr	Cu	Ni	Pb	Zn
23 (1,1) ²	77.3	69.3	14.2	90.0	150.0	23 (1,1)	19.3	25.4	6.6	24.0	48.4	1(3,3)	46.67	43.67	9.88	66.7	91.17
24 (1,1)	43.0	35.8	8.2	46.0	80.0	24 (1,1)	45.0	53.5	13.2	60.0	116.0	2(3,3)	42.00	38.17	8.87	60.0	86.33
25 (1,1)	53.0	45.0	9.0	56.0	95.0	25 (1,1)	16.5	20.2	5.2	22.0	45.3	3(3,3)	39.22	34.40	7.86	52.4	78.78
36 (1,1)	12.4	18.4	8.0	24.0	56.0	36 (1,1)	3.4	6.4	4.4	13.0	20.9	4(8,7)	22.64	31.78	8.44	45.1	63.14
34 (1,1)	76.7	76.7	15.8	80.0	146.0	34 (1,1)	95.0	108.0	21.0	111.0	198.0	5(3,3)	75.06	85.06	15.81	104.8	156.5
33 (1,1)	24.2	41.0	5.6	52.0	76.0	33 (1,1)	373.0	548.0	56.3	53.0	845.0	6(7,7)	65.26	120.80	12.52	134.9	228.90
32 (1,1)	13.6	19.2	2.6	32.0	32.2	32 (1,1)	17.1	31.0	4.0	29.0	47.7	7(7,7)	11.93	14.96	2.70	30.2	33.99
43 (1,1)	24.2	28.0	10.0	28.0	62.0	43 (1,1)	9.1	4.6	4.0	25.0	29.0	8(3,3)	65.63	88.41	19.29	90.2	147.80
45 (1,1)	65.0	58.0	18.4	80.0	147.0	45 (1,1)	30.2	37.0	33.9	45.0	85.3	9(3,3)	54.56	55.84	14.71	80.3	113.80
57 (1,1)	4.6	2.2	3.4	90.0	28.2	57 (1,1)	4.7	-4.0	-4.0	-8.0	20.8	10(3,3)	23.97	20.70	6.80	29.6	47.72
55 (1,1)	20.8	13.4	9.6	4.0	55.0	55 (1,1)	9.6	9.8	7.3	15.0	29.1	11(3,3)	18.08	14.22	5.97	26.2	37.00
37 (1,1)	74.0	81.0	17.0	92.0	164.0	37 (1,1)	44.6	63.2	11.3	63.0	110.0	18(3,3)	34.08	50.61	10.38	53.1	71.96
62 (1,1)	11.2	1.6	5.0	18.0	28.8	62 (1,1)	8.3	-4.0	5.9	19.0	30.3	19(3,3)	27.10	5.24	4.56	24.7	41.34
19 (1,1)	9.4	4.8	3.2	22.0	25.6	19 (1,1)	7.7	4.8	4.6	17.0	32.8	20(3,3)	7.21	5.75	5.20	19.5	27.74
11 (1,1)	20.8	3.8	6.4	30.0	61.0	11 (1,1)	11.3	6.5	5.9	20.0	53.8	21(3,3)	23.67	10.95	6.33	33.2	59.67
30 (1,1)	11.4	5.8	2.0	20.0	25.6	30 (1,1)	35.7	31.5	8.8	45.0	73.4	22(3,3)	8.34	4.46	1.93	15.6	22.66
35 (1,1)	67.3	76.7	16.8	82.0	142.0	35 (1,1)	14.6	16.5	4.7	19.0	33.3	40(7,7)	47.72	57.93	17.57	88.6	125.08
39 (1,1)	2.2	1.6	2.0	4.0	8.6	39 (1,1)	-4.0	-4.0	-4.0	-6.0	5.9	41(7,7)	2.35	0.78	0.58	4.2	6.60
40 (1,1)	12.8	1.6	4.0	16.0	60.0	40 (1,1)	6.7	-4.0	4.2	17.0	41.8	45(7,7)	14.54	2.83	3.61	21.1	45.84
59 (1,1)	14.0	2.8	3.8	8.0	47.0	59 (1,1)	7.1	-4.0	-4.0	10.0	23.1	43(7,7)	6.58	1.84	1.22	7.4	13.75

¹ grabs per station

² total cores

Table 8. Comparison of metal levels and sediment composition.

	Metal Level	% Silt ¹	% Clay ¹	Total Organic Carbon ²
Fire Island Control	Low	0.1	0.8	0.4
Cent. Gulf of Maine	Med	73	25	19
Block Island Outer Shelf	Med	62	23	15
Sludge Settling Site	High	6	5	12

¹ Silt and clay values are % by weight.

² Organic carbon is in mg/g dry weight.

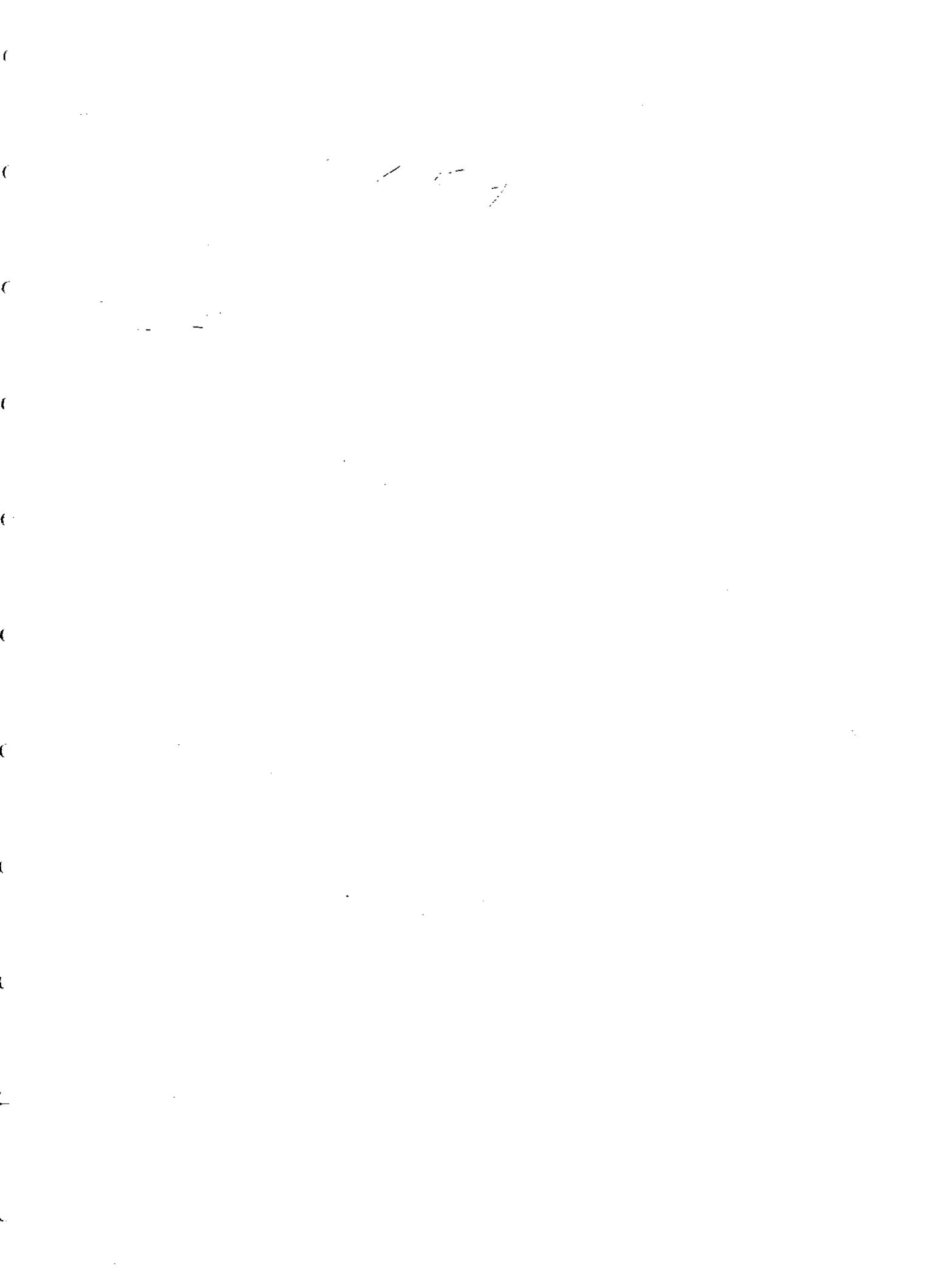
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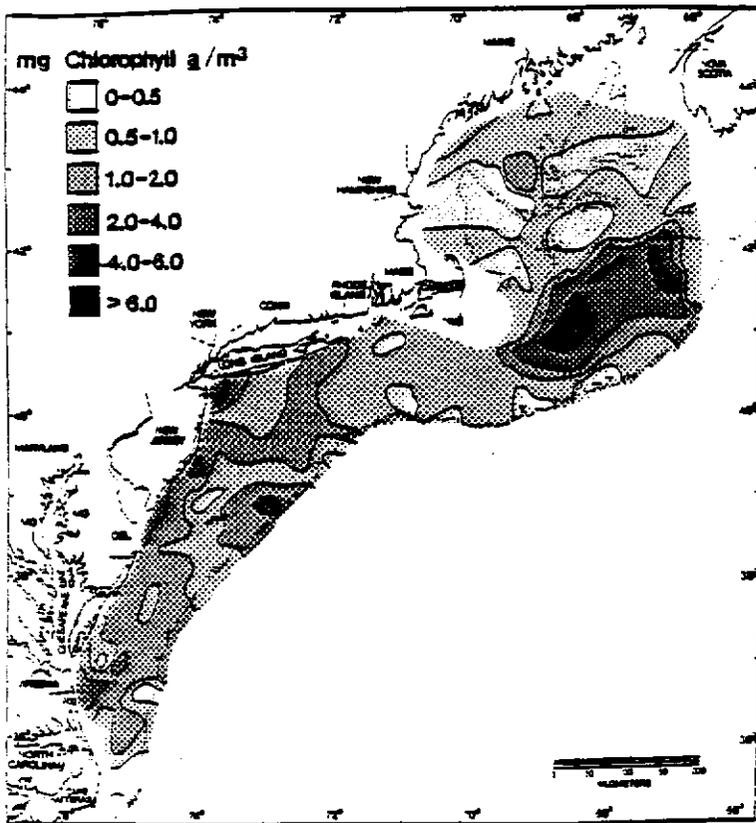
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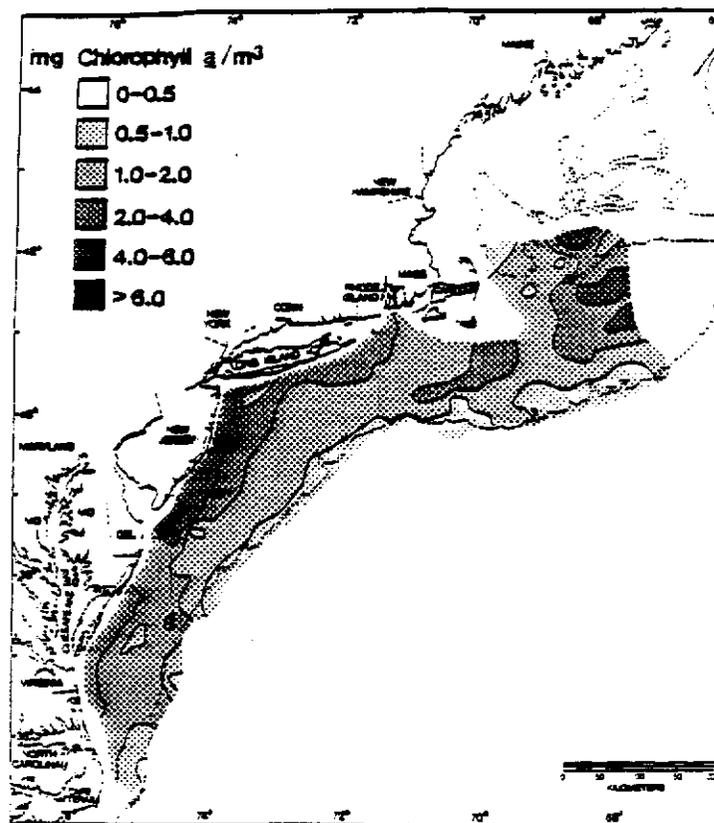


COMPARISON OF OUR ESTIMATES OF ANNUAL PRIMARY PRODUCTION FOR CAPE HATTERAS-GULF OF MAINE SHELF WITH ANNUAL ESTIMATES FOR OTHER SYSTEMS.

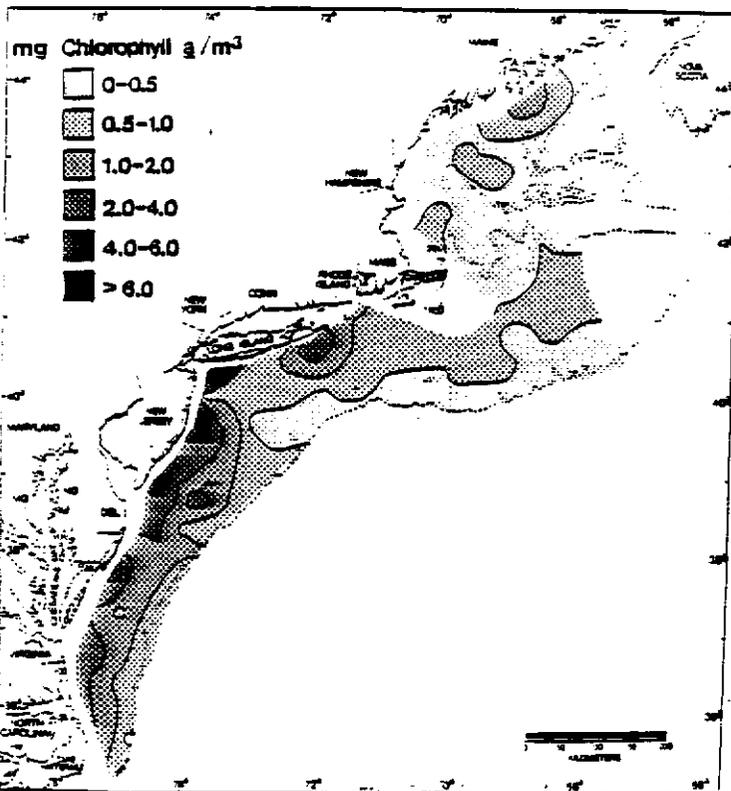
AREA	gC/M ² /YEAR	REFERENCE
OCEANIC	55-70	STEEMAN-NIELSEN, 1957
NORTH SEA	90-100	STEELE, 1974
COASTAL WATER, JAPAN	90	HOGETSU, 1979
EASTERN SCOTIAN SHELF	102-128	MILLS AND FOURNIER, 1979
NORTHERN BALTIC	127	WULFF, 1979
BLOCK ISLAND SOUND	300	SMAYDA, 1973
OFF LONG ISLAND COAST, 20 M	343	MANDELLI ET AL., 1970
NEW YORK BIGHT APEX	370-480	MALONE AND CHERVIN, 1979
COASTAL WATER OFF INDIA	434	QUASIM, 1979
CAPE HATTERAS-GULF OF MAINE	402-726 (TOTAL) 344-600 (PARTICULATE)	PRESENT STUDY
GEORGIA COAST OFF ALTAMAHA RIVER	547	THOMAS, 1966
RARITAN-LOWER NEW YORK BAY	750-1053	O'REILLY ET AL., 1976



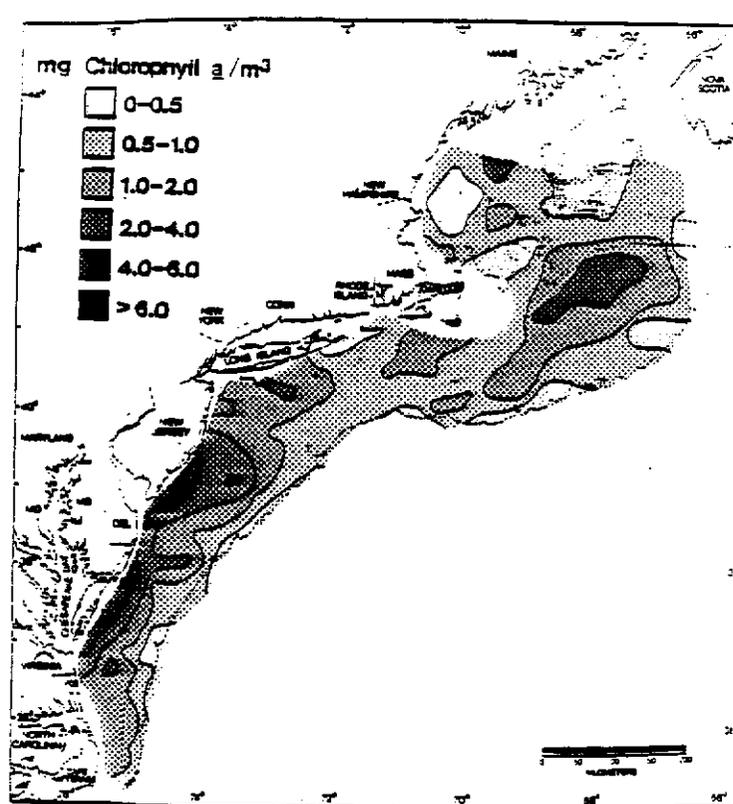
Distribution of chlorophyll a during DeLong II 79-05, May 5-29, 1979.



Distribution of chlorophyll a during Albatross IV 79-06, June 15-July 13, 1979.



Distribution of chlorophyll a during Belogorsk 79-01, Aug. 11-Sept. 2, 1979.



Distribution of chlorophyll a during Albatross IV 79-11, Oct. 4-29, 1979.