

*James A. Gibson  
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**NOAA Technical Memorandum NMFS-F/NEC-56**

**Characterization of the  
Middle Atlantic Water  
Management Unit of the  
Northeast Regional Action Plan**

**U.S. DEPARTMENT OF COMMERCE  
National Oceanic and Atmospheric Administration  
National Marine Fisheries Service  
Northeast Fisheries Center  
Woods Hole, Massachusetts**

**July 1988**

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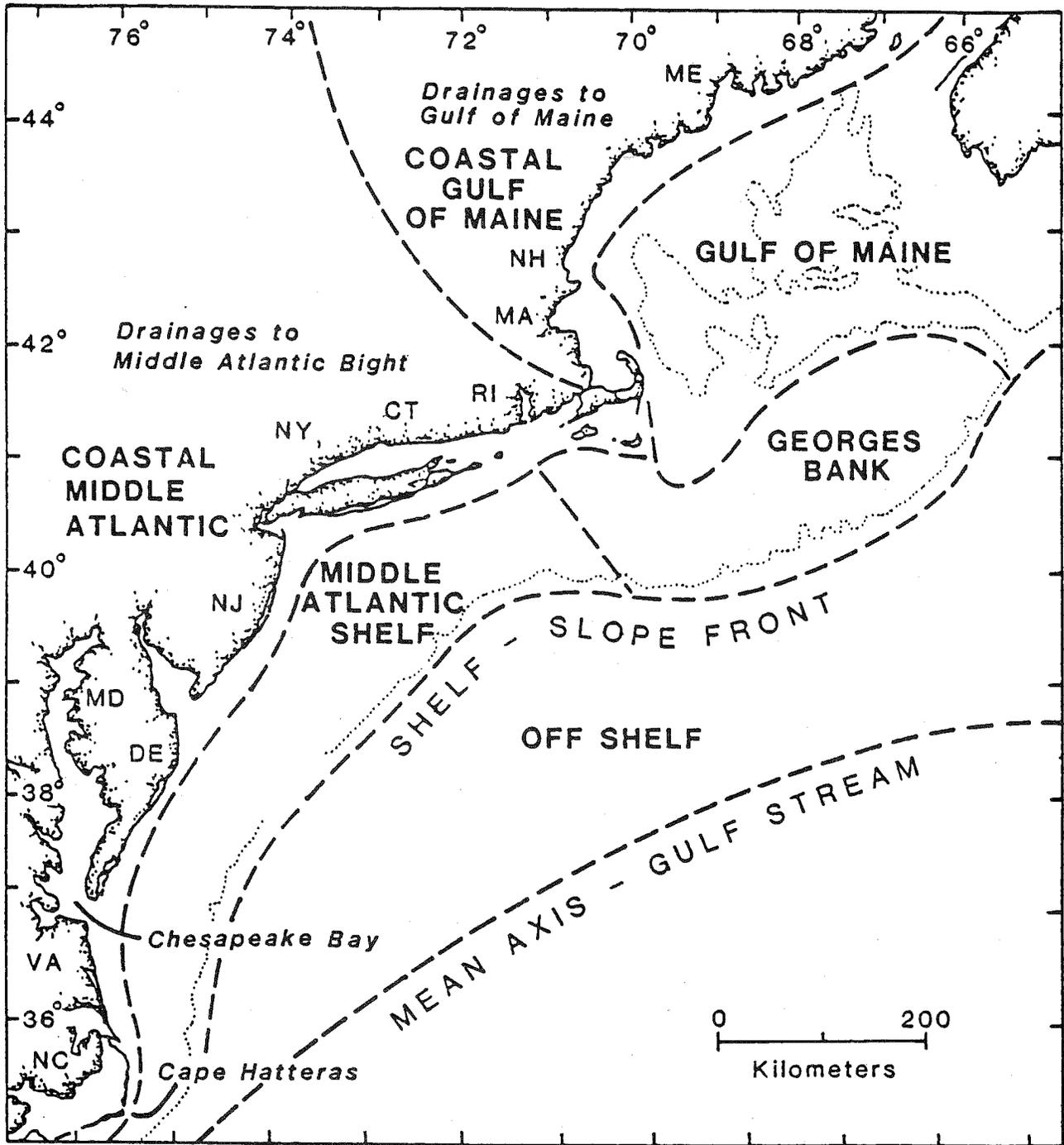
# **Characterization of the Middle Atlantic Water Management Unit of the Northeast Regional Action Plan**

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Northeast Regional Action Plan Water Management Units

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## ACKNOWLEDGMENTS

The nature of multiple authorship, the setback of a major laboratory fire and the press of conflicting assignments have all conspired to produce a prolonged gestation for this report.

The need for a general background on research and survey results along with relevant literature of the Middle Atlantic Shelf Water Management Unit (WMU) remains and the various managers and support staffs responding to environmental problems and conflicts which have reft the Middle Atlantic Bight waters should find this compilation useful. To all the authors go my thanks for their cooperation in the preparation of this document

The material of each study topic arrived from the various authors, but integration of review comments invariably resulted in draft iterations. These were prepared by Mme. Kathe Melkers and Catherine Noonan of the Sandy Hook Laboratory staff. To them I express sincere thanks for their patience and diligence.

To Ms. Michele Cox, scientific illustrator at the Sandy Hook Laboratory, I extend special appreciation for execution and/or layout of all the figures and contributed artistic suggestions in the formative period of the volume.

## INTRODUCTION

The National Marine Fisheries Service includes aquatic habitat considerations in its programs and decisions. To meet environmental policy requirements, the Region has established a Regional Action Plan (RAP) which provides improved communication between the Region, Center, and Washington office. It has evolved since 1981 so as to 1) identify living resources of importance, 2) enumerate and rank habitat issues, 3) develop strategies which address the issues, and 4) oversee habitat considerations through NMFS programs.

The RAP process encourages synthesis of numerous and occasionally disparate data sets. Such synthesis is designed to supply awareness, advice and direction early in the planning process as a help in resolving major problems, thus avoiding conflict and controversy while saving time and money.

This volume is mostly a collection of synthesis documents which characterize the environmental and living resources of Middle Atlantic shelf waters. This series of papers provides RAP a review of the general and cryptic source material available. Our goal was to provide a convenient source for resource information.

It is obvious from the contents that we no longer grope in ignorance about the Middle Atlantic Bight. Information on dynamics of the ecosystem has been accruing, particularly over the last several decades. Unfortunately, growth in population, urbanization and industrialization has resulted in progressive despoilation of marine waters for three centuries. Many processes are still unknown or poorly understood -- the inventory and fates of contaminants is still incomplete, for example. This volume is intended as a starting place for Middle Atlantic Bight managers called to assess impacts on living marine resources imposed from a continuing suite of environmental insults.

# Physical Oceanography of the Middle Atlantic Bight

by

Steven K. Cook<sup>1</sup>

## INTRODUCTION

The compilation of the summary document was primarily gleaned from three sources: Summary of the Physical Oceanography Processes and Features Pertinent to Pollution Distribution in the Coastal and Offshore Waters of the Northeastern United States, Virginia to Maine (Ingham et al., 1982); Coastal and Offshore Environmental Inventory - Cape Hatteras to Nantucket Shoals (Saila et al., 1973); Summarization and Interpretation of Historical Physical Oceanographic and Meteorological Information for the Mid-Atlantic Region (Williams and Godshall, 1977); "Personal Communication" References were also helpful.

Over 120,000 observations of various types made from 1850 to present (see Table 1) were used in these summaries. As reflected by the number of observations used and the large body of literature associated with this compilation, the physical oceanography of the Middle Atlantic Bight is certainly as well studied as any coastal marine area in the world.

## AVERAGE CONDITIONS

Coastal and offshore waters of the United States north of Cape Hatteras, can be subdivided on the basis of oceanographic characteristics into four subareas: the Gulf of Maine, Georges Bank, the Middle Atlantic Bight, and the Slope Water-Gulf Stream area. Most of the general, descriptive oceanographic reports and atlases relevant to this area deal with only one or two of these subareas, except for the summary reports by Bumpus (1983) and Hopkins and Garfield (1977). Nevertheless, a general summary of average oceanographic and meteorological conditions in the whole area can be obtained from these two reports and from those prepared by Beardsley and Boicourt (1981), Godshall et al. (1980), Williams and Godshall (1977), and Bumpus (1976).

The average circulation off the northeastern U.S. involves seasonally variable gyres in the Gulf of Maine and on Georges Bank, slow westward and southward flow on the continental shelf in the Middle Atlantic Bight, similarly slow southwestward flow in the slope water which occasionally carries one or more Gulf Stream warm core rings (eddies), and relatively rapid northeastward flow in the Gulf Stream (Ingham et al., 1982).

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"Shelf water in the Middle Atlantic Bight undergoes stratification in the spring and summer, involving the development of a surface mixed layer of warm water underlain by a distinct thermocline. Beneath this seasonal thermocline over much of the shelf south of Cape Cod is a layer of water called the cool pool, or cold bottom water, isolated from surface heating effects by the thermocline. Deepening of the surface mixed layer and the attendant erosion of the thermocline begins in late summer and by late October-mid November thermal stratification is completely destroyed. From then until spring the water mass is vertically isothermal with the coldest water found nearshore and a weak horizontal gradient toward warmer water offshore.

An abrupt gradient to warmer, saltier water, called the Shelf/Slope Front, is usually located in the vicinity of the edge of the continental shelf. Long-term average motion of the shelf water mass is approximately parallel to the bathymetry toward the southwest, with speeds of about  $5-10 \text{ cm}\cdot\text{sec}^{-1}$  at the surface and  $2 \text{ cm}\cdot\text{sec}^{-1}$  or less in the bottom water (Hansen, 1977; Han and Niedrauer, 1981; EPA, 1978). Short period events such as storms, can cause much more energetic variations in the flow field and tidal currents on the inner shelf can range up to  $100 \text{ cm}\cdot\text{sec}^{-1}$  near entrances of estuaries and generally up to  $20 \text{ cm}\cdot\text{sec}^{-1}$  near entrances of estuaries and generally up to  $20 \text{ cm}\cdot\text{sec}^{-1}$  elsewhere.

The shelf water can be divided into two regimens, low salinity (below 33.2 o/oo and high salinity (above 33.4 o/oo) as revealed by the volumetric analyses of Hayes (1975) and Wright and Parker (1976). The less saline mode is generally found along the inner shelf in depths less than 60 m, and the more saline is found farther offshore in depths greater than 60 m. Nearly half the annual runoff into the Middle Atlantic Bight usually occurs during the spring (Bigelow and Sears, 1935), lowering nearshore surface salinities to less than 32 o/oo. During the year  $157 \text{ km}^3$  of runoff in the Middle Atlantic Bight mixes with slope water to produce about 2,400 - 3,400  $\text{km}^3$  shelf water (Wright, 1976a; Bush, 1981). Shelf water losses from the Middle Atlantic Bight occur near Cape Hatteras where the Gulf Stream entrains it (Fisher, 1972) and across the Shelf/Slope Front in turbulent exchange processes.

The slope water mass has been thought of as a mixture of shelf water and Gulf Stream water (the water masses which abut it on the shoreward and seaward sides), because its temperature and salinity ranges lie in between those of its neighboring masses. Recent work by Fairbanks (1982) using oxygen isotope ratios to identify source areas of Atlantic coastal water masses revealed that slope water mainly is derived from the Labrador Sea with some Gulf Stream water mixed in (via warm core rings). The average motion of this water mass is much like that of the shelf water, parallel to the bathymetry and toward the southwest. Aperiodically, the slope water area is invaded by meanders of the Gulf Stream of warm core rings separated from the Stream, either of which radically change the local water mass properties and circulation at any given location.

Circulation of the surface layer of shelf and slope water is strongly influenced on short (multi-day) time scales by weather conditions in the overlying air mass. Summaries of long-term mean weather conditions have been prepared for the Middle Atlantic Bight by Williams et al. (1977) and Godshall et al. (1980). Together, the two summaries adequately cover the

geographic area of concern to this study in terms of surface wind, visibility, air temperature and superstructure icing. Earlier atlases for the North Atlantic (Meserve, 1974; U.S. Naval Oceanographic Office, 1963; and Naval Weather Service Detachment, 1976) include our area of interest only in their broader portrayal of mean monthly or seasonal conditions." (Ingham et al., 1982).

For the Middle Atlantic Bight, Williams et al. (1977) attribute the northwesterly wind field of winter to the dominance of the Icelandic Low (cyclonic), yielding a vector mean of 7-9 knots ( $3.5-4.5 \text{ m}\cdot\text{sec}^{-1}$ ) from the WNW-NW. The summer wind field is dominated by the Bermuda Subtropical High (anticyclonic), characterized by SW winds of 3.5-4.5 knots ( $1.8-2.2 \text{ m}\cdot\text{sec}^{-1}$  vector mean).

In their discussion of estuarine and continental shelf circulation in the Middle Atlantic Bight, Beardsley and Boicourt (1981) summarize what is known about atmospheric forcing over the continental shelf. They point out that synoptic scale ( $>2$  days,  $>500$  km) disturbances are responsible for most of the surface wind variance over the shelf and open ocean. This is manifested in the Middle Atlantic Bight as frequent, intense cyclones (low pressure system); 2.5 per month in summer, 5 per month in winter and more intense in winter than in summer. The cyclones are produced by the interaction between warm, moist, maritime air and cooler, drier, continental air, and characteristically intensify as they move northeastward along the shelf toward Georges Bank and Nova Scotia. The mean surface wind stress is eastward-southeastward except in summer, when it is northeastward, and the mean stress is generally stronger offshore (2 to 8 times at the shelf edge) and veers cyclonically (up to  $30^\circ$ ) with increasing distance offshore.

Air temperature in winter over coastal water is strongly influenced by the cold, continental air masses moving over the ocean during episodes of strong W-NW winds. Lettau et al. (1976) prepared a plot of monthly average air temperatures along the New York and New Jersey coasts which shows a minimum of about  $2^\circ\text{C}$  in January-February and a maximum of about  $25^\circ\text{C}$  in July-August. According to the plot, fall cooling occurs more rapidly than spring warming,  $-4.4^\circ\text{C}/\text{month}$  vs.  $+4.0^\circ\text{C}/\text{month}$ . Farther seaward the magnitudes of the minimum and maximum would be moderated, but the profile of the annual cycle would be very similar. About 100 km off the New Jersey coast, the January-February minimum is about  $4^\circ\text{C}$  and the July-August maximum is about  $25^\circ\text{C}$ . Southward, in the vicinity of Norfolk, the same distance offshore, the minimum is about  $7^\circ\text{C}$  and the maximum is about  $28^\circ\text{C}$ ." (Ingham et al., 1982).

## TEMPERATURE

The waters of the Middle Atlantic Bight undergo an annual cycle of temperature. The twelve charts in Schroeder (1966) show the average surface temperatures for each month of the year. These averages range from a minimum of  $<3^\circ\text{C}$  in New York Bight in February to  $>27^\circ\text{C}$  off Cape Hatteras in August. The annual range of surface temperature at any location may be greater than  $15^\circ\text{C}$  in the slope water to greater than  $20^\circ\text{C}$  next of the shore off the Mid-Atlantic States. Further plots of average temperature data in sections are available in Walford and Wicklund (1968) and at various levels and sections east of  $72^\circ\text{W}$  longitude in Colton and Stoddard (1972). Examples of nearly

synoptic surface temperature distributions are available from the monthly Airborne Radiation Thermometer flights of the U.S. Coast Guard Oceanographic Unit. The best description of the annual cycle of temperature is found in Bigelow (1933) and is quoted, in part, herewith:

Winter Minimum. Temperature is at its minimum for the year late in February or early in March, with no constant latitudinal differences in this respect between the northern and southern parts of the area, though the precise date varies considerably, both regionally and from year to year.

At this season the temperature is lowest next to the land, highest along the outer edge of the shelf; and as the latitudinal difference between the offings of Martha's Vineyard and of Chesapeake Bay is then only  $1-3^{\circ}$ , successive isotherms at any chosen depth run roughly parallel to the trend of the continent. In normal winters, the temperature falls to about  $2-3^{\circ}$  next to the coast and to  $7-11^{\circ}$  along the 200 meter contour as far west as New York to  $3-4^{\circ}$  and  $9-10^{\circ}$  respectively off Cape May; to  $5-5.5^{\circ}$  and  $9-10^{\circ}$  at the same relative positions off Chesapeake Bay.

The water next to the coast has about the same temperature from Chesapeake Bay southward nearly to Cape Hatteras, but there is then an abrupt transition to higher values just south of the Cape; and while offshore water of  $19-20^{\circ}$  may skirt the edge of the continent as far north as latitude  $36^{\circ}$ , the isotherms there trend sharply offshore, to the northeastward, as this season with surface readings lower than  $12^{\circ}$  normally extending at least 80-90 miles out beyond the 200 meter contour line off New York.

At the coldest season the whole column of water is close to homogeneous in temperature from the surface down to the bottom (usually the surface is fractionally coldest), over the entire continental shelf out to the 100 meter contour line.

In normal winters the bottom water along the 150-250 meter zone at the edge of the continent is about  $9-11^{\circ}$ , and this warm zone is bounded inshore by colder bottom water ( $2-6^{\circ}$  in depths of 20-30 meters) southward nearly to the latitude of Cape Hatteras. Deeper down the slope, bottom temperature declines progressively to abyssal values.

Vernal Warming. Vernal warming, commencing late in February, or early in March, is at first irregular, or may be even temporarily reversed, while subsurface temperatures midway out on the shelf may continue to decline slowly for some days after the surface has commenced to warm. When warming is definitely in progress, the temperature of the water on the shelf at first increases through the whole column, most rapidly so next the land. After late April or early May the surface warms much more rapidly than the deeper levels so that a thermocline of increasing steepness develops over the whole shelf to the west of the offing of Martha's Vineyard.

In the extreme southern part of the area the temperature of the whole column of water across the shelf rises to a value as high as that of the warm bottom zone along the edge of the continent ( $9-10^{\circ}$ ), or higher, before the thermocline is established. And on Nantucket Shoals, at the opposite end of the area, the whole column, surface to bottom, continues to warm at a nearly uniform rate right through the spring. But the thermocline develops

throughout the intervening sector before the bottom water on the deeper half of the shelf has warmed more than  $1-2^{\circ}$  above its winter minimum, and while it still continues some  $4-6^{\circ}$  colder than the bottom along the continental edge.

The thermal convergence that exists near Cape Hatteras in winter loosens through the spring. After the end of May the south-north transition from higher surface temperatures to lower is no more abrupt there than elsewhere along the coast. On the other hand, a transition zone of this same order develops in spring at the opposite (N.E.) end of the area in the region of Nantucket Shoals.

During May, the latitudinal gradient of temperature along the continental shelf between the offings of Martha's Vineyard and of Chesapeake Bay increases to about  $6^{\circ}$  at the surface, and to about  $4-5^{\circ}$  on bottom, whereas the gradient from the coastline out to the edge of the continent decreases to some  $2^{\circ}$  at the surface, and the offshore boundary of the cold ( $4-6^{\circ}$ ) bottom water on the shelf assumes a wedge-like contour, jutting seaward into the warmer water offshore.

The vernal advance is complicated, on one hand, by intrusions of cold water from the east at the surface, and on the other hand, by indrafts of warm water over the bottom from offshore. Available data are not sufficient to show how regularly recurrent these cold surface intrusions are. When well developed they result in the development of tongues of low temperature spreading westward and southward from the offing of Cape Cod, along the outer zone of the shelf, but seldom if ever passing the offing of New York.

Summer. Surface temperature continues to rise rapidly over the entire area during June, except on Nantucket Shoals, where surface warming is so retarded by active turbulence that the surface is some  $4-5^{\circ}$  colder there than to the westward, after the middle of the month. Cold surface pools, of small extent, may also develop temporarily near land, from local upwellings.

During June the thermocline increases in steepness over the greater part of the area, except on Nantucket Shoals, where a thermocline develops only locally and sporadically, if at all.

Surface temperature normally reaches its annual maximum throughout the area in August; it then continues close to stationary throughout that month, and sometimes into the first week of September. The latitudinal gradient, between the offings of Chesapeake Bay and of Martha's Vineyard, is then  $4-5^{\circ}$ ; the gradient, transverse to the shelf, usually less than  $3^{\circ}$ .

In summer, the surface temperature is much more variable on Nantucket Shoals than to the westward and southward, both regionally and with changes of the tide, as well as averaging several degrees lower.

The thermal gradient between surface and bottom throughout the region generally reaches its maximum and the thermocline is steepest, shortly before autumnal cooling of the surface begins. The surface, along the 35-50 meter contour zone, is then some  $9-11^{\circ}$  warmer than the bottom in the offing of Chesapeake Bay;  $13-16^{\circ}$  warmer than the bottom off Cape May and New York.

The superficial 10-15 meters are now close to homogeneous, the greater part of the vertical gradient is condensed between the 15 meter and 30 meter levels, and the underlying water, like the surface stratum, is close to homogeneous, not only vertically but transversely to the shelf down to a depth of about 70-80 meters.

In normal summers the bottom, southward as far as latitude about  $38^{\circ}$  is considerably colder midway out on the shelf than it is either in small depths nearer land on the one hand, or along the outer edge of the shelf on the other hand. This cold belt usually extends from about the 30 meter contour out about to the 80 meter contour, and there is little variation in temperature within it, either transverse to the slope or over considerable distances along the shelf. The offshore boundary of this cold bottom-mass continues to show a wedge-like conformation indenting more or less into the warmer water offshore throughout the summer.

The thermal transition is comparatively abrupt between the cold water in on the shelf and bottom water some  $4-5^{\circ}$  warmer all along the edge of the continent, where the bottom temperature is about the same in July and August ( $9-13^{\circ}$ ) as at other times of the year.

In most summers the inshore boundary to this warm offshore bottom-belt coincides roughly with the 90-120 meter contour line, its offshore (lower) boundary with the 200-250 meter contour line. In late summer it extends eastward along Georges Bank, but the channel separating the latter from Browns Bank is normally its limit in that direction.

Autumnal Progression. The rate at which the surface cools during the early autumn varies locally and through short periods with strength of the wind and with the roughness of the sea. The surface over Nantucket Shoals (cooler than elsewhere in this general vicinity in summer) shows little or no cooling before the end of October. Thus, the abrupt transition between lower surface temperatures on the Shoals and higher to the westward, that exists from spring through summer, is obliterated in October or early November. On the other hand, this same season sees the redevelopment of the Cape Hatteras convergence, which exists through the winter but breaks down in spring.

During autumn, the temperature becomes increasingly equalized from the surface downward. Available data suggest complete mixture down to a depth of 40-50 meters by the end of October in normal years, the deeper strata warming as the surface cools, except where counteracted by local upwellings, such as occur on the eastern side of Nantucket Shoals.

By the middle of November, temperatures of  $10-12^{\circ}$  are to be expected right across the shelf from surface to bottom off southern New England and off New York;  $12-14^{\circ}$  off Cape May;  $13-14^{\circ}$  off Chesapeake Bay, usually with the surface fractionally the coldest level, this being the season when temperature is most nearly uniform regionally. The whole mass of water is then so close to uniform, out about to the 80 meter contour line, both from surface to bottom and from the shore line seaward, that there is no thermal separation between the bottom water along the continental edge ("warm zone" of winter, spring and summer) and farther in on the shelf. but this state lasts for only a brief period.

In late autumn and early winter cooling proceeds most rapidly near the land. By mid-December the water is coldest inshore, surface to bottom, the thermal pattern is of the winter type with the isotherms paralleling the coastal trend at all depths, and a cold inshore boundary has been reestablished to the bottom water warmer than  $8-9^{\circ}$  that washes the edge of the continent. By the middle of the month, mean temperatures are about  $5-8^{\circ}$  along shore, and  $10-13^{\circ}$  along the outer edge of the shelf, with a latitudinal range of about  $2^{\circ}$  between southern New England and Chesapeake Bay, and with vertical equalization so nearly complete that the differences between surface and bottom is in most cases less than  $0.5^{\circ}$  at given stations.

Cooling proceeds through January until, by the end of the month, the temperature, surface to bottom, has ordinarily fallen below  $5-6^{\circ}$  all along the coast; to  $8-9^{\circ}$  midway out on the shelf; but is still  $10-12^{\circ}$  along the outer edge of the latter. And cooling continues through the later winter until the minimum for the year is reached late in February, or early in March.

No thermal evidence has been found of any widespread influx of warm coastal water into the region from the south, of any floodings of the surface with pure oceanic water of high temperature, nor of upwellings onto the shelf of cold abyssal waters, such as have sometimes been postulated in the past on theoretic grounds.

#### SALINITY

The annual cycle of salinity results from the annual cycle of stream flow of the rivers tributary to the Middle Atlantic Bight and the mixing of slope water from offshore onto the shelf. This cycle is summarized in Bigelow and Sears (1935) and is quoted, in part, as follows:

The distribution of salinity over the continental shelf, Cape Cod to Chesapeake Bay, is coastal in character, with values increasing from 32 o/oo or less, next (to) the land, and 32-35.5 o/oo near the continental edge, where complex interdigitations may occur along the zone of mixture between inshore and offshore waters. Water slightly more saline than 35 o/oo is normally in contact with the bottom on the upper part of the continental slope with slightly lower values deeper down the slope.

There is little difference in salinity (and no abrupt transitions) lengthwise of the shelf, from the Gulf of Maine in the Northeast nearly to Cape Hatteras, regardless of depth or season. Just south of Cape Hatteras, however, a wedge of pure oceanic water ( $>35.5$  o/oo) presses in across the shelf (here only 27 miles wide) causing an extremely abrupt transition, southward, to much higher values, and entirely separating the shelf and slope water bands to the north from the low coastal salinities farther south. Available data suggest that this situation exists throughout the year.

The chief factor tending to alter the basic salinity pattern over the shelf are: (1) freshening by river water entering close to the surface inshore, and (2) salting by indrafts of slope water, over the bottom from offshore. The latter similarly affects (i.e., increases) temperature. But the former does not appreciably affect temperature, while the chief warming and cooling factors (solar and back radiation) affect salinity only indirectly.

Salinity is at its maximum at the end of the winter. The voluminous discharge of land water, in spring, reduces it to its minimum by early summer. Through the autumn, when indrafts from offshore more than counterbalance the inflow of river water, and when vertical mixing becomes more active as vertical stability is reduced by surface chilling, salinity again increases, and its distribution returns to the winter state.

Winter Maximum. Salinities on the shelf are highest in late February or early March, surface values between the offings of Martha's Vineyard and of Chesapeake Bay then averaging about 32.1 o/oo along the continental edge (200 meter contour); about 33.5 o/oo along the mid-belt of the shelf, and about 32-33 o/oo at the inshore stations, with values of 32 o/oo confined to the mouths of Delaware and Chesapeake Bays, and alongshore from the latter. The lowest value recorded, for the open sea, at this season, was about 30 o/oo.

The vertical range of salinity on the shelf averages smallest in winter, steep gradients at that season being confined to inshore localities where lowest surface values show recent increments of river water. Elsewhere, out to the 80-90 meter contour, the rate of vertical change in salinity, in February-March, has averaged less than 0.1 o/oo - per 20 meters of depth, usually with salinity lowest at the surface, but occasionally with small vertical reversals. Along the edge of the continent (100-200 meter zone), increase in salinity, with depth, is usually (but not always) more rapid in the deeper strata. Outside the 200 meter contour line, vertical distribution may or may not be complicated by interdigitation between shelf and slope waters (usually with maximum values at 150-175 meters), and a definite convergence often develops along short sectors. Below 300 meters, there is little vertical alteration, salinity being about 34 o/oo down to 900-1000 meters, and in some profiles the outermost station has lain in a belt of water homogeneous downward, from 100 meters or so.

Mean bottom values, February-March, are about 32.5 o/oo along the 20 meter line; 33.4 o/oo at 30-45 meters; 33.5 o/oo at 45-60 meters. At 60-100 meters mean values increase from about 32.8-33.3 o/oo off Martha's Vineyard, to 34.2-34.6 o/oo off Chesapeake Bay. Between 110-240 meters and 300-500 meters, water of 35-35.5 o/oo touches bottom along the slope usually (but not always) as a continuous band; in some winters as far eastward as longitude about 68°, but perhaps never farther east.

Vernal Progression. On the average about 50 percent of the total annual discharge of river water is concentrated in March, April, and May. The resultant freshening, while extremely irregular, is considerable over the whole shelf, as far north and east as longitude 71°30', but hardly affects the short sector thence eastward, past Martha's Vineyard, to Nantucket Shoals. Freshening is most pronounced close in to the sites of discharge; approximate minimum values to be expected 8-10 miles out from land, during spring, are: Martha's Vineyard, 31.9 - 32 o/oo; Montauk, 30.8 o/oo; New York, 27 o/oo; Atlantic City, 30.3 o/oo; Cape May, 30.5 o/oo; coast of Virginia, 31.3 o/oo; Chesapeake Bay, about 27 o/oo; Bodie Island, 30 o/oo. Minimal values, inshore, may develop in April, May, June, or even in summer; east of New York, the mean for June is about the same as for May. Values below 31 o/oo are confined to small pools, but by some time in May, a band less saline than 32 o/oo develops along the coast as far as longitude 71°30', either continuous or more or less interrupted. The isohaline for 32 o/oo indicates that the

outflow from Long Island Sound spreads offshore and westward; that from New York harbor offshore and southward. The discharge from Delaware Bay seems chiefly to be incorporated nearby; that from Chesapeake Bay may or may not form a temporary fan.

Available data indicate that surface water  $<32$  o/oo develops to greatest breadth in the offing of New York, where it may spread offshore for 90-100 miles; whereas off Chesapeake Bay, it is never more than about 50 miles broad. To the southward of Delaware Bay it reaches its greatest expansion before June, contracting thereafter, either to isolated pools or disappearing altogether. To the northward, it may reach its greatest breadth in May, with no great change in June; or it may continue to expand during the latter month, with surface water  $>33$  o/oo withdrawing to the outer edge of the shelf, or even beyond the latter.

In some years when indrafts of slope water are small, or in sectors but little affected thereby, the effects of vernal freshening (decreasing with depth) are appreciable down to 70-80 meters. But strong pulses of slope water may cause alteration of the reverse order in the deeper strata along the outer belt of the shelf. In spring such indrafts occur chiefly close to bottom; their volume, date, and extent of area affected, vary widely from year to year. In years of this type, the effects of vernal freshening may thus be entirely counteracted, on bottom, right into the 20 meter line.

Freshening at the surface, and indrafts of slope water below, combine to increase the vertical gradient of salinity over the shelf as a whole, though this alteration is much less regular, both seasonally and regionally, for salinity than for temperature. Steepest gradients develop in the upper 20 meters off New York, off Delaware Bay, and especially off Chesapeake Bay where a mean vertical gradient of  $>8$  o/oo per 20 meters has been recorded on three occasions. But in such situations the gradient may alternately increase, decrease and increase again within short periods. Comparatively steep gradients may also develop temporarily within short sectors along the continental edge, depending on the interaction there between shelf water ( $<33$  o/oo) and slope water ( $>35$  o/oo). Elsewhere over the shelf, and especially to the eastward of New York, the vertical gradient may be variously distributed between surface and bottom, regional contrasts being widest in this respect in May, and tending somewhat to smooth out in June. Successive isohalines tend to assume positions more nearly horizontal across the shelf with the advance of spring; a convergence zone tends to develop between coast water (recently freshened) and shelf water; while a steeper convergence between shelf and slope waters appears over the outer edge of the shelf on many of the spring and early summer profiles.

Midsummer. In exceptional years, the effects of vernal freshening may not culminate before late summer. In normal years, however, the band  $<32$  o/oo shows little expansion or contraction from June through August; the trend of mean values to the east of New York is almost stationary during this period, and inshore values may be as low as in June. In individual years the inshore belt  $<32$  o/oo may either be continuous, in July, extending out to the edge of the shelf off New York, or it may already be broken into isolated pools. Similarly, the isohaline for 33 o/oo may still lie outside the 100-200 meter zone with 34 o/oo nearby, or it may already be well inshore of the continental edge. To the northward of latitude 39 $^{\circ}$ , in July-August, surface waters

occasionally as deep as 800 meters. Still deeper down the slope, bottom values are close to 34.9 o/oo. The annual variation in the bottom salinity in summer, out to the 100 meter line, is 0.5-1.5 o/oo on the upper part of the continental slope, but bottom values below about 150 meters show a maximum yearly range of only about 0.5 o/oo (35.0-35.5 o/oo).

The maximum recorded value along the slope as defined by the 200-1200 meter contour at any intermediate depth between the offings of Chesapeake Bay and Martha's Vineyard, is 35.4-35.7 o/oo. Farther south near Cape Hatteras, water >36 o/oo is over the slope in summer as it is also in winter. It may also come within 25 miles of the continental edge near longitude 69<sup>o</sup>, at the 40-100 meter level, but it is much farther out along the intervening sector, its distance from the continental edge off New York usually being more than 150 miles.

Autumnal Progression. The slight increase in the rate of discharge from the rivers, from summer through autumn, is not sufficient to counteract the effect of surface cooling in reducing the vertical stability of the water column, and permitting increasingly active mixing. The vertical range of salinity between surface and bottom thus tends to decrease during the autumn, the surface salinity to increase, but rapidity of these changes varies from year to year. Mean values east of New York, average about 0.7 o/oo higher for September than for July; about 0.1 o/oo higher in October than in September. Even in years when summer salinities are abnormally low, and the seasonal schedule correspondingly delayed, surface values have increased considerably by November. And while, in more normal years, the eastern sector shows little mean alteration offshore through October and November, all readings close in to New York for November have been >32.0 o/oo. The general trend from November through December (as indicated by mean values to the east of New York) is either close to stationary, or values >35 o/oo may press in over the extreme edge of the slope. Further increase of 0.3-0.4 o/oo in January brings the surface salinity again to its annual winter maximum, except that very low values (29-30 o/oo) have been recorded in the immediate offing of Chesapeake Bay in January. This general increase in surface salinity is accompanied by dissipation of any pools of low salinity off New York, and off the bays to the southward and tends to equalize the regional contrast, thus bringing the horizontal distribution back to the more simple state characteristic of late winter.

The fact that subsurface salinities also increase through autumn, to reach their yearly maximum in winter is conclusive evidence that indrafts from offshore, at that season, are sufficient to counteract not only the coincident inflow of river water, but also the accumulated surplus of the latter. But it is not likely that an autumn ever falls when such indrafts are rapid enough to prevent some progressive vertical equalization of salinity, and some slackening of the offshore convergence between shelf and slope waters. Interdigitation along the continental edge between shelf and slope waters may, indeed, strengthen from July to September; convergence between these two waters has been as abrupt on some of the October profiles as at any time of year; and, comparatively homogeneous strata above strata of discontinuity may also persist through late autumn. But in most years, considerable decrease in the vertical gradient has already taken place by October. By December, it averages less than 0.2 o/oo per 20 meters, over the shelf as a whole, so to continue during the next two months. The only notable exceptions to this rule

are in the immediate vicinity of the mouth of Chesapeake Bay, where recent discharges of land water may cause extremely steep vertical gradients near land, in January of some years.

As vertical equalization progresses, the isohalines on any given profile not only decrease in number, but tend to rise more steeply from the bottom toward the surface. The net result is that by December, the vertical pattern of salinity has returned to the winter state, described above.

Examples of the February and July temperature, salinity, and density structure in a section extending across the continental shelf south of Montauk Point, Long Island, New York, typical of the two extremes of the nearly vertically homogenous distribution of mid-winter to the vertically stratified condition of mid-summer (Ketchum and Corwin, 1964) are reproduced as Fig. 1. The annual cycle of temperature at three of the stations in Fig. 1 show in Fig. 2 the development of the lens of warm surface water, the gradual deepening of the thermocline, and the delayed warming of the deeper waters." (Saila et al., 1973).

#### DENSITY STRATIFICATION

The water volume in the Middle Atlantic Bight is divided into a narrow, coastal, low salinity band affected primarily by outflow from three major estuaries, a shelf region ranging between 20 m and 100 m depth, and the outer shelf region at the shelf break. The shelf break receives intrusions of more saline and warmer slope water and is characterized by the shelf-slope front.

The shelf region is occupied by low salinity water ranging between 30 o/oo near shore to 35 o/oo at the bottom along the shelf break. The average salinity over the shelf is around 32.5 o/oo at the surface to 35 o/oo along the bottom. Water temperature varies seasonally, ranging from 2° in the nearshore zone during February-March to values as high as 30°, but generally 25-26°C in late summer. In winter the water is vertically homogeneous with temperature increasing seaward at all depths. The water begins to warm by late April with a thermocline established by early June. The intensity of the thermocline increases and reaches a maximum in mid-August to early September. As the surface waters continue to warm, the thermocline deepens and increases in intensity. The warmer surface waters then begin to mix downward increasing the bottom temperature. Maximum bottom temperatures are reached approximately one month after the surface temperature has reached a maximum (Ketchum and Corwin, 1964). Cooler air temperatures by this time have produced fall overturn which breaks down thermal stratification and enhances vertical mixing.

The intensity of the thermocline varies as a function of wind and solar heating. With an early spring onset of southerly winds and atmospheric heating a strong thermocline can be set up reducing vertical mixing to near zero. Added to this can be large freshwater runoff from the estuaries creating large salinity differences further intensifying stratification. Strong southerly winds can also provide a mechanism for invasion of warm high-salinity slope water onto the shelf of mid-depths or along the bottom, compensating for offshore transport in the surface layer. During the winter when this occurs a weak thermohaline stratification appears with slope water

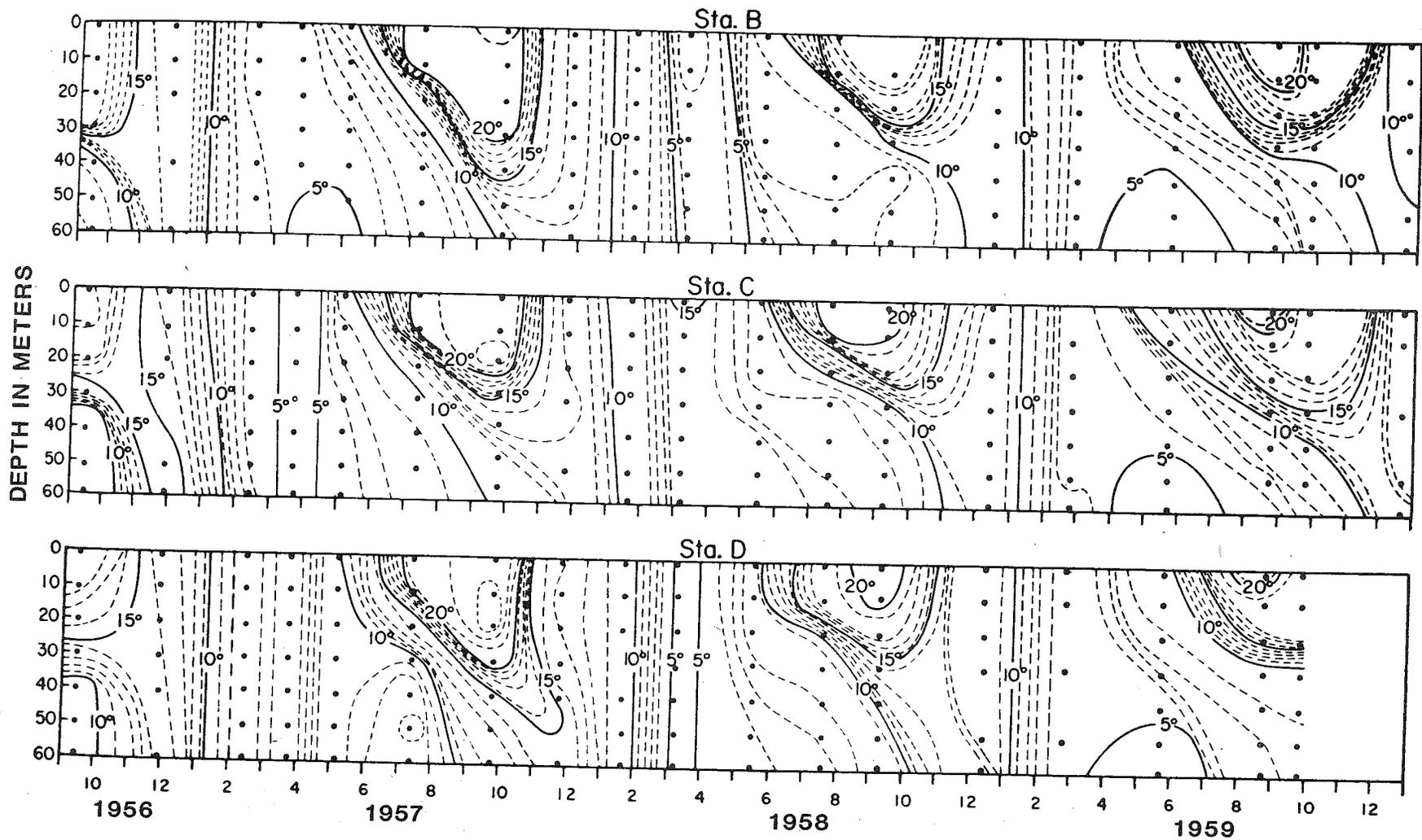


Figure 1. The annual cycle of temperature at three stations. (after Ketchum and Corwin, 1964).

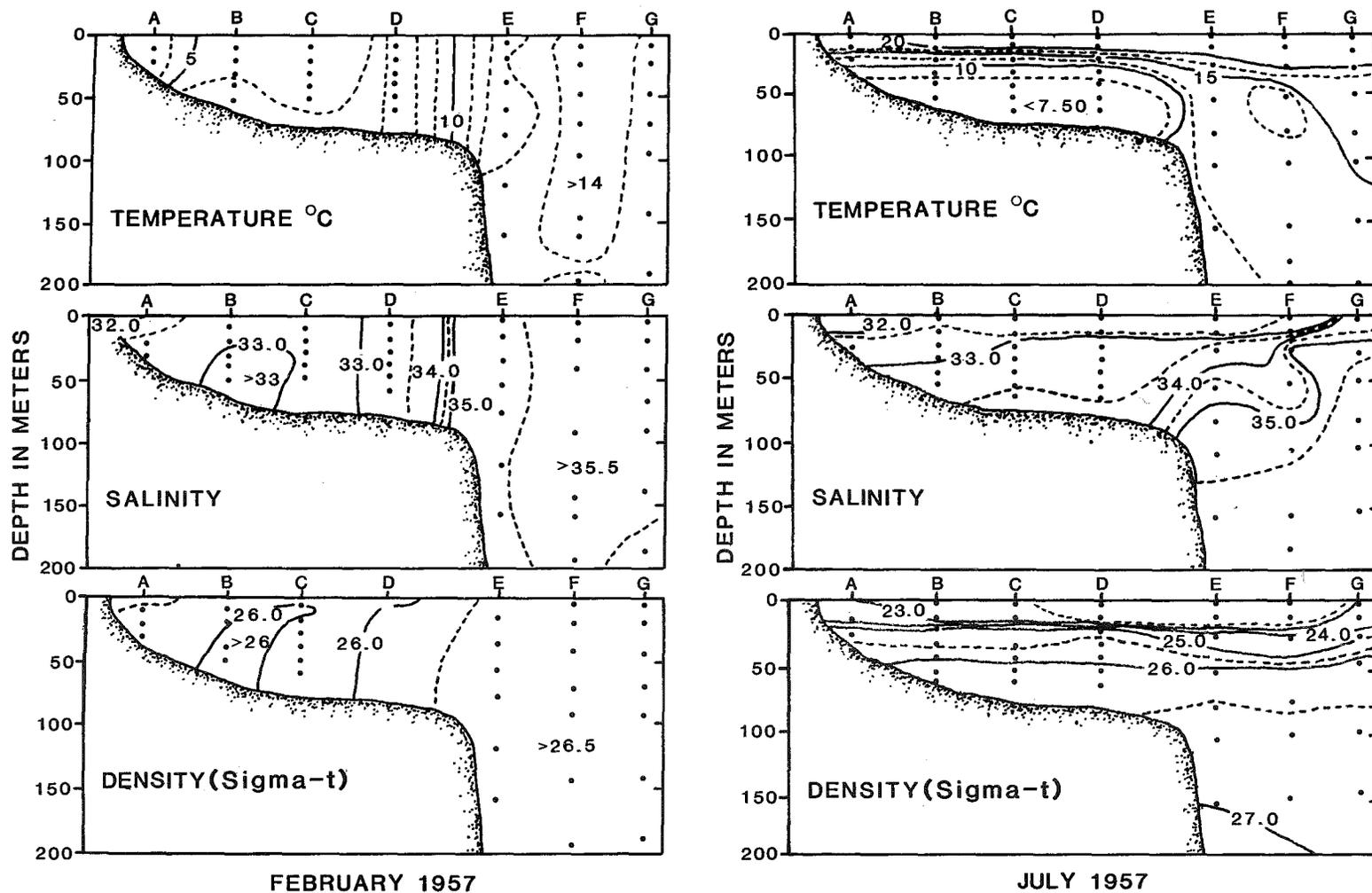


Figure 2. February and July temperature, salinity and density sections across the continental shelf south of Montauk Point (after Ketchum and Corwin, 1964).

moving in along the bottom. During the summer, the warmer, more saline water appears to move along the shelf into the vicinity of the 10 m isobath (Boicourt and Hacker, 1976).

Slope Water. Wright (1976a) subdivided the slope water into three layers; surface, permanent thermocline, and deep, based on thermal characteristics. The surface water layer exists in the upper 200 m where seasonal changes due to surface warming and cooling and wind mixing occur, and where shelf water incursions occur to a depth of approximately 120 m. The annual meteorological cycle leads to stratification of these waters and the development of a seasonal thermocline beginning in May and persisting until October or November when cooling and storm activity destroy it (Ingham et al., 1977). When the seasonal thermocline is well developed, a warm ( $20^{\circ}$ - $25^{\circ}$ C) mixed layer 30-40 m thick is present. Below this mixed layer in the seasonal thermocline temperature gradients can be as great as  $0.5^{\circ}\text{C}\cdot\text{m}^{-1}$ . Figure 3 shows a vertical temperature section from July 1978 from New York City southeast to the 106 Mile Dumpsite and beyond. The near-surface mixed layer and the seasonal thermocline are shown to be well developed in both the shelf and slope water regions. When winter cooling and storm wind-mixing occur, the water column becomes nearly isothermal to approximately 100-200 m depth or the top of the permanent thermocline (Fig. 4).

Movement of the shelf slope front into the slope water area may have different results depending on the season. Overspreading of the area by shelf water in winter and spring would bring in colder and less saline water into the surface slope water layers. This would form an inverted thermocline (but not a pycnocline) with warmer more saline slope water underlying colder less saline shelf water. During the summer and early fall, however, overspreading by shelf water at the surface would have little effect on the thermal stratification because of uniform surface heating of both shelf and slope waters.

The second layer in the slope water, the permanent thermocline layer, exists between the depths of approximately 200 and 600 m ( $13^{\circ}$ C to  $5^{\circ}$ C) where thermal gradients average about  $0.02^{\circ}\text{C}\cdot\text{m}^{-1}$ . Water at these depths is beyond the reach of local meteorological effects and remains relatively constant except for warping of temperature strata caused by aperiodic incursions of the north wall of the Gulf Stream or warm core Gulf Stream rings.

The third layer, deep slope water, exists from about 600 m to bottom and is a zone of very slow temperature decrease to a minimum of  $2.2^{\circ}$ C at about 4000 m. Variations in the lower portions of this layer over the continental rise may be due to the position of the Western Boundary Undercurrent, a deep geostrophic, near-bottom current. (Ingham et al., 1982).

#### TIDAL CURRENTS

Tidal currents are the horizontal movements of water that accompany the rising and falling of the tide. The horizontal movements of the tidal current and the vertical movement of the tide are intimately related parts of the tide-producing forces of the sun and moon. Therefore, tidal currents, like the tides, are periodic. It is the periodicity of tidal currents that distinguish them from other currents in the sea which are generally called non-tidal or residual currents. These latter currents are due to causes

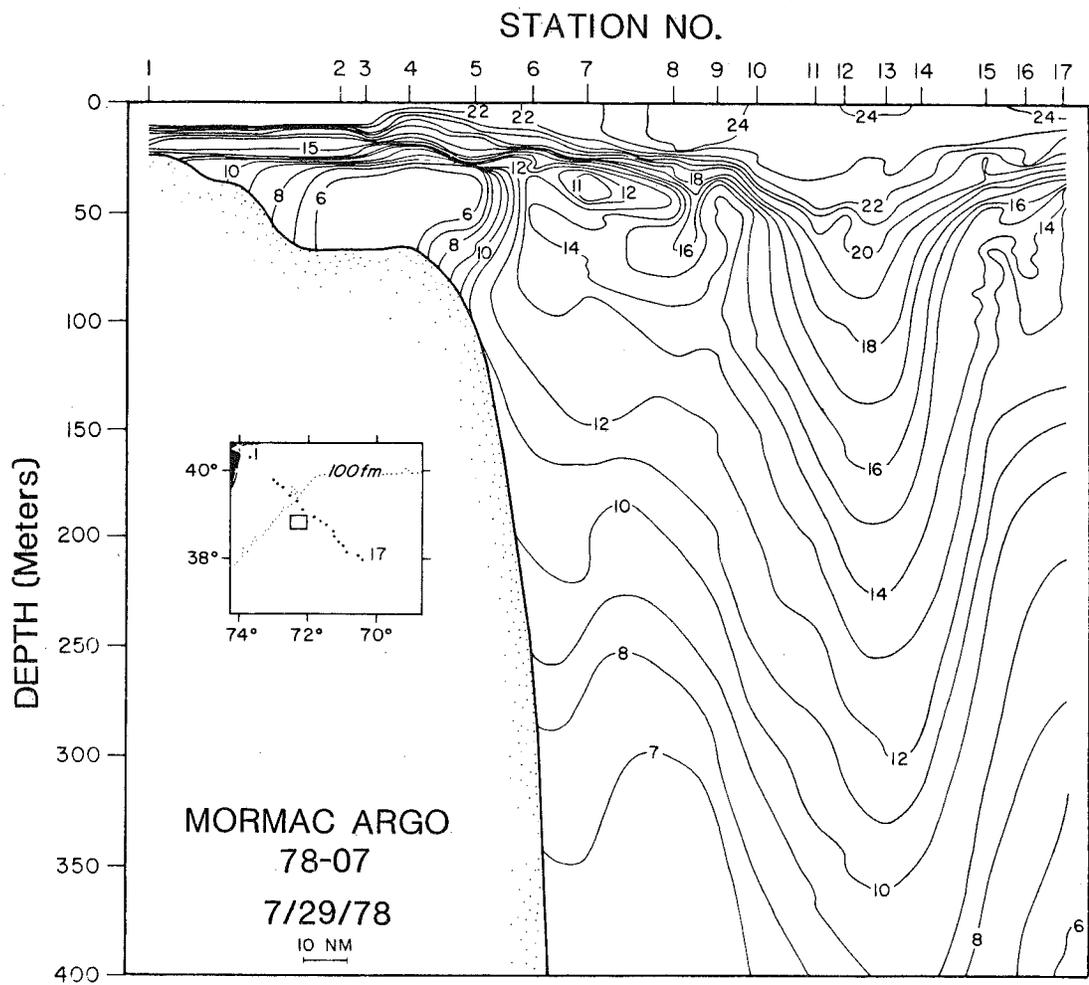


Figure 3. Vertical section of temperature ( $^{\circ}\text{C}$ ) showing thermocline development in shelf and slope waters. From Cook and Hughes, 1980.

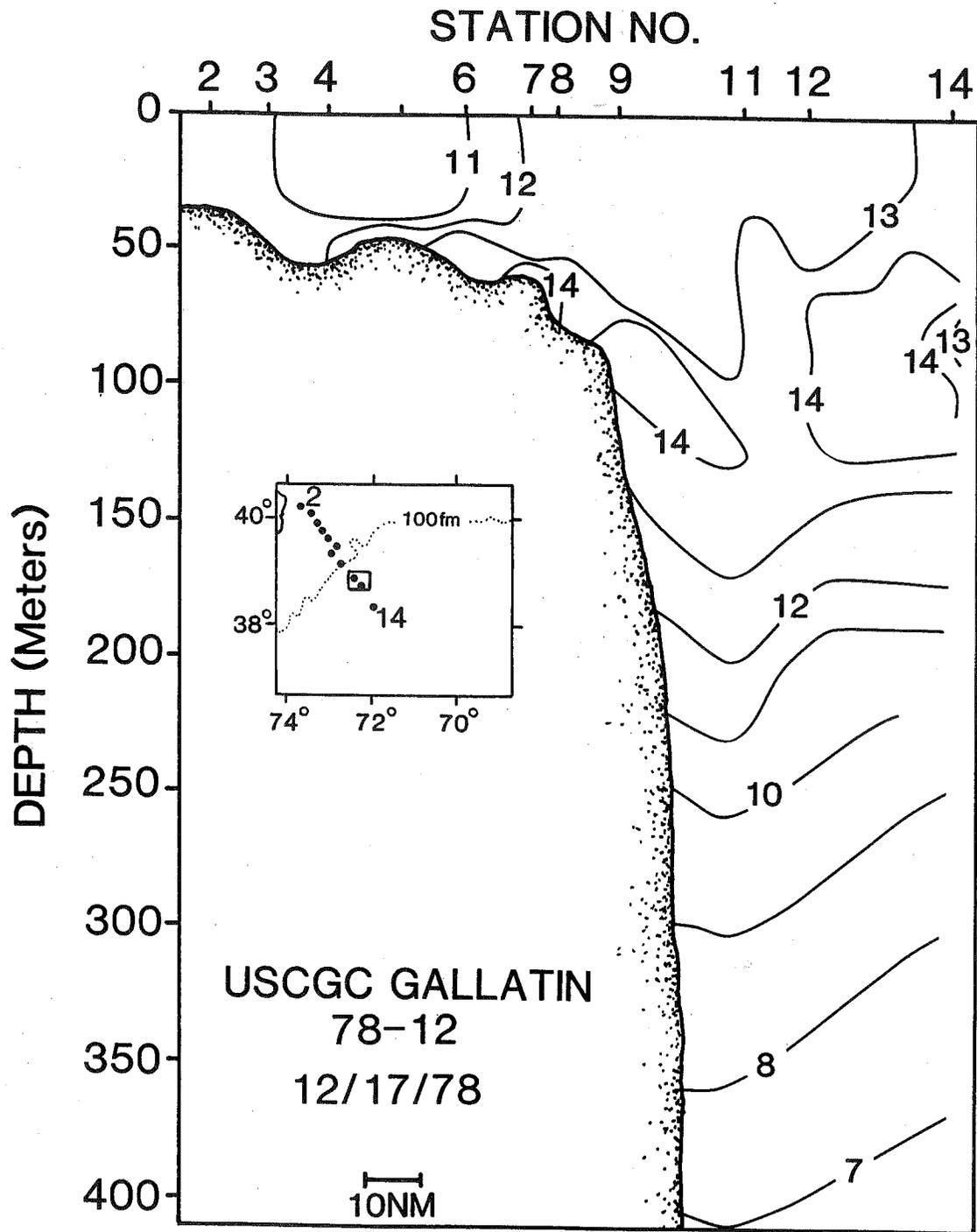


Figure 4. Vertical section of temperature ( $^{\circ}\text{C}$ ) showing late fall conditions in outer shelf and slope waters. From Cook and Hughes, 1980.

independent of the tides such as wind, freshwater runoff, and differences in density. Currents of this type do not exhibit the periodicity of tidal currents.

Tidal and non-tidal currents occur together in the open sea and in inshore waters; the actual current experienced at any point is the resultant of the two types. Tidal currents generally attain considerable velocity in narrow entrances in bays, in constricted parts of rivers, and in passages from one body of water to another. Along the coast and farther offshore, tidal currents are generally of moderate velocity; over the shelf they are generally less than 0.2 knot.

Within the channel of a bay or river, the current is compelled to follow the direction of the channel, upstream on the flood and downstream on the ebb. In the open sea this restriction does not exist, and the tidal currents change direction continually, rotating clockwise. In an average period of 12 hours 25 minutes, the current direction rotates completely round the compass.

A characteristic feature of the rotary current is the absence of slack water. Although the current generally varies from hour to hour, this variation from fastest current to slowest current to fastest current again does not provide for a period of slack water. When the velocity of the rotary current is least, it is known as the minimum current; and when it is greatest, it is known as the maximum current. The minimum and maximum velocities of the rotary current are thus related to each other in the same way as slack and strength of a reversing current, a minimum velocity follows a maximum velocity by an interval of about 3 hours, being followed in turn by another maximum after a further interval of 3 hours.

Rotary tidal currents are subject to the periodic variations found in tides and reversing currents. At times of full and new moon the velocity of the rotary current is greater than the average, while at times of the moon's first and third quarters the velocities are less than average. Likewise, when the moon is in perigee, stronger currents occur; whereas when the moon is in apogee, the currents are weaker.

#### SUB-TIDAL NEAR-BOTTOM CURRENTS

Superimposed upon the weak alongshore mean currents previously discussed are currents in the tidal (6-24 hours) and sub-tidal (2 to several days) frequencies which have been measured by many workers in the past several years with current meters.

As stated earlier, tidal currents have regular semi-diurnal (12 hour) periods and are generally strongest near the coast. The tidal currents are generally described as rotary, constantly varying in direction, thus describing what are known as tidal ellipses. The tidal currents decrease in magnitude away from the coast and also decrease with depth.

Subtidal currents are mostly barotropic (caused by changes in sea level) and constant with depth. The sea level changes are due to meteorological forcing caused by either local winds or the propagation of a shelf wave from some distant oceanic or meteorological event (Ou et al., 1981; Bennett and Magnell, 1979; Scott and Csanady, 1976; Beardsley and Flagg, 1976). Beardsley

and Butman (1974) proposed a conceptual model to explain simultaneous measurements on the continental shelf. They proposed that offshore winter storms dominate the shelf circulation by causing strong westward wind stresses south of New England which drive water shoreward (north). This causes sea level to rise along the coast which sets up a cross-shelf (seaward) pressure gradient force causing a flow to the west. This current parallels the westward wind stress which caused the initial setup. Storms located over the land, however, cause eastward wind stresses setting up a large alongshore pressure gradient force which causes large current oscillations but little net alongshore flow. These storms cause Ekman transport away from shore and cause sea levels to fall along the coast. Bishop and Overland (1977) showed that during the winter season wind-driven circulation predominates on the shelf while during the summer, density driven currents are more common.

Many workers have found that these meteorologically forced subtidal currents increase in magnitude away from the coast and decrease near bottom. Boicourt and Hacker (1976) showed near-bottom currents of between 12 and 36  $\text{cm}\cdot\text{sec}^{-1}$ , increasing in a seaward direction. They also showed that cross-shelf currents may be enhanced by near-bottom onshore flow along the outer shelf in response to offshore Ekman flow at the surface under certain wind conditions. Beardsley et al. (1976) showed that currents veered shoreward closer to bottom, suggesting that near-bottom materials may move shoreward, in agreement with the earlier sea bed drifter work.

Seasonal stratification due to the development of a pycnocline in shelf water has several implications for the current structure, response and sediment transport of the region. Patchen et al. (1976) determined for the apex of New York Bight that weak stratification resulted in the entire water column responding strongly to the wind, while response was limited to the upper stratified layer when a thermocline was present. Man et al. (1980) showed a decoupling of currents above and below the pycnocline in the New York Bight, with near-bottom currents varying from northward to southwestward. Shonting (1969) reported similar results for Rhode Island Sound where the surface flow above the seasonal pycnocline was strongly isolated from the lower layer.

Nearshore current meter data collected in the apex of New York Bight by Swift et al. (1976) showed a strong onshore transport component. A similar onshore transport was noted by Han and Mayer (1981) on the Long Island inner shelf near the 37 m isobath in late fall. Current records showed both tidal and subtidal forcing, while onshore near-bottom flow appeared to respond to the net offshore surface flow resulting in a zero net cross-shelf flux. Only strong onshore or easterly winds produced an offshore near-bottom component. (Ingham et al., 1982).

#### BOTTOM CURRENTS

Sea bed drifter studies have provided an inexpensive way to study the net bottom currents on the continental shelf. Bumpus (1973) released thousands of sea bed drifters, about 16% of which were returned from region beaches or waters. These data showed a general onshore (northward) bottom movement south of Long Island and New England at speeds of about  $1\text{-}2\text{ cm}\cdot\text{sec}^{-1}$ . Over the outer shelf the bottom drift was directed westward at about the same speeds. Off the New Jersey coast, currents converge towards the coast between about

38.5°N and 40°N latitude. South of this region, the drift tends towards Chesapeake Bay at about  $2 \text{ cm}\cdot\text{sec}^{-1}$ . Hardy et al. (1976) and Charnell and Hansen (1974) found similar results in other long-term sea bed drifter studies. They also noted, however, a strong near bottom estuarine-like circulation into Long Island Sound and New York Harbor at  $2 \text{ cm}\cdot\text{sec}^{-1}$ . They found an apparent divergence along the Hudson Shelf Valley where east of the valley bottom drift was northward while west of the valley more westward bottom drift was observed. Bottom drifter releases during April 1979-March 1980 reported by Pape (1981) on the continental shelf in the vicinity of Delaware Bay showed predominantly onshore movement, strongly convergent on the Bay mouth.

Long-term, near-bottom currents were studied in the Hudson Shelf Valley and Canyon system by Keller et al. (1973) and Nelsen et al. (1978). Current meter measurements showed flow reversals up and down canyon with velocities of  $8\text{-}15 \text{ cm}\cdot\text{sec}^{-1}$ , with a maximum of  $27 \text{ cm}\cdot\text{sec}^{-1}$  in the upper central portion of the canyon. Nelson et al. (1978) concluded from current meter data and wind records that unchannel near-bottom flow was related to westerly winds driving surface waters seaward during the winter, while during the summer seaward near-bottom flow prevailed (Ingham et al., 1982).

#### MONTHLY CURRENT VECTORS

Figures 5 to 16 show monthly current vectors for the Mid-Atlantic region. Shown also are current constancy, speed, and direction (Williams and Godshall, 1977).

#### FRONTS

Where two water masses in the ocean meet, there is frequently a front, across which there is a sharp transition between the different characteristics of the two water masses. Typically, major advective exchange between the water masses is restricted and occurs only sporadically across fronts. Frontal regions are commonly convergence zones, and consequently floating or suspended materials, in the water tend to become concentrated along them.

Shelf-Slope Front. The shelf-slope front is located over or near the outer edge of the continental shelf, separating less saline and usually cooler shelf water from the slope water which lies offshore. The front is continuous from Cape Hatteras to Georges Bank and is present throughout the year. The shelf-slope front extends from the surface to the bottom, typically touching bottom at depths between 75 and 100 m and slopes seaward, with the surface intersection situated about 25 to 55 km offshore from the bottom contact (Beardsley and Flagg, 1976).

The horizontal salinity gradient across the shelf-slope front is typically 1 to 2 o/oo over 10 to 50 km. Near-bottom temperature gradients are about  $2\text{-}4^{\circ}\text{C}$ , but are much less intense from late June to September as the summer thermocline and a warm surface mixed layer cuts across the front (Bowman and Wunderlich, 1977). The vertical temperature and salinity structure within the front can develop complex patterns because of interleaving of shelf and slope waters in the form of offshore extrusions of "cold pool" water at mid-depth, and intrusions of slope water onto the shelf along the bottom and exchanges of surface waters. Gordon and Aikman (1981)

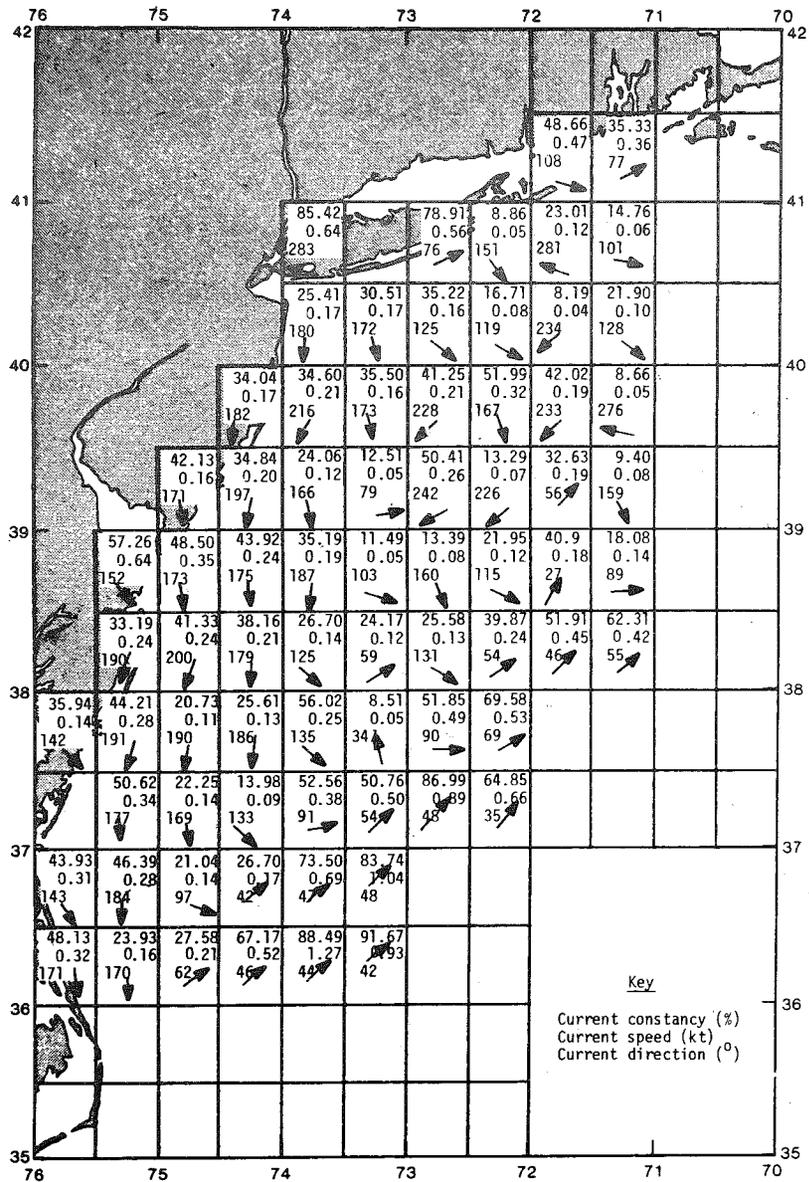


Figure 5. January mean current vectors.

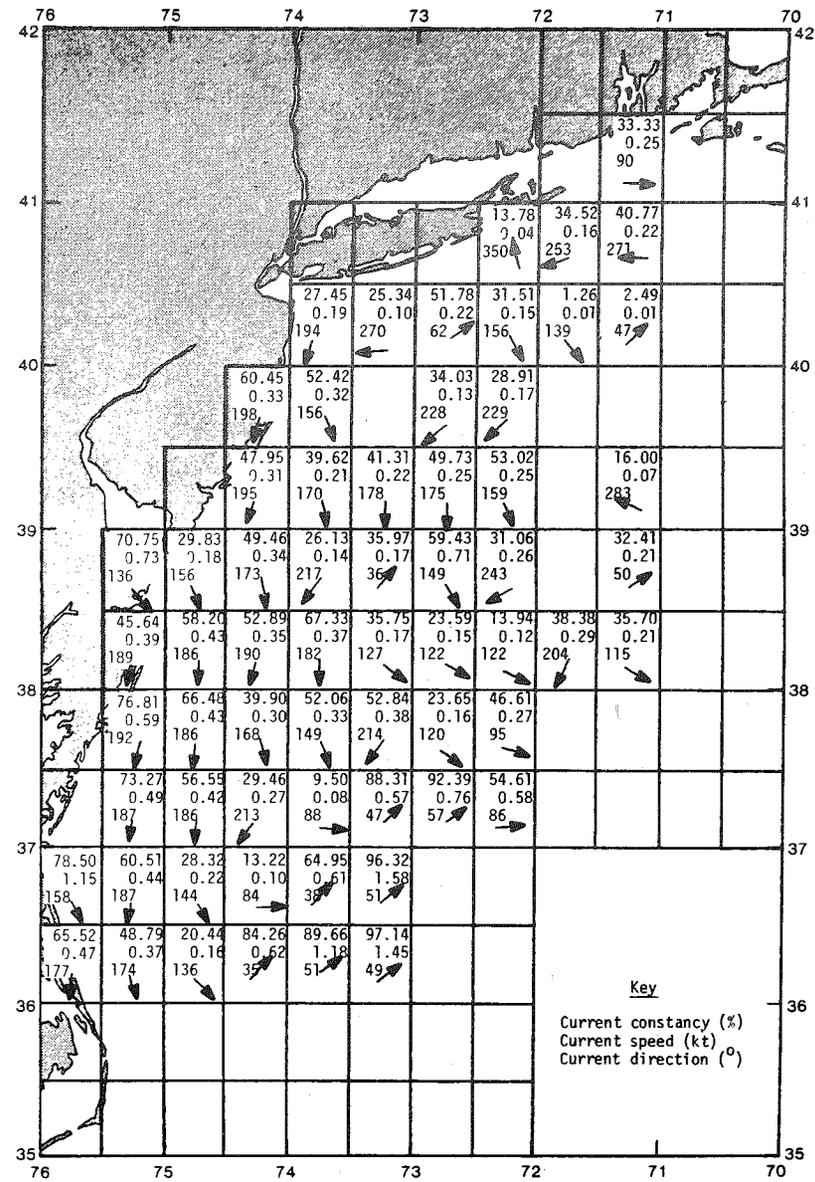


Figure 6. February mean current vectors.

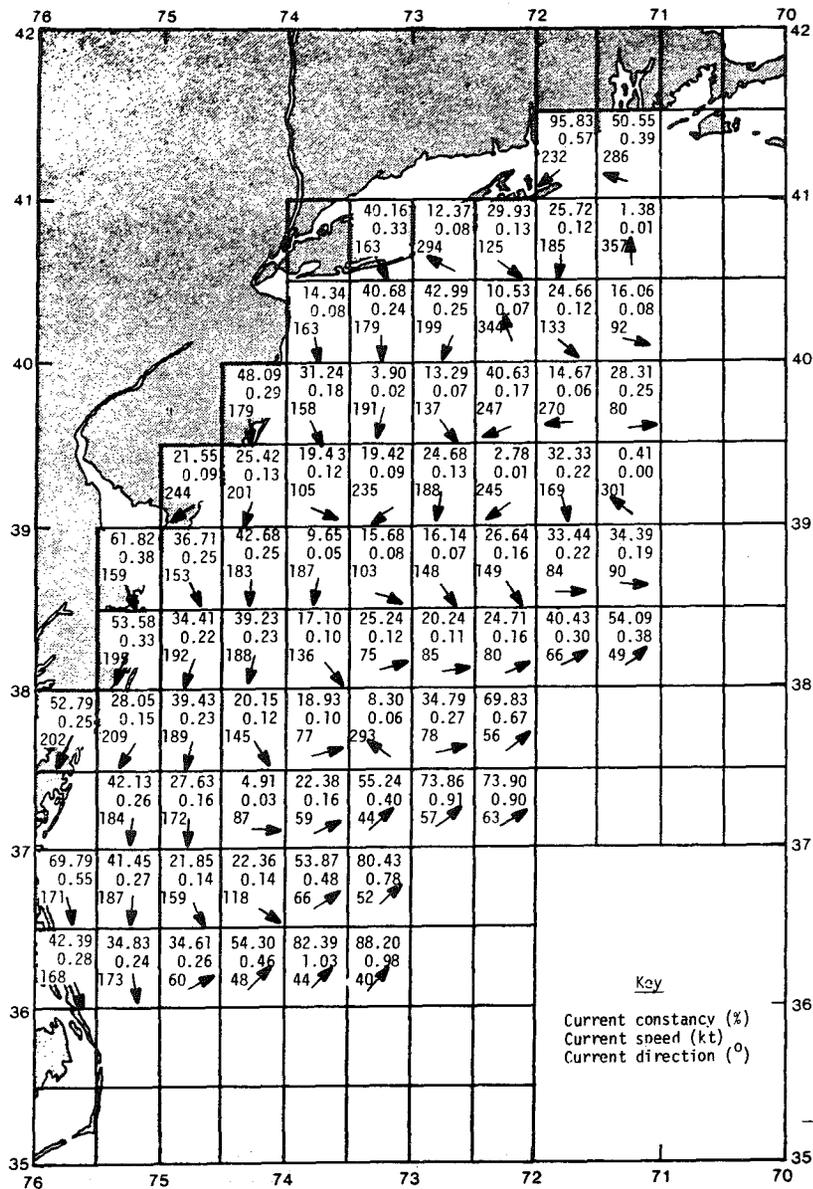


Figure 7. March mean current vectors.

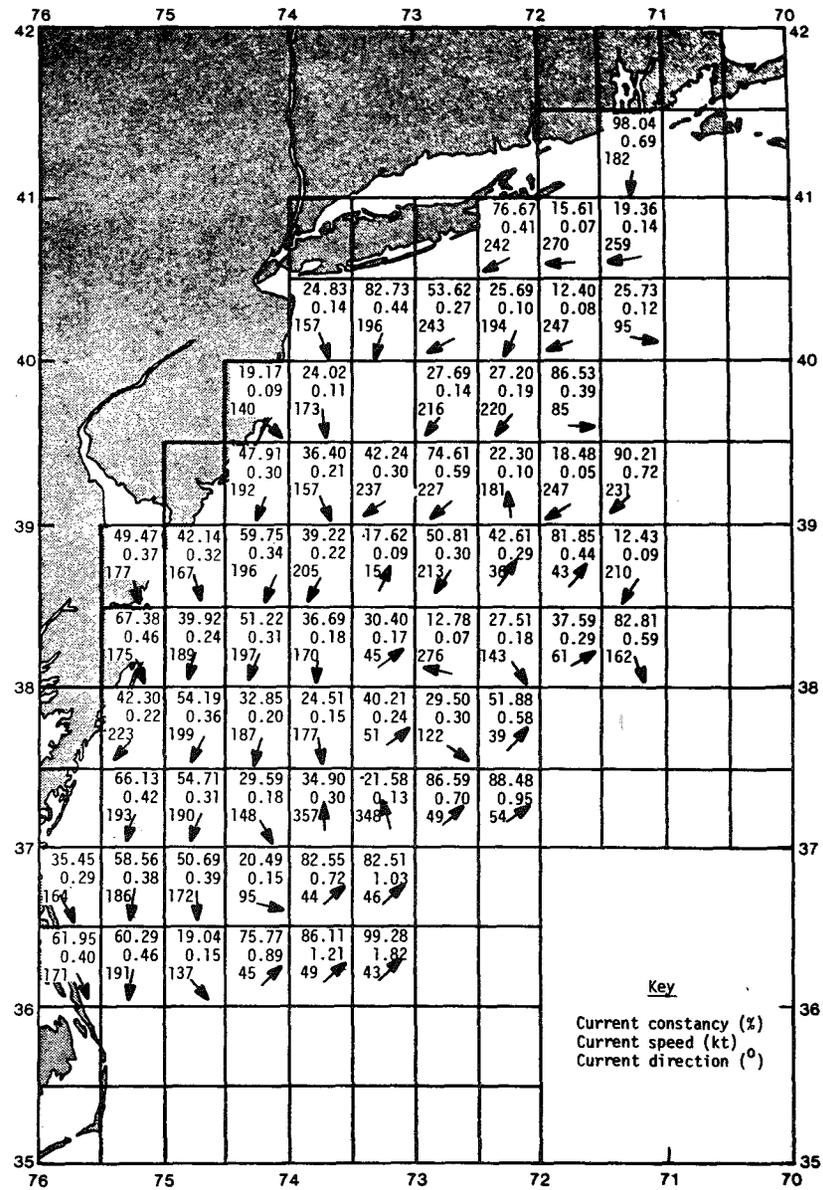


Figure 8. April mean current vectors.

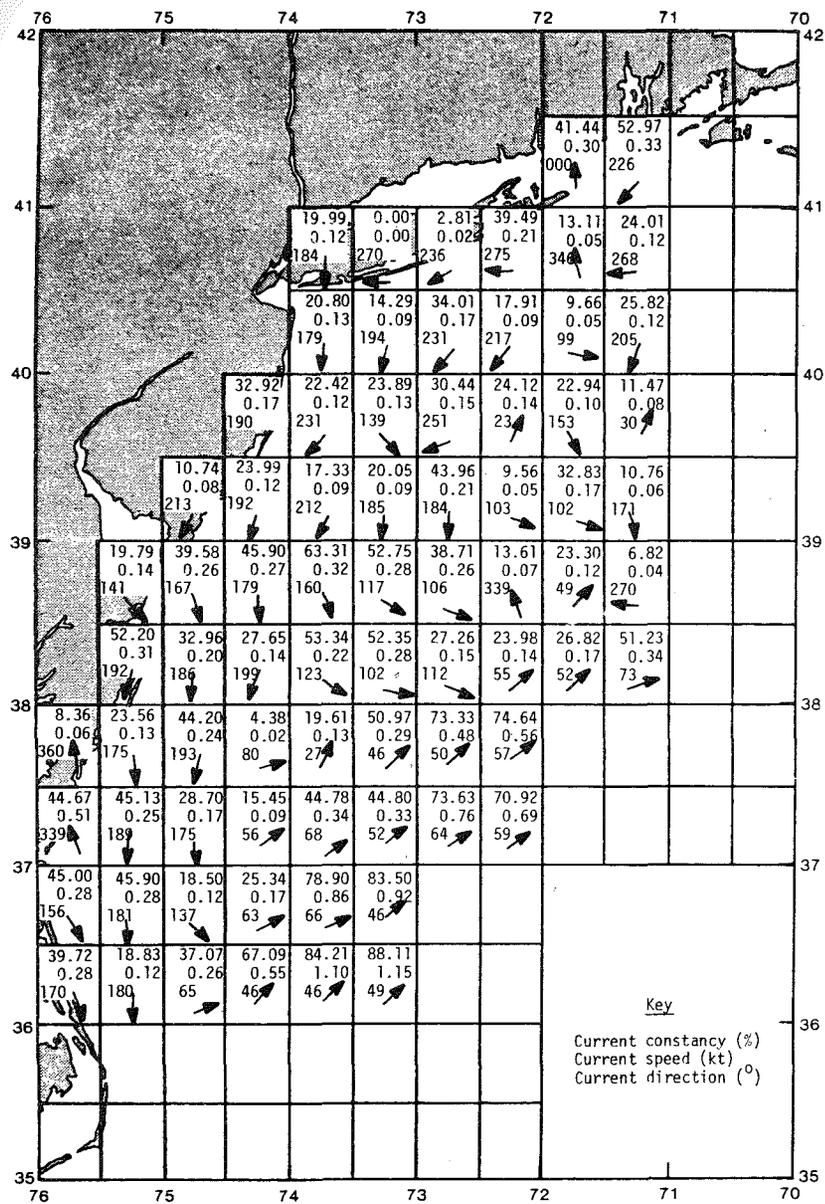


Figure 9. May mean current vectors.

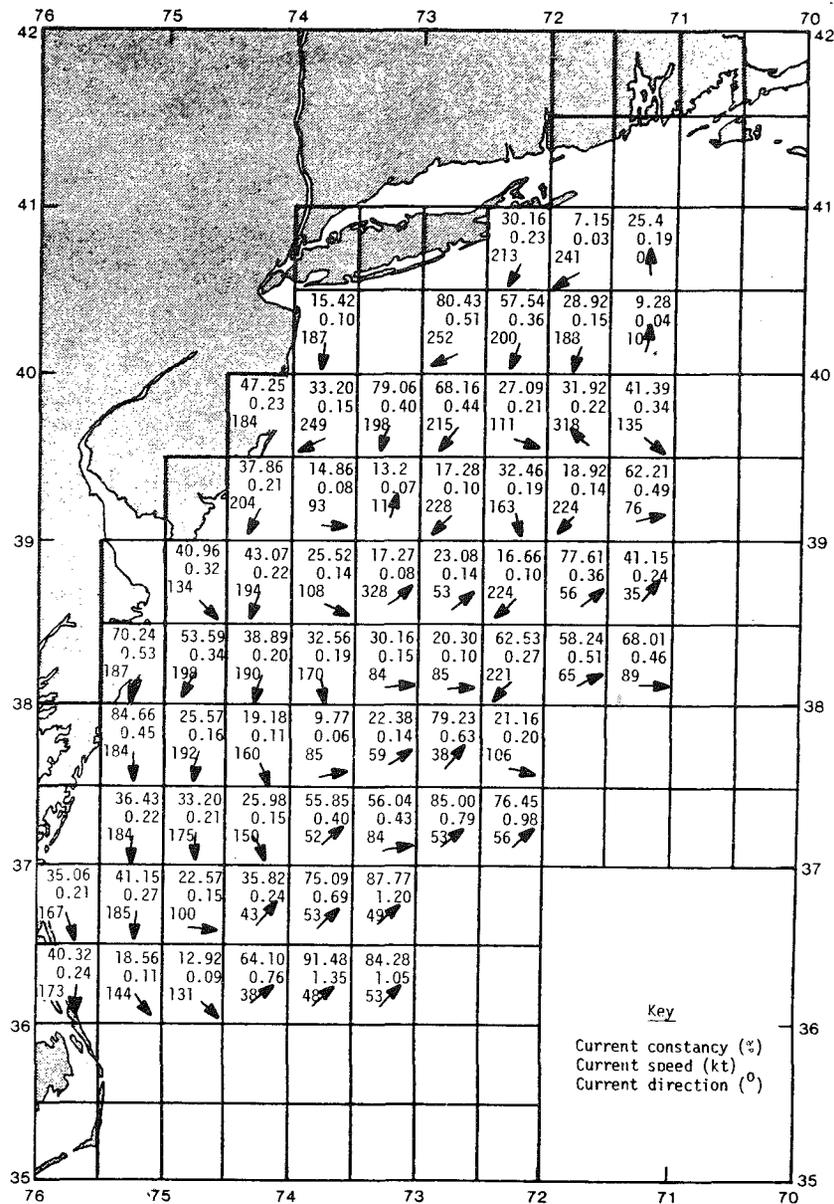


Figure 10. June mean current vectors.

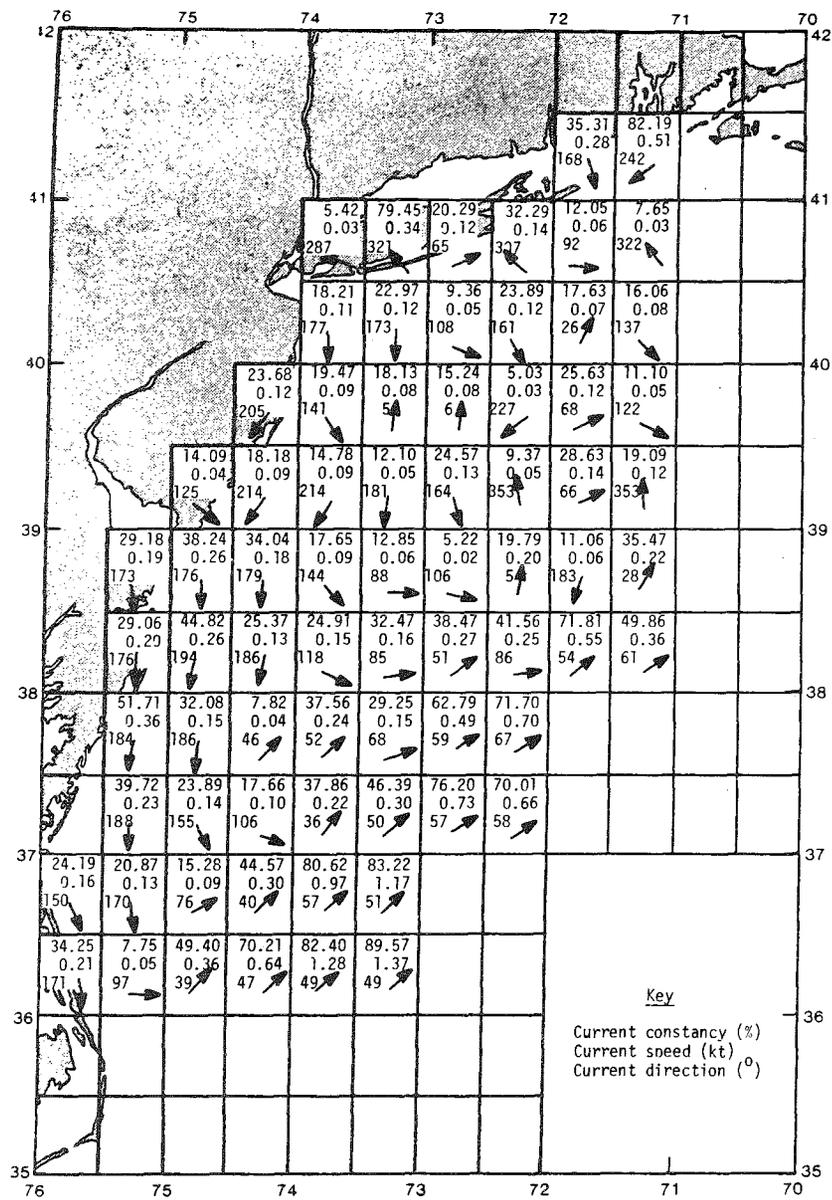


Figure 11. July mean current vectors.

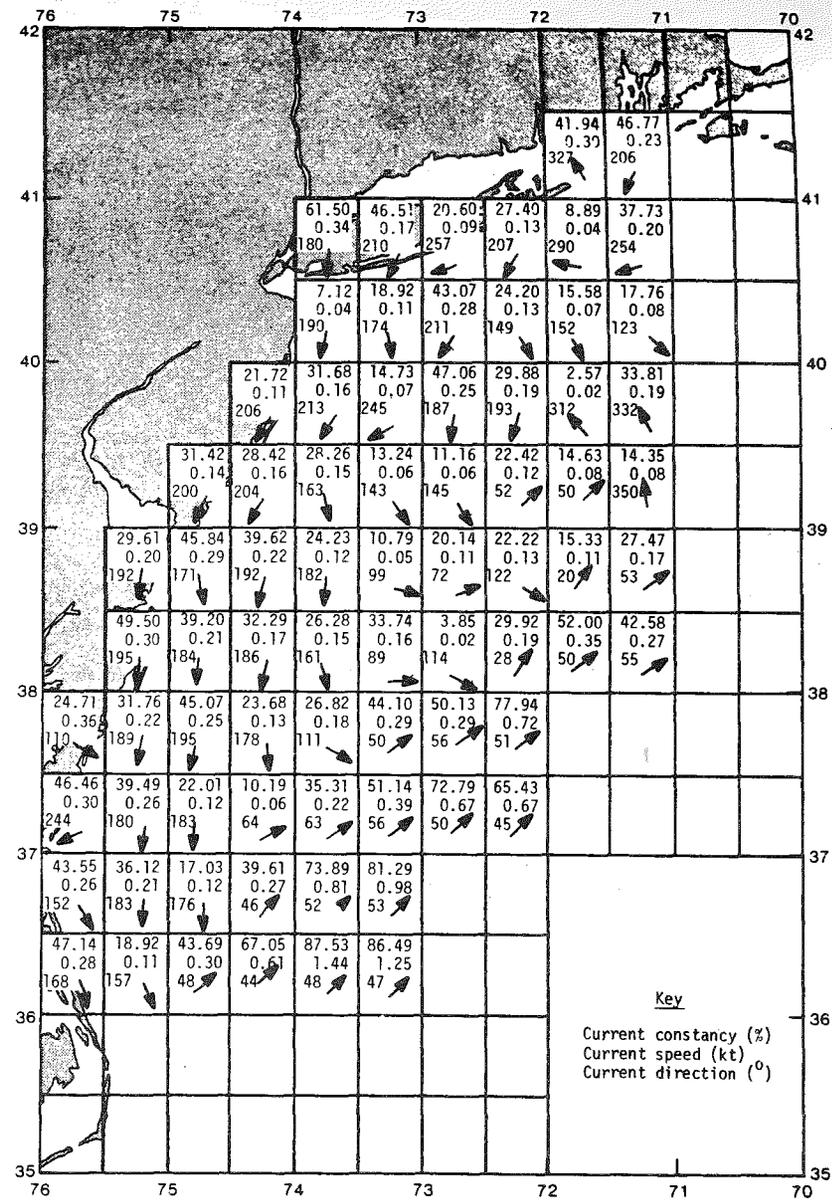


Figure 12. August mean current vectors.

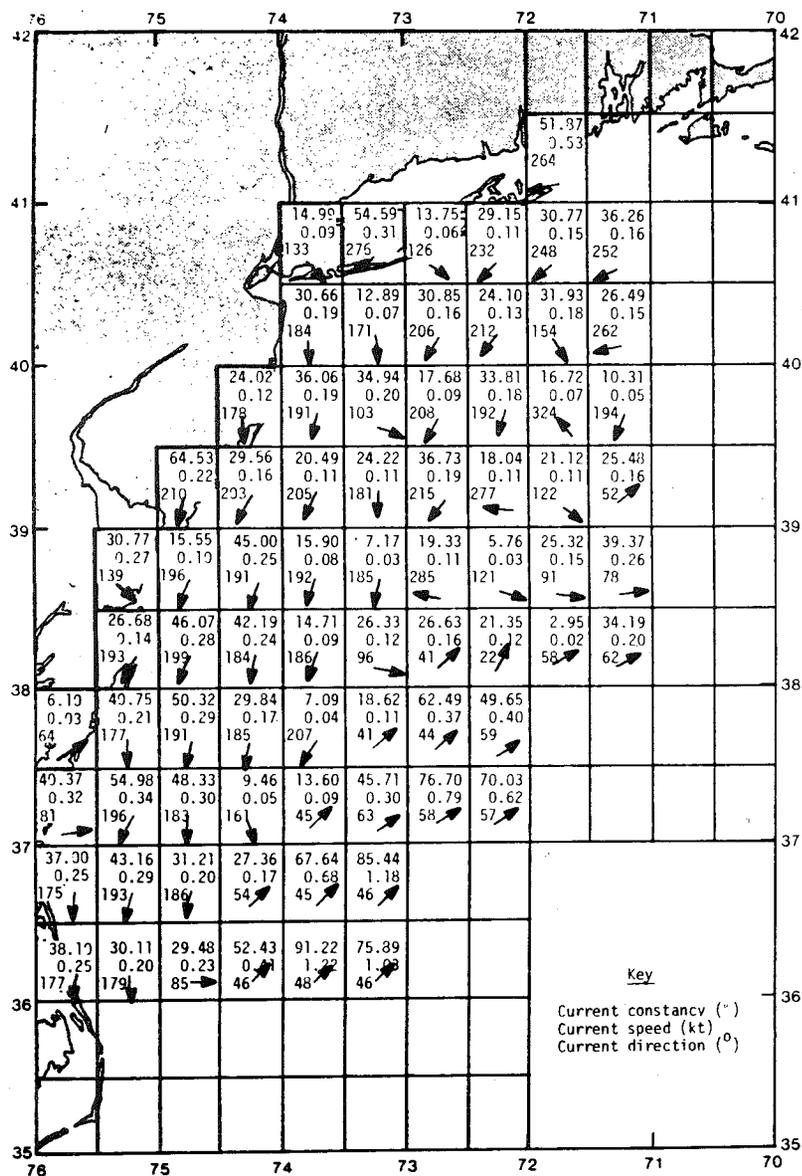


Figure 13. September mean current vectors.

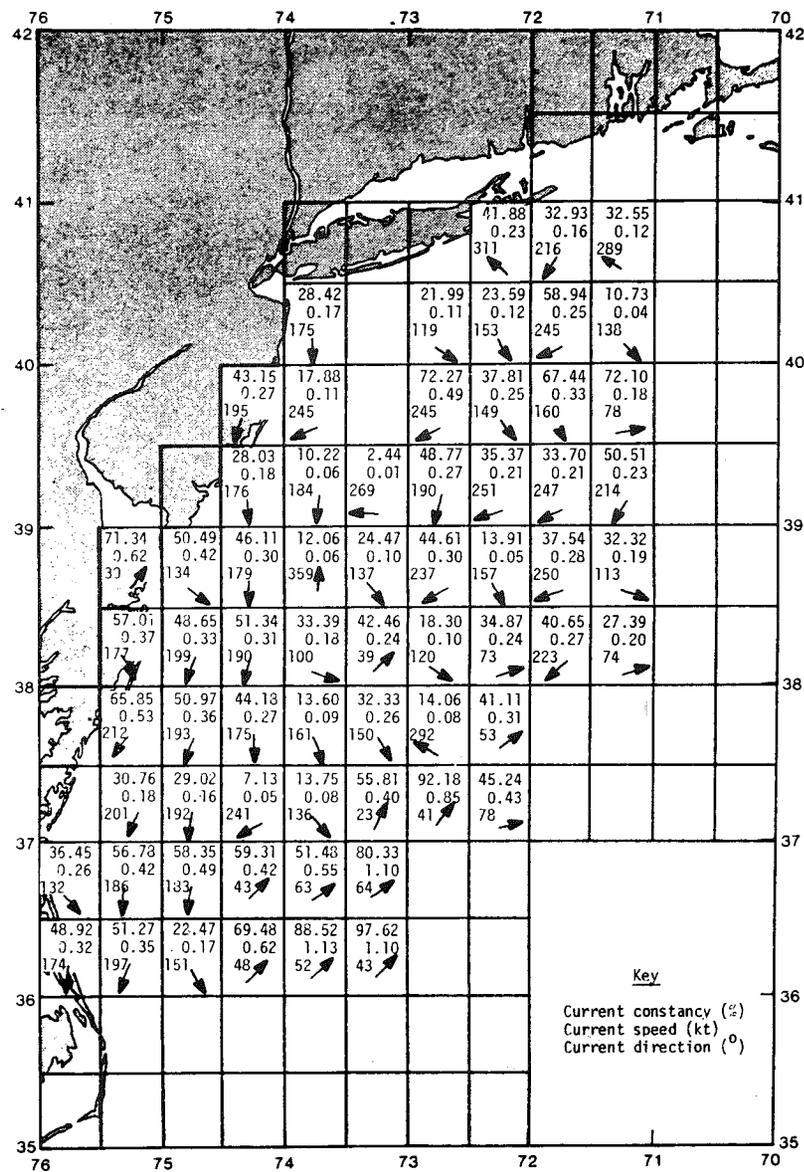


Figure 14. October mean current vectors.

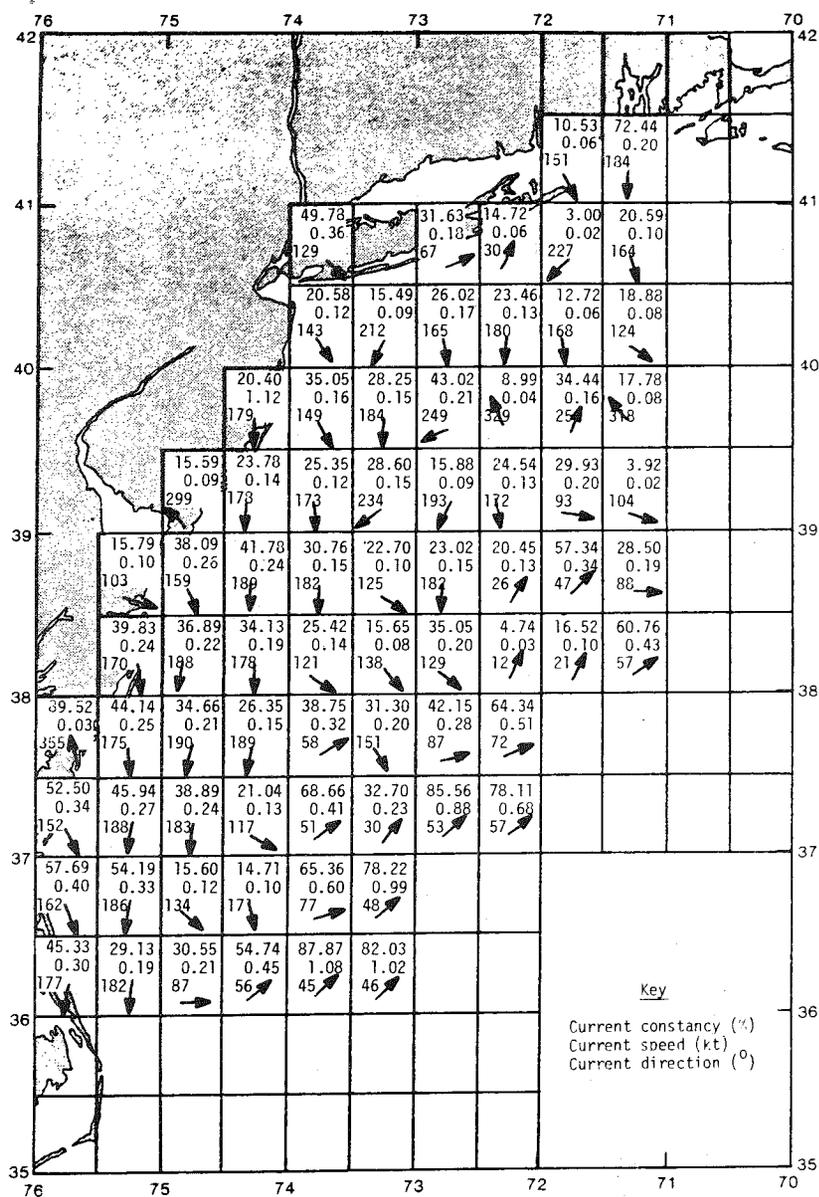


Figure 15. November mean current vectors

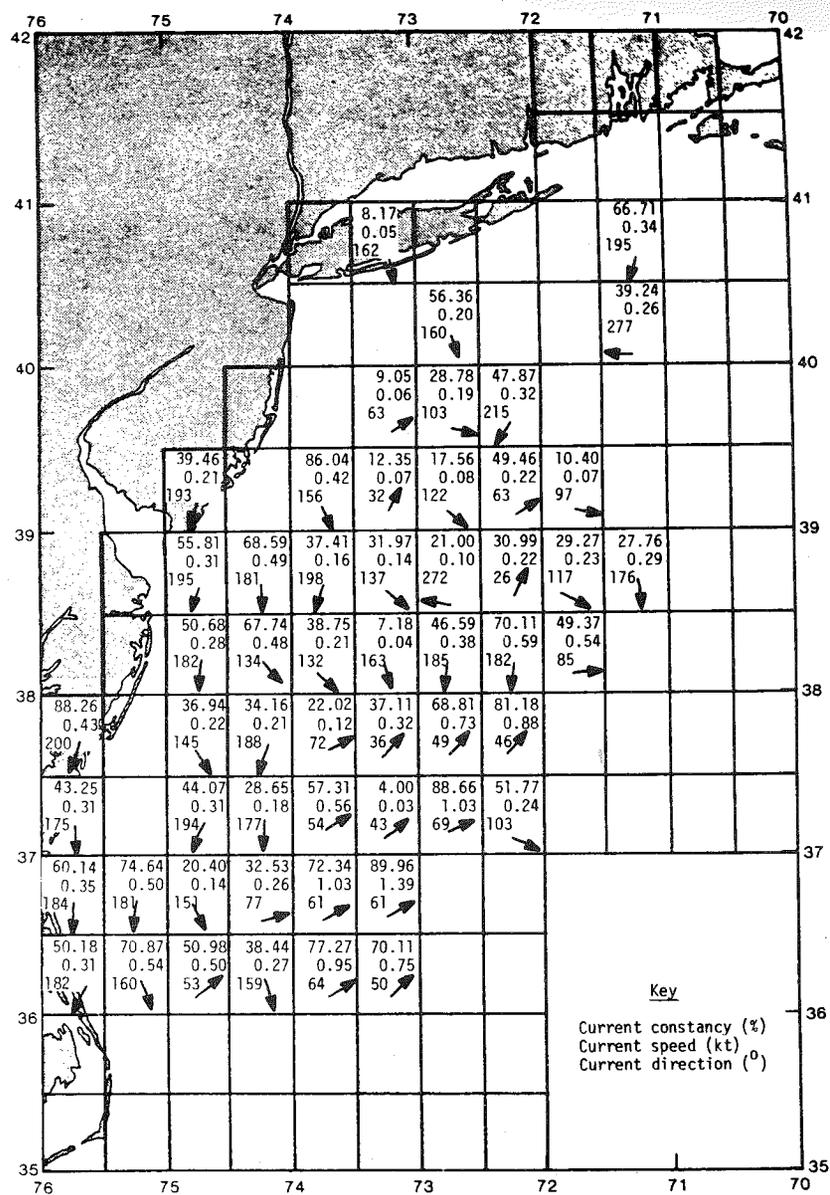


Figure 16. December mean current vectors.

hypothesized that considerable transfer of salt occurs from slope water to shelf water across this front during the summer stratified season. During this period the horizontal density gradient is minimal across the front facilitating the transfer of about half the salt required annually to balance freshwater inflow.

Examination of sea surface temperature patterns has shown that the front exhibits large wavelike motions of 100- km or more, propagating at speeds of about  $5 \text{ cm}\cdot\text{sec}^{-1}$  (Halliwell, 1978; Gunn, 1979). Robinson et al. (1974) found meanders along the front on scales of tens of kilometers with displacement speeds of 5 to  $20 \text{ cm}\cdot\text{sec}^{-1}$ . Such variations in the frontal position have been attributed to a dynamic response to atmospheric forcing (Stommel and Leetma, 1972; Csanady, 1973; Flagg and Beardsley, 1978), Gulf Stream meandering (Wright, 1976), to the passage of warm-core rings through the slope water (Beardsley and Flagg, 1976; Celone and Chamberlin, 1980) and because of destabilization of the front resulting from river discharge into the shelf water (Ketchum and Keen, 1955; Ketchum and Corwin, 1964).

Wind stress may be another cause of the offshore movement of the shelf-slope front due to Ekman transport (Boicourt and Hacker, 1976; Beardsley and Flagg, 1976) or interference with the normal momentum balance of the front in a direction parallel to the front, thus causing geostrophic adjustment normal to the front (Csanady, 1978). Warm core Gulf Stream rings may also cause seaward extensions of the shelf/slope front due to the rings' currents (Morgan and Bishop, 1977). Local baroclinic instability of the front over steep topography could be another factor affecting its movement. (Flagg and Beardsley, 1978).

Cresswell (1967) reported on the presence of detached parcels of shelf water within the slope water, which he believed had separated from the front by "calving", and Wright (1976) concluded that the detachment of such parcels, along with seaward excursions of the front, may account for most of the exchange required for salt balance of the shelf waters. The highly variable location (Fig. 17) of the shelf-slope front from Cape Hatteras to Georges Bank has been examined from weekly interpretations of surface thermal patterns using satellite-derived infrared imagery beginning in 1973 (Ingham, 1976). Gunn (1979) compiled five-year means of these records and found that the mean position of the surface front remains close to the location of the 200 m isobath and variability averages about 50 km around the mean position. Hilland and Armstrong (1980) examined this five-year compilation and described seasonal tendencies to the front's position, finding the front to be located more offshore during the first half of the year (maximum excursion in February to April) and more shoreward during the latter half of the year (extreme incursions in July to September). For the period of record for these analyses (1974-1979), the most anomalous offshore excursion occurred in 1978 when the front generally was positioned distinctly offshore of normal (up to 150 km off southern New England) during spring and summer (Hilland and Armstrong, 1980). This record excursion of the front in 1978 may have resulted from increased advection of shelf water from the east (Chamberlin, 1978) or from total absence of warm core rings in the slope water (Hilland and Armstrong, 1980).

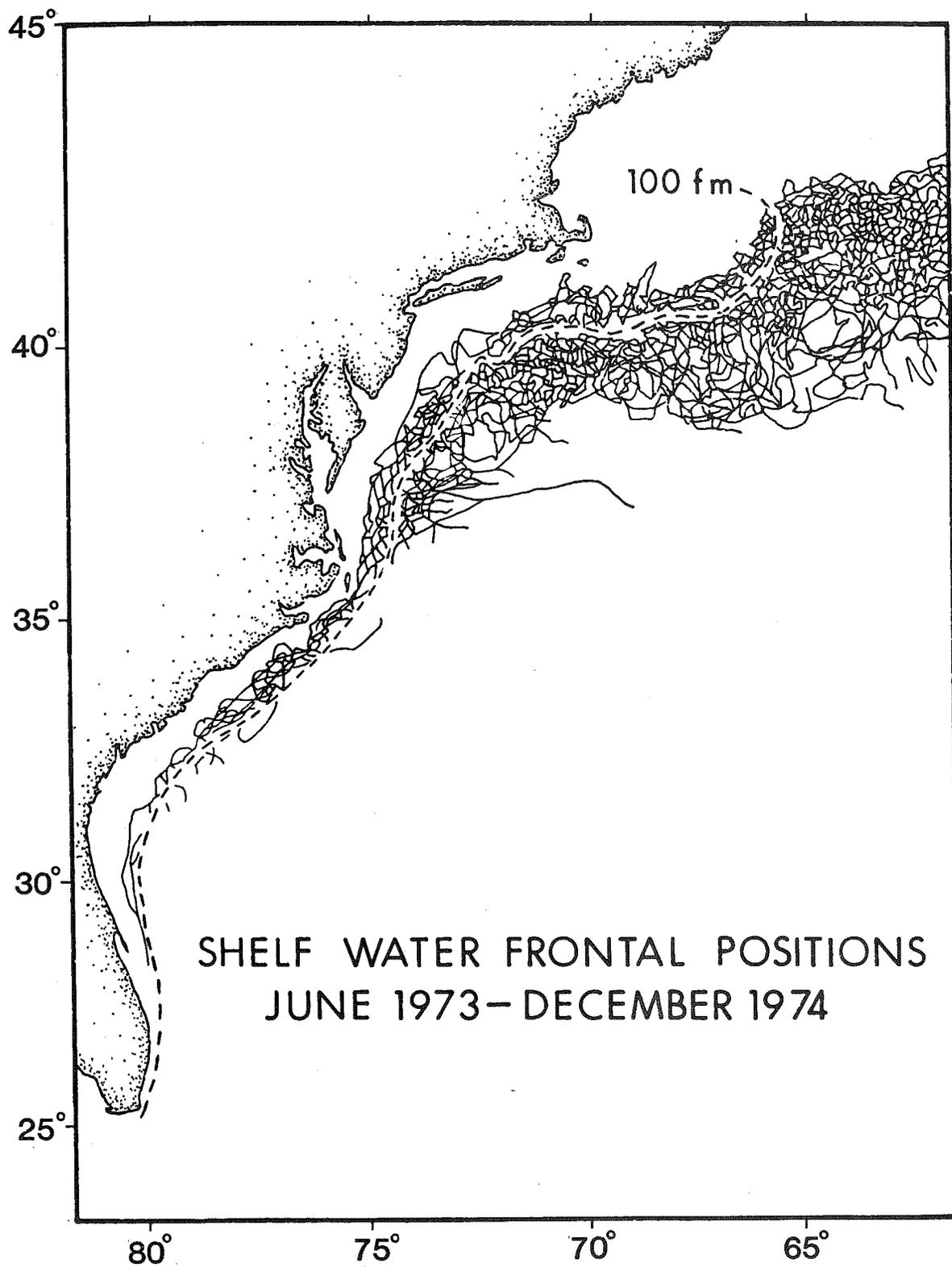


Figure 17. Composite plot of locations of the shelf-slope front during June 1973-December 1974 compiled from weekly frontal analysis charts derived from satellite infrared imagery. From "the Environment of the United States Living Marine Resources - 1974".MARMAP Contribution No. 104. NOAA, National Marine Fisheries Service. Unpublished report.

Gulf Stream Front. The Gulf Stream front is a narrow zone of abrupt horizontal change in temperature and salinity caused by the strong velocity shear between the weak, southwesterly flow in the slope water and the strong northeastward and eastward flow of the Gulf Stream. The front is continuous off the east coast of North America and has been observed to depths of 2000 m. In the upper 400 m there are distinct differences in water masses across the front, between the cooler, less saline slope water and the warmer, more saline Gulf Stream water. The front inclines downward in the offshore direction.

Along its course, large perturbations develop in the Gulf Stream front because of meandering of the Gulf Stream. Hansen (1970) described the Gulf Stream meandering as "quasi-geostrophic", comprised of frontal waves which progress eastward with phase speeds of 5 to 10  $\text{cm}\cdot\text{sec}^{-1}$  and wave length of 200 to 400 km. The amplitude of the waves at the surface typically increases toward the east almost linearly downstream from Cape Hatteras, coursing a swath about 100 km wide off Cape Hatteras to more than 300 km wide south of the Scotian Shelf (Hansen, 1970). Current meter measurements made by Schmitz et al. (1970) indicated that the meanders extend to considerable depth (2,585 m). Although the meandering of the front is usually limited to the slope water region, on occasion meanders may penetrate to the shelf water (Gotthardt and Potocsky, 1974).

The surface position of the Gulf Stream front has been monitored from ship reports, airborne infrared data, bathythermographs, and satellite-derived infrared imagery and shown in monthly maps since 1966 ("the Gulf Stream Monthly Summary" and "Gulfstream"). Since 1973 the U.S. Naval Oceanographic Office and the National Earth Satellite and Data Information Service of NOAA have prepared weekly charts of the Gulf Stream front position.

Nantucket Shoals Front. Most of the information on the hydrographic characteristics of Nantucket Shoals was collected in a series of cruises during May, July, and September 1978 (Limeburner and Beardsley, 1979). Along the eastern and southern side of the shoals the general characteristics of a tidally-generated front (boundary of well mixed area) were found at about the 40 m contour. The shallower region was always homogeneous since the mixing caused by the high tidal currents overcomes the heating and freshwater inputs that tend to produce vertical stability. Outside the 40 m contour the frontal structure was complicated by localized upwelling regions. These were spatially variable, but generally found in an area 15 km wide and 50 km long. Although general frontal characteristics were seen in the temperature, salinity, and density fields, the vertical difference of density defines the well-mixed zone most clearly. Within the shallow area of the shoals the vertical density differences were always  $0.1 \text{ g}\cdot\text{l}^{-1}$  or less while in the stratified area values up to  $4.0 \text{ g}\cdot\text{l}^{-1}$  were found in July.

After fall overturn of the water column the fronts along the eastern and southern side of the shoals disappeared. This was due to the atmospheric cooling and increased wind stress. Limeburner (1979) found well mixed conditions both on Nantucket Shoals and to 100 m depth in the Gulf of Maine from data collected in January and March (Ingham et al., 1982).

## WARM CORE RINGS AND GULF STREAM MEANDERS

Meanders and warm core rings formed in the Gulf Stream are mesoscale (100 km or more) features which exhibit relatively slow translational speeds (kilometers per day) and rapid angular speeds (kilometers per hour). Both types of motion can affect the transport or dispersion of suspended or dissolved pollutants dumped into the meanders and rings or in the water they entrain from the shelf and slope water masses. The current shear found near the high speed ( $>1 \text{ m}\cdot\text{sec}^{-1}$ ) portion of these features can be an effective dispersive mechanism, while also transporting any entrained organisms or materials considerable distances along circuitous trajectories.

Warm core rings and Gulf Stream meanders are apparently the principal source of physical variability in the slope water region off the Northeast coast. Monitoring this variability has only been possible since 1973, when high resolution infrared data became available routinely from NOAA environmental satellites.

North of Cape Hatteras the Gulf Stream turns northeast into deep water and tends to meander with increasing amplitude downstream. The meanders, with wave lengths of about 320 km, have been found to propagate downstream at an average speed of about  $6 \text{ cm}\cdot\text{sec}^{-1}$  (Halliwell and Mooers, 1979). Meanders reaching amplitudes of around 150 km or more, often detach from the Stream and close into rotating masses of water called Gulf Stream rings.

Warm core rings form in slope water from meanders on the left (shoreward) side of the Gulf Stream (Fig. 18). The detached meanders close into clockwise (anticyclonic) rotating masses of water with measured velocities from as slow as 30-50 cm/sec (Saunders, 1971) to as fast as 140 cm/sec (Cheney, 1978). These rings have a warm core because they enclose Sargasso Sea water that moved shoreward with the originating meander. Greatest in area near the sea surface, when newly formed they have ranged in diameter from about 150 to 230 km and may reach depths of over 2000 m. Unlike Gulf Stream meanders which move in the direction of the Stream, warm core rings move in the slope water in a direction opposite to that of the Stream, at average speeds up to about 15 cm/sec over extended periods. However, they have been observed to stop or move in other directions for days or even several weeks. Because most warm core rings seen off New England and the Middle Atlantic coast have formed southeast of Georges Bank, where Gulf Stream meanders often reach high amplitude, many have been absorbed back into the Gulf Stream near their place of origin within a few weeks or months after formation, by encountering one of these meanders. Those which escaped such destruction and reached the longitude of Cape Cod usually have persisted for a few more months until eventually resorbed by the Gulf Stream at the latitudes of Virginia, where the Stream runs close to the continental slope. The frequency distribution of ring longevity provides more direct evidence that warm core rings tend to be either short- or long-lived. The production rate of rings occurring in the slope water west of  $60^{\circ}\text{W}$  longitude during the past seven years has varied from six in 1974 to eleven in 1979 (Fitzgerald and Chamberlin, 1981). During these years, variation in the number of rings simultaneously present has ranged from eight during a period of a week or two in early May 1977 (Mizenko and Chamberlin, 1979) to none during a six-week period from March to mid-April, 1978 (Celone and Chamberlin, 1980).

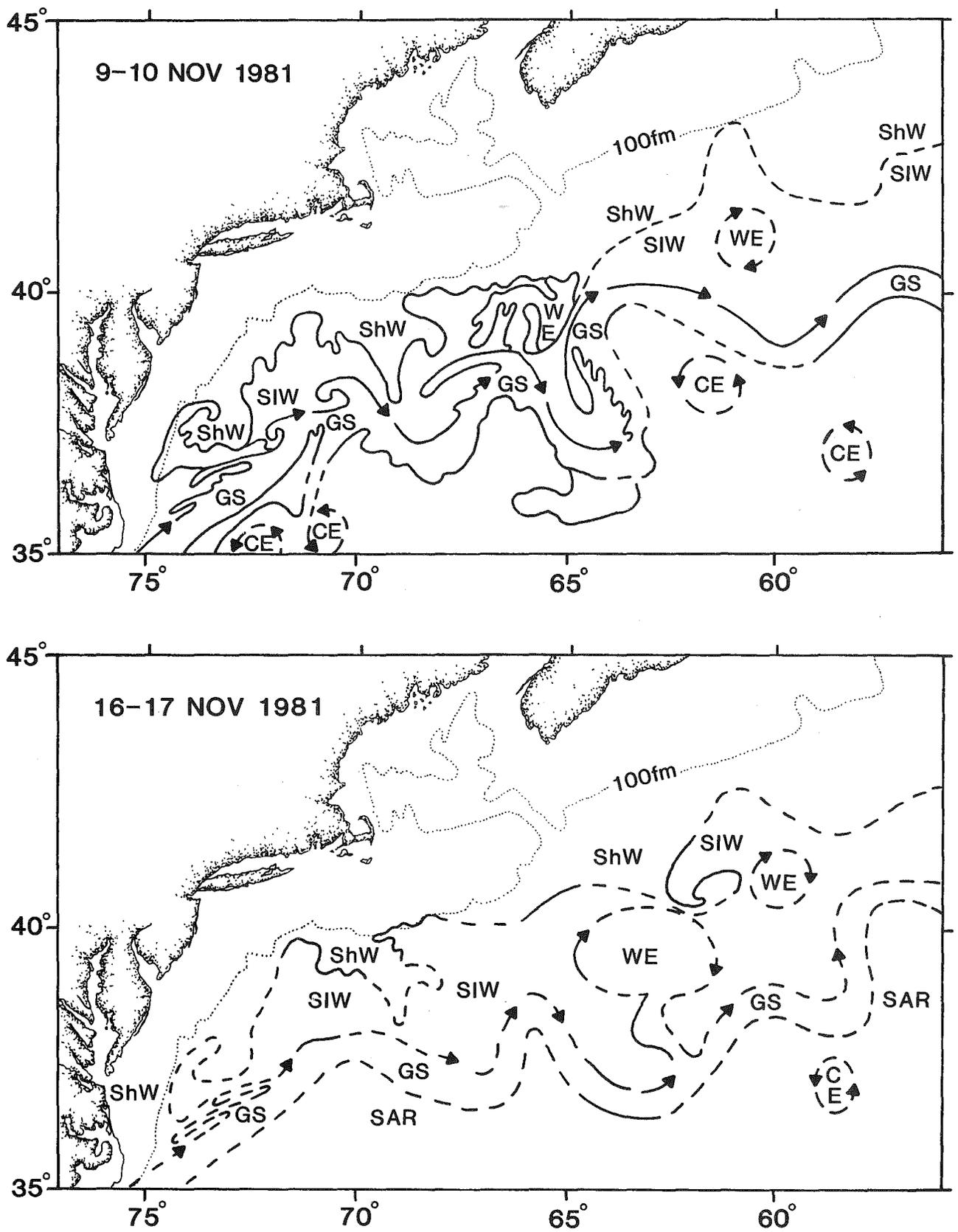


Figure 18. The birth of warm core ring (WE) from a Gulf Stream meander at about 39°N, 63°W. From weekly oceanographic analysis charts produced jointly by the National Weather Service and National Earth Satellite Service of NOAA (Ingham et al., 1982).

Continental Shelf Interactions with Rings and Meanders. Warm core rings and Gulf Stream meanders and interactions between these features are not only a principal source of circulation and water mass variability in the slope water region, but also apparently the principal mechanisms for shoreward transfer of Gulf Stream water and kinetic energy into the vicinity of the continental shelf. Three kinds of interaction with continental shelf waters have been observed:

- a. removal of shelf water by "entrainment",
- b. injection of slope water and modified Gulf Stream water onto shelf, and
- c. modification of circulation on the shelf.

Satellite infrared data provide direct information only on the first of these influences, entrainment, because of its visibility at the sea surface, but detection of entrainment is not possible when clouds block transmission of thermal infrared from sea surface to satellite. Satellite data are not adequate for estimates of volume transport from entrainment because they measure only the surface area of entrained water and show its general direction of movement, but provide no information on either its depth or speed.

Injections of slope water and modified Gulf Stream water onto the shelf by warm core rings has been frequently observed in vertical temperature sections from shipboard data. Pronounced examples have been reported for southern New England (Crist and Chamberlin, 1979) (Fig. 19). Because injection onto the shelf is predominantly subsurface, satellite data provide only circumstantial evidence by showing where this process may be taking place.

Information is scarce on the influence of warm core rings on shelf circulation except for what can be inferred ordinarily regarding entrainment immediately adjacent to rings. One fortuitous data set showing this sort of influence was from drogued buoys on SW Georges Bank in November 1977, which showed reversal of "the expected downcoast (southwestward) mean flow" apparently caused by a warm core ring (EG&G, 1978). Again as in the case of injections, the satellite data only indicate where such a circulation influence may be taking place.

Pronounced differences in the interaction of warm core rings and Gulf Stream meanders with shelf water are apparent between Georges Bank and the Middle Atlantic continental shelf. These differences relate primarily to the propagation characteristics of the rings and meanders. Although a number of the analyses necessary to make quantitative comparison have not been completed, the differences can be described qualitatively.

- a. Those which approach Georges Bank do so when younger, larger, and stronger in rotary flow than when they later enter the waters off the Middle Atlantic shelf.
- b. About 35% more rings occur in the vicinity of Georges Bank.

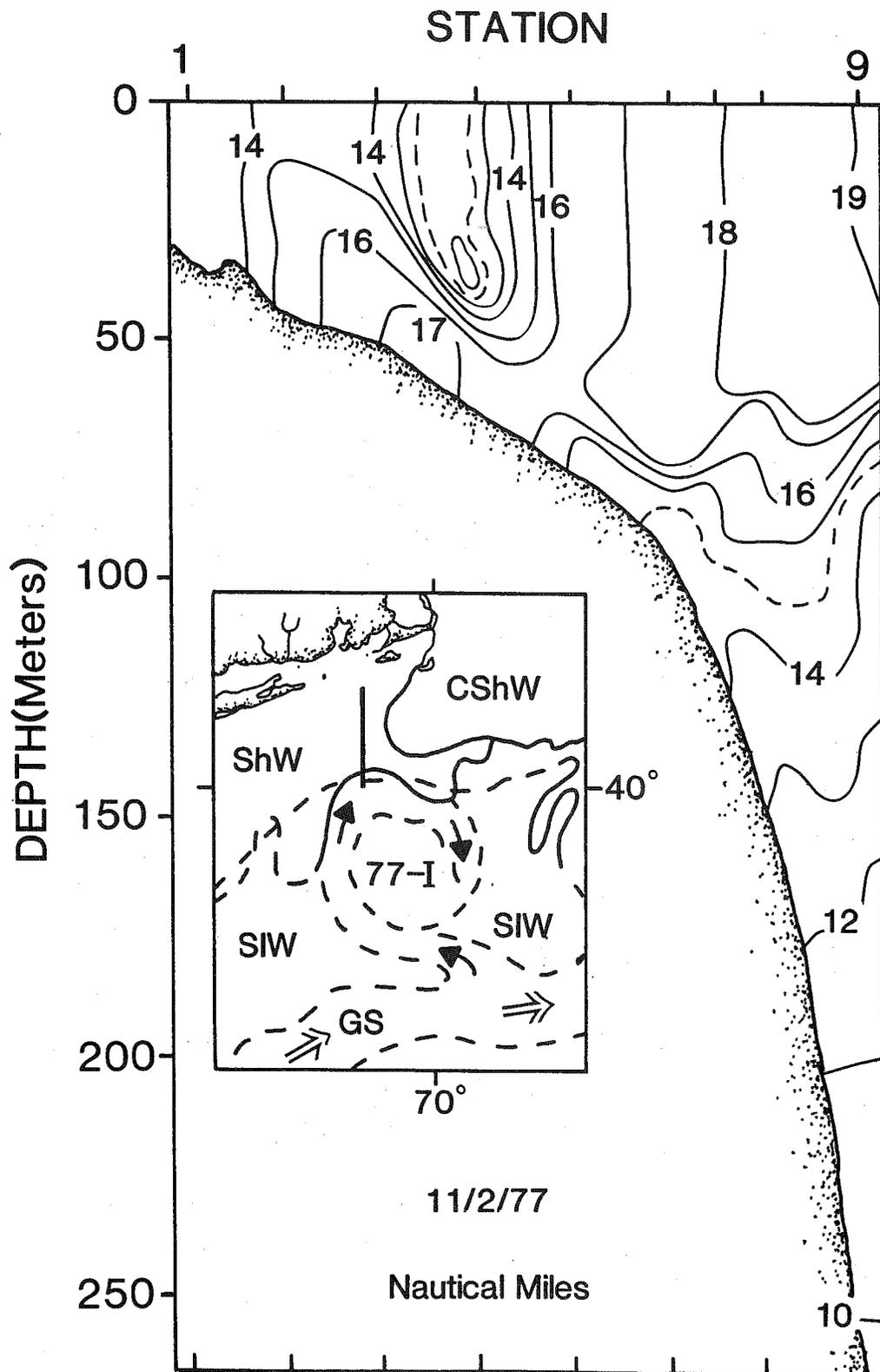


Figure 19. Injection of warm slope water, possibly mixed with Gulf Stream water, onto the continental shelf by the circulation of warm core ring 77-I, as revealed by an XBT temperature ( $^{\circ}\text{C}$ ) section conducted on 2 November 1977 along the  $71^{\circ}\text{W}$  meridian across the continental shelf. From Crist and Chamberlin, 1979. Inset chart shows location of temperature section and warm core ring 77-I. (Ingham et al. 1982)

- c. Most rings in the Middle Atlantic maintain close contact with the continental slope, especially in the Hudson Canyon area and southward.
- d. Entrainment of Gulf Stream water into the vicinity of the continental slope is characteristic of rings that occur south of Georges.
- e. Longevity of rings is more variable in the vicinity of Georges than in the Middle Atlantic.
- f. High amplitude meanders are common S and SE of Georges Bank but extremely rare in the Middle Atlantic.
- g. Low amplitude of the Stream just north of Cape Hatteras sometimes brings it close to the continental slope as far north as the offing of Chesapeake Bay causing entrainment of shelf water and the Stream may directly force warm saline water onto the shelf. (Ingham et al., 1982).

#### COLD POOL

"The cold pool", so named by Bigelow in 1933, is a continuous subsurface water type located on the continental shelf bottom between Georges Bank on the northeast to Cape Hatteras at the southwest. This feature was referred to as remnant "winter water" by Bigelow (1933); Ketchum and Corwin (1964); and Whitcomb (1970) who believed it to be formed from the winter cooling of mixed Middle Atlantic Bight shelf water. With hydrographic data portrayed by Colton et al. (1968) and Limeburner et al. (1978), the feature can be traced to the north along the eastern edge of Georges Bank and into the Gulf of Maine, where temperature and salinity relationships suggest a possible source of replenishment (Beardsley et al., 1976; Hopkins and Garfield, 1979). To the south the cold pool feature has been traced past the offing of Chesapeake Bay to Cape Hatteras where three major water masses (shelf, slope, and Gulf Stream) meet.

The cold pool becomes an identifiable feature each year beginning with spring surface warming and the onset of thermal stratification (generally in April to early May) and lasts throughout the summer into early fall, until the normal seasonal overturn (from October to December, but mostly in November) mixes away the vertical density structure and the water column becomes vertically isothermal.

The cold pool normally covers an area on the bottom between the 40 and 100 meter isobaths (20-60 fathoms) an area of approximately 88,000 km<sup>2</sup> between Georges Bank and Cape Hatteras. The average thickness of the feature is about 35 meters and extends from the bottom to the base of the seasonal thermocline (within 20-30 meters of the surface). This represents volume of 3,100 km<sup>3</sup>, or about 30% of the total volume of shelf water in the Middle Atlantic Bight.

The cold pool is a relatively slowly changing feature (by virtue of its bathymetric location) when compared to the more active zones of lateral mixing seaward and vertical mixing shoreward, with a long-term average flow of about 1-3 cm·sec<sup>-1</sup> southwestward (Mayer et al., 1979). However, the cold pool is in a state of constant change, and it can be acted on by several processes either singly or simultaneously, some of which are:

Wind events can cause upwelling nearshore, moving the shoreward leading edge of the cold pool toward the beach and sometimes even into the surf zone (Hicks and Miller, 1980). Other wind events, if persistent enough, also can influence the offshore edge of the cold pool, forcing it and the shelf water-slope water front to move seaward (Csanady, 1978).

Gulf Stream rings migrating along the shelf edge to the southwest through the Middle Atlantic Bight can cause perturbations in the subsurface shelf-slope front and the seaward edge of the cold pool by advecting upper slope water ( $>12^{\circ}\text{C}$ ) shoreward over the edge of the continental shelf, sometimes moving the cold pool off the bottom and causing it bulge seaward, leading to "calving" (Whitcomb, 1970; Wright, 1976).

Bathymetric features such as the Hudson Shelf Valley and the submarine canyons which underlie the outer edge of the cold pool at several locations can affect the cold pool. Canyons range from Corsair at the eastern edge of Georges Bank to Norfolk at the southern end of the Middle Atlantic Bight. Flow in the canyons can cause movement in the position of the cold pool. According to Molers et al. (1979) down canyon transport of cold pool water was observed along the southwestern side of Wilmington Canyon. In contrast to this, Han and Niedrauer (1981) observed that cold pool water did not sink into the Hudson Shelf Valley, but rather stayed at the same level as on the surrounding shelf. Nevertheless, bottom water flow in the canyons and shelf valleys should act to displace the cold pool either onshore or off.

At the southern edge of the cold pool, near Cape Hatteras, where the shelf is narrow, the Gulf Stream entrains both surface shelf water and subsurface cold pool water (Ford et al., 1952; Fisher, 1972; Kupferman and Garfield, 1977).

Seasonal and Interannual Variations. Depending on geographic location, the cold pool attains its minimum temperature in early spring to early summer (Table 3). Off southern New England the minimum is usually recorded in mid-March ( $1.1\text{--}3.3^{\circ}\text{C}$ , mean  $2.1^{\circ}\text{C}$ ), but off New York it is in early June ( $3.8\text{--}4.7^{\circ}\text{C}$ , mean  $4.1^{\circ}\text{C}$ ). Off southern New England, the minimum cold pool temperatures ranged from  $1.1^{\circ}\text{C}$  to  $3.3^{\circ}\text{C}$  averaging  $2.1^{\circ}\text{C}$  in 1977-81, while off New York they ranged from  $3.8^{\circ}\text{C}$  to  $4.7^{\circ}\text{C}$ , averaging  $4.1^{\circ}\text{C}$  (Table 3).

Maximum cold pool temperatures occur when the vertical stratification of the water column is destroyed during fall overturn. The warmest temperatures off southern New England ( $11.6\text{--}13.0^{\circ}\text{C}$ , mean  $12.3^{\circ}\text{C}$ ) precede the maximum temperatures off New York by an average of only 20 days (usually in November). Differences between seasonal maximum and minimum temperatures are larger off southern New England (almost  $13^{\circ}\text{C}$ ) than off New York (about  $9^{\circ}\text{C}$ ).

Role of Convective and Advective Mechanisms. Traditionally the cold pool has been described as a stationary parcel of remnant winter water that slowly eroded away during the summer and early fall. Then, because the coldest part of the cold pool in summer often was located off New York, it was suggested that the source of the cold water was within the Middle Atlantic Bight. Recent analyses of more detailed thermohaline data and long-term current meter measurements have shown a slow ( $1\text{--}3\text{ cm}\cdot\text{sec}^{-1}$ ), mean flow of the cold pool from the northeast to the southwest (Beardsley et al., 1976; Mayer et al., 1979).

Data collected in the cold pool from ships of opportunity along two transects in the Middle Atlantic Bight (south across the shelf along 71°W and southeast across the shelf from New York) also indicate that pulses of cooler water are advected southwestward between these two transects until mid-June with a speed consistent with current meter observations.

With the onset of spring warming and development of thermal stratification, vertical mixing processes essentially cease between the cold pool and the surface. As an indication of how weak this vertical mixing is, estimates of vertical velocities for subsurface fronts in slope water (seaward edge of cold pool) average about 1 meter·day<sup>-1</sup> (Garrett and Horne, 1978). While the cold pool is easily identifiable along its lateral boundaries as a thermal feature and less so as a salinity feature, it is totally unidentifiable laterally as a density feature. Therefore, mixing could occur with surrounding water masses along density surfaces laterally (cross shelf) far easier than with overlying water" (Ingham et al., 1982).

#### UPWELLING

The process of upwelling, whether wind-driven (divergent transport of surface water by wind action) or dynamic (interaction of currents and bathymetry) involves divergent horizontal transport of surface water which is replaced by deeper water with different properties. The area of upwelled water usually is bounded by a front, where upwelled water converges on the indigenous surface water. Upwelling of anoxic bottom water, such as that which occurred along some New Jersey beaches in the summer of 1976, can impact on marine organisms in the nearshore area and human utilization of these waters.

Frequently, upwelling leads to increased phytoplankton productivity, because of the higher concentrations of dissolved nutrients carried by the upwelled water. If this occurs in a nearshore area that already carries high nutrient concentrations from runoff and discharges of waste materials from urban centers, it may drive the coastal ecosystem closer to eutrophication. Some of the nearshore band of high phytoplankton productivity found along the northern New Jersey coast involves the interaction of these two enrichment processes.

Middle Atlantic Bight. During the periods of prevailing southwesterly winds, mostly in the summer months, upwelling should occur along the New Jersey-Virginia coast. An analysis of surf temperatures, wind velocities, and nearshore temperature sections off Monmouth Beach, N.J. by Hicks and Miller (1980) demonstrated the linkage between southerly winds and shoreward motion of the cold bottom water, which in many cases came into the surf zone.

In the analysis of data and events involved in the development of anoxic conditions in the bottom water and resulting high benthic mortalities off New Jersey in the summer of 1976, some evidence of upwelling was uncovered. Mayer, Hansen and Minton (1979) found indications of upwelling off northern New Jersey in 5 of 13 months and off western Long Island in 8 of 12 months of current meter data; in each case it was persistent enough to register in monthly mean current vectors. Analysis of wind field observations for the inner New York Bight for February-June 1976 by Diaz (1979) produced monthly mean offshore transports (computed Ekman) in the surface layer each month, but

strongest off New Jersey in February. Steimle and Sindermann (1978) reported observations of dead and dying fish and hydrogen sulfide odors in the surf zone of the south central coast of New Jersey in late July and early August, indicating upwelling of the anoxic bottom layer into the surf zone. Nelsen et al. (1978) and Mayer and Han (in press) have identified a relationship between local wind stress and onshore flow of bottom water in the Hudson Shelf Valley (upwelling) in the apex of New York Bight.

Upwelling conditions along the south coast of Long Island have been found to be dependent upon local winds. Scott and Csanady (1976) found that eastward wind stress caused offshore flow in the surface layer and compensating onshore flow near-bottom, during summer stratified conditions in 32 m water depth 11 km offshore. They found westward wind stress caused flow in the reverse directions. Han and Mayer (1981), however, observed offshore surface currents and onshore near-bottom currents during periods of both eastward wind stresses, at a point 6 km offshore in 18 m water depth. Upwelling in response to westward wind stresses there is inconsistency with Ekman theory. They found offshore bottom layer flow (downwelling) only in response to strong westward and northward wind stresses.

Indirect evidence of upwelling south of Long Island has been reported by Walsh et al. (1978) in distributions of chlorophyll, nutrients, and zooplankton together with some wind and current data. These data showed episodic mixing and upwelling events associated with the passage of storms. During stratified periods, storms caused upwelling along the coast as evidenced by higher nutrient concentrations. During unstratified periods storms caused increased nutrient concentrations throughout the water column over a broader area, due to mixing of near-bottom nutrients upward. (Ingham et al., 1982).

Figures 20 through 25 show 10-year (1974-1983) wind stress ( $10^{-3}$  dynes/cm<sup>2</sup>) and mean monthly Ekman Transport (metric tons/sec/km) for two locations within the Middle Atlantic Bight. These figures also show the conditions or difference between mean wintertime (onshore Ekman) and mean summertime (offshore Ekman) transports contributory to upwelling or downwelling.

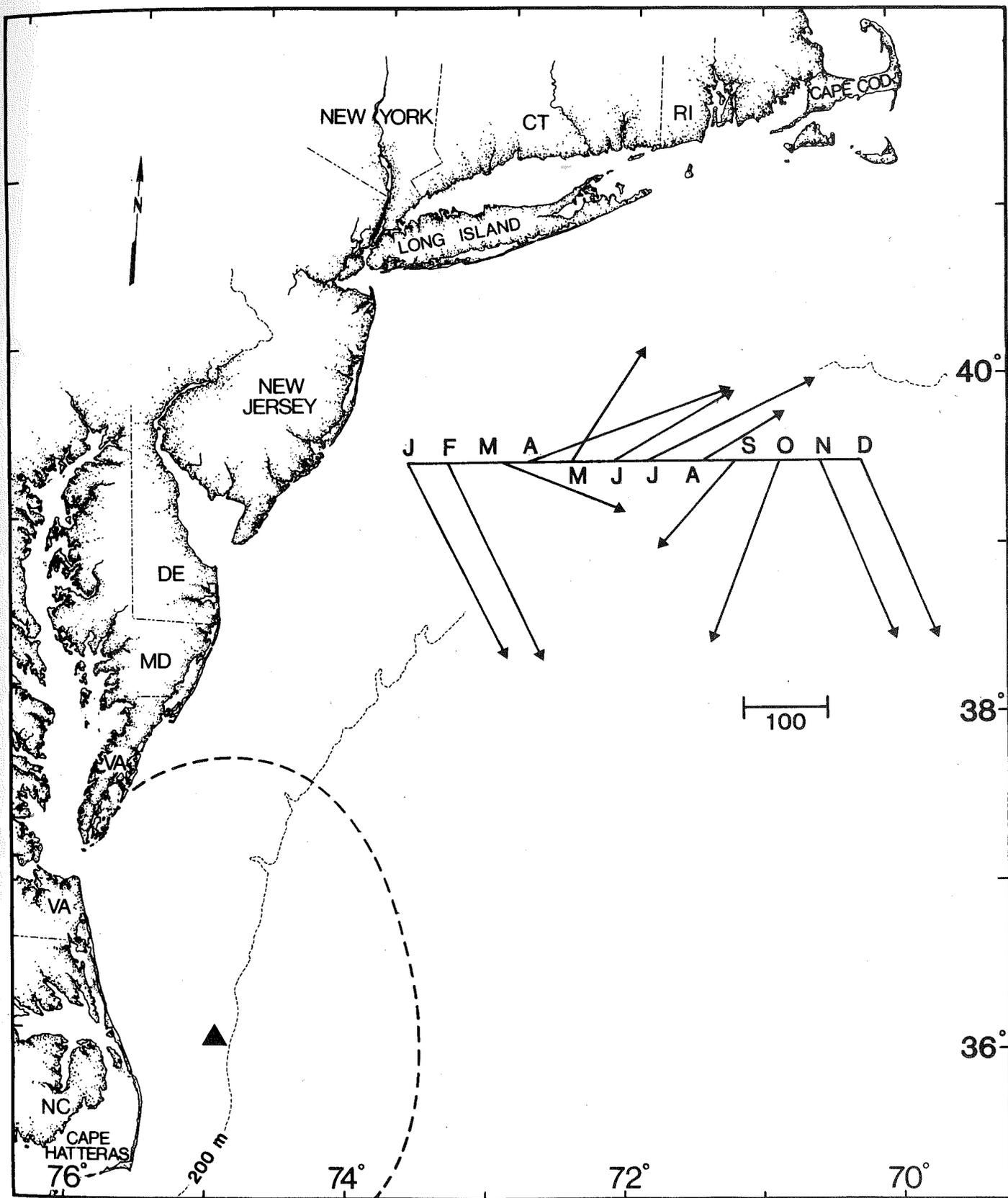


Figure 20. Ten year (1974 - 1983) mean monthly computed surface wind velocity (cm/sec) in the vicinity of 36°N 75°W.

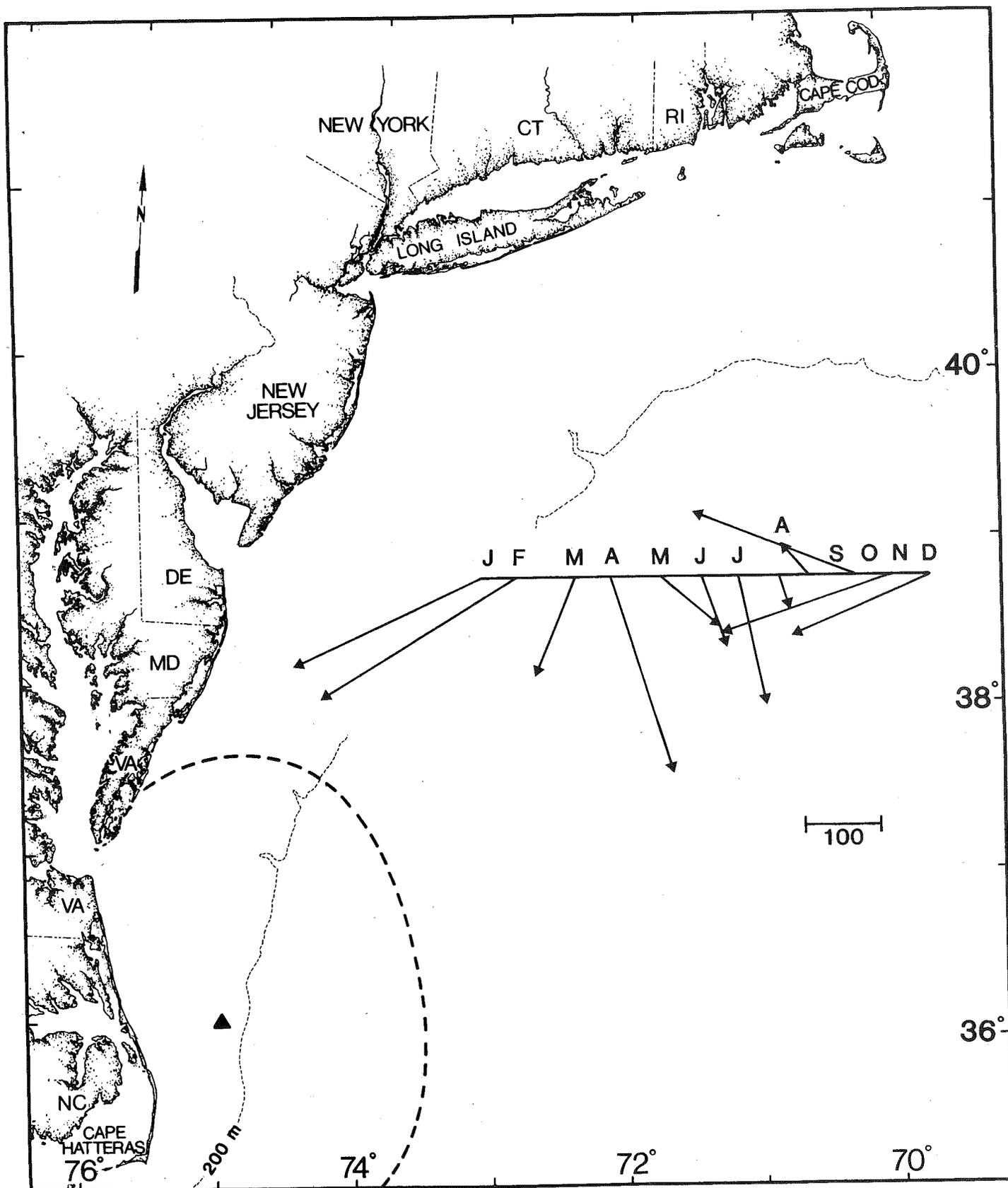


Figure 21. Ten year (1974 - 1983) mean monthly wind stress ( $10^{-3}$  dynes/cm<sup>2</sup>) in the vicinity of 36°N 75°W.

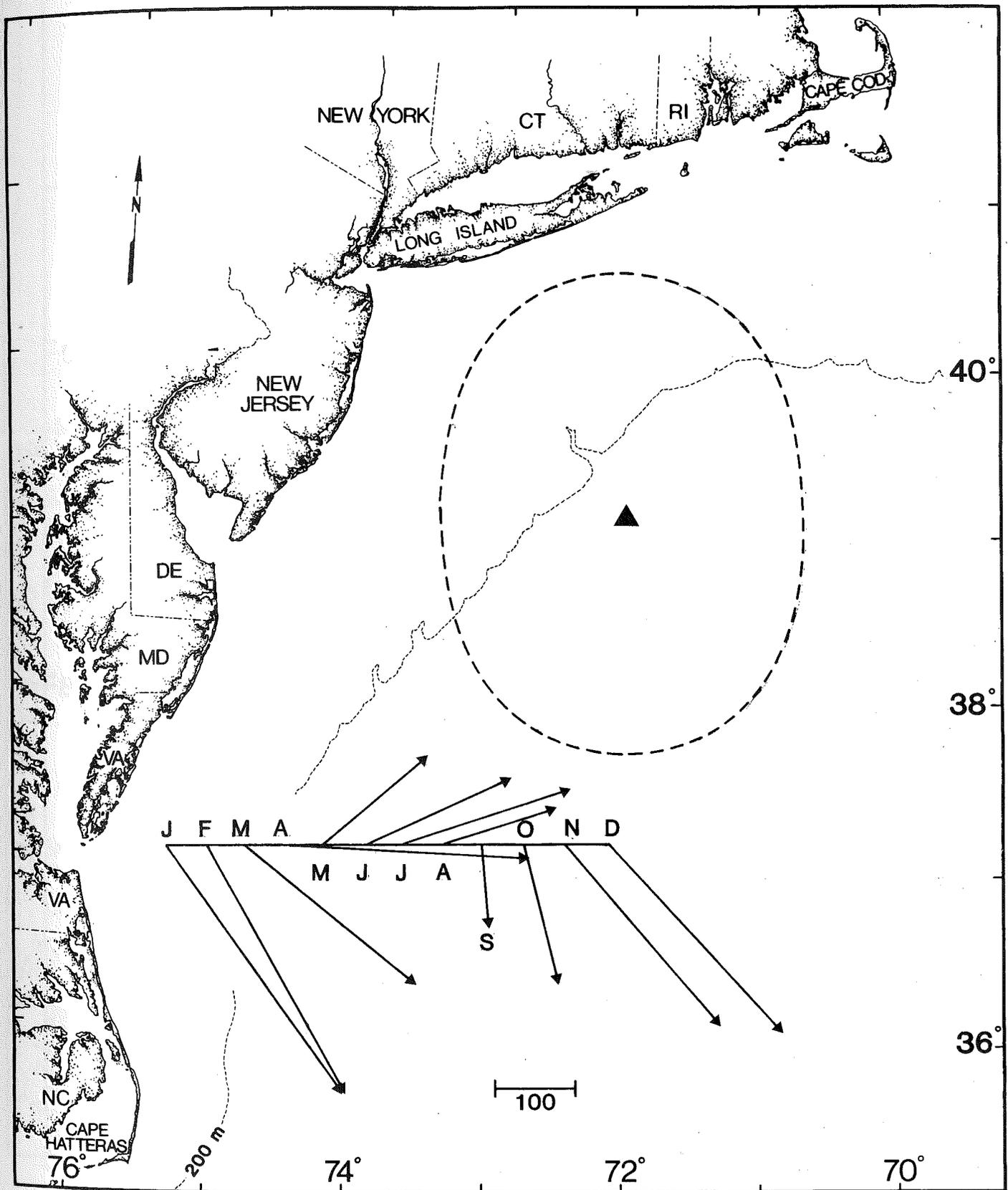


Figure 22. Ten year (1974 - 1983) mean monthly Ekman Transport (metric tons/sec/km) in the vicinity of 36°N 75°W.

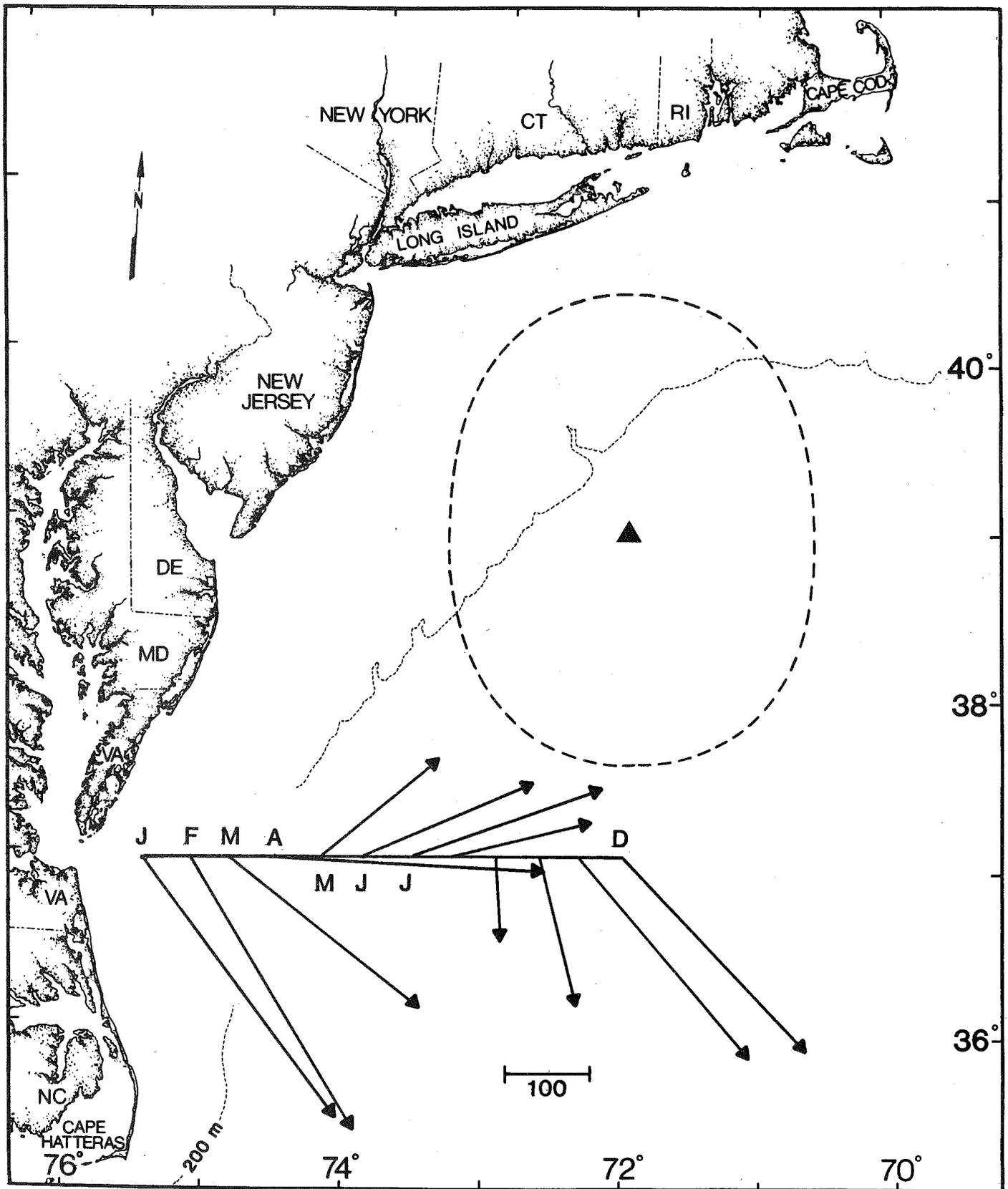


Figure 23. Ten year (1974 - 1983) mean monthly computed surface wind velocity (cm/sec) in the vicinity of 39°N 72°W.

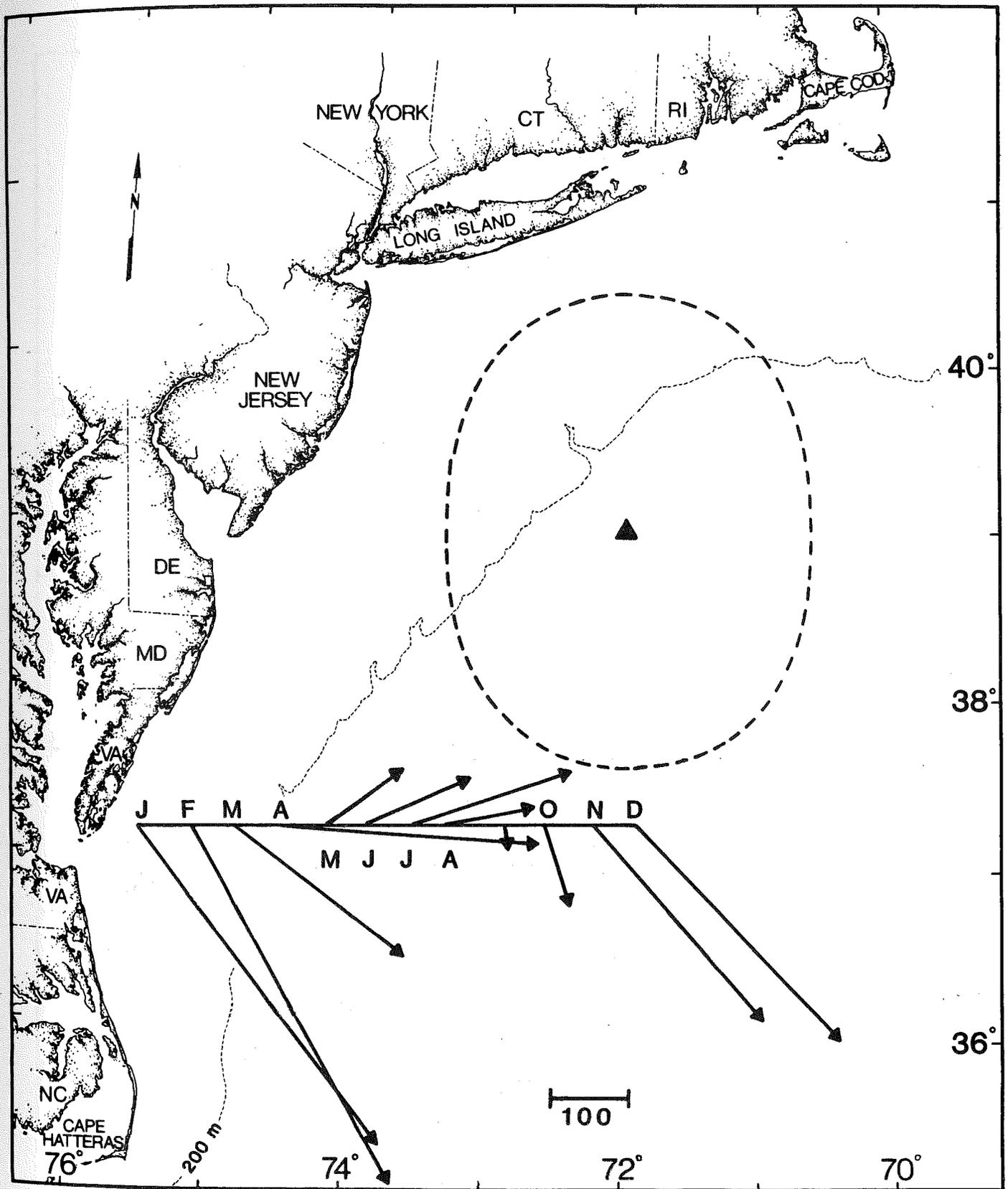


Figure 24. Ten year (1974 - 1983) mean monthly stress ( $10^{-3}$  dynes/cm<sup>2</sup>) in the vicinity of 39°N 72°W.

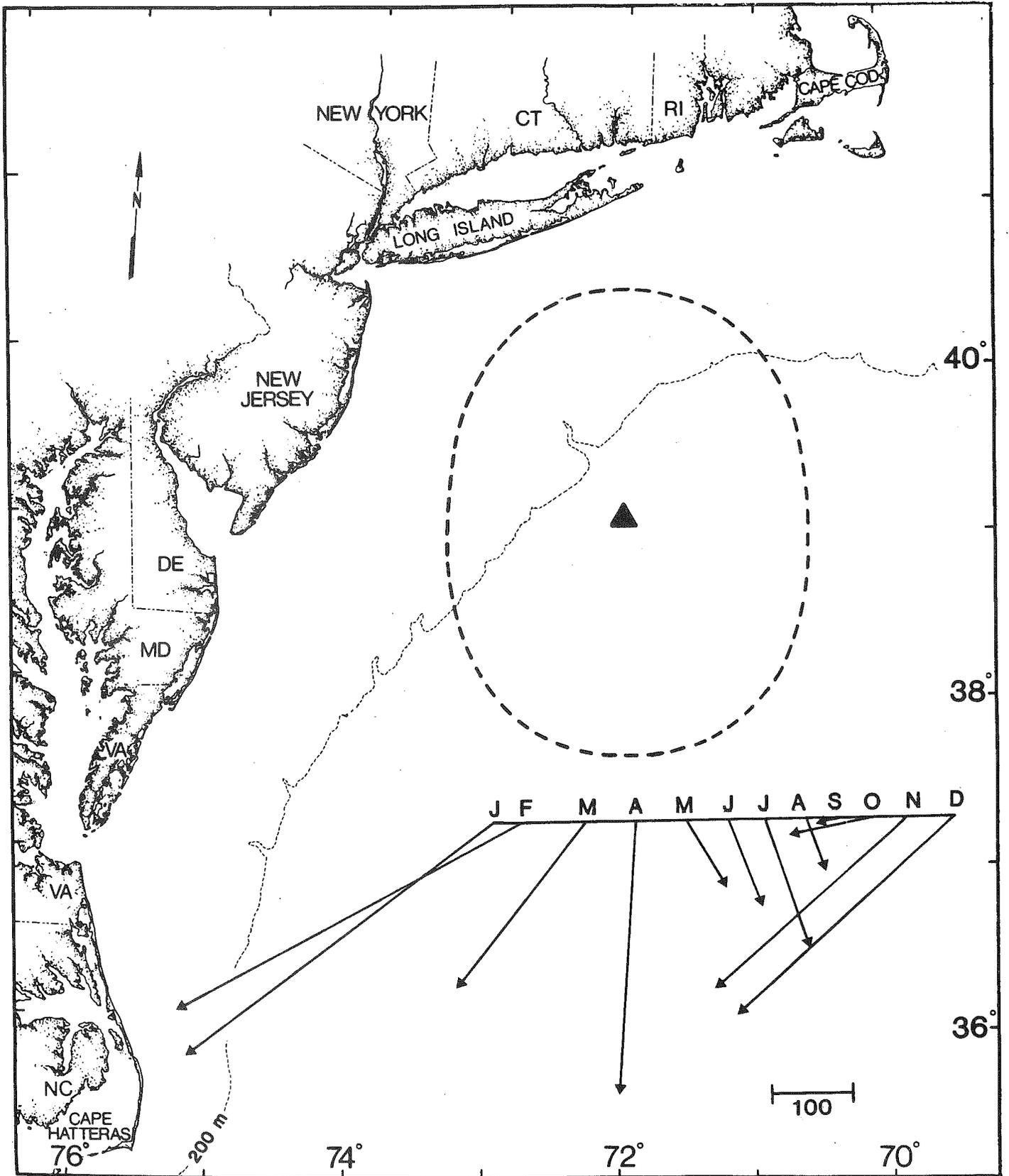


Figure 25. Ten year (1974 - 1983) mean monthly Ekman Transport (metric tons/sec/km) in the vicinity of 39°N 72°W.

## BIBLIOGRAPHY

- Beardsley, R. C., W. C. Boicourt and D. V. Hansen. 1976. Physical oceanography of the Middle Atlantic Bight. Am. Soc. Limnol. Oceanogr. Spec. Symp., Vol. 2: 20-34.
- Beardsley, R. C. and W. C. Boicourt. 1981. On estuarine and continental shelf circulation in the Middle Atlantic Bight. Chap. 7 (p. 198-234). In Evolution of Physical Oceanography Scientific Surveys in Honor of Henry Stommel. The MIT Press, Cambridge, MA, 623 pp.
- Beardsley, R. C. and B. Butman. 1974. Circulation of the New England continental shelf: Response to strong winter storms. Geophys. Res. Letters 14: 181-184.
- Beardsley, R. C. and C. N. Flagg. 1976. The water structure, mean currents and shelf water/slope water front on the New England continental shelf. Mem. Soc. Royale des Sci. de Liege. 6(10): 209-225.
- Bennett, J. R. and B. A. Magnell. 1979. A dynamical analysis of currents near the New Jersey coast. J. Geoph. Res. 84(C3): 1165-1175.
- Bigelow, H. B. 1933. Studies of the waters on the continental shelf, Cape Cod to Chesapeake Bay. I. The Cycle of temperature. Papers in Physical Oceanography and Meteorology 2(4): 1-135.
- Biscayne, P. E. and C. R. Olsen. 1976. Suspended particulate concentrations and compositions in the New York Bight. In Special Symposia, Vol. 2, Middle Atlantic Continental Shelf and New York Bight. M. G. Gross (ed.). Amer. Soc. Limnol. Oceanogr. pp. 124-137.
- Bishop, J. M. and J. E. Overland. 1977. Seasonal drift on the Middle Atlantic Shelf. Deep-Sea Res. 24: 161-169.
- Boicourt, W. C. and P. W. Hacker. 1976. Circulation on the Atlantic continental shelf of the United States, Cape May to Cape Hatteras. Mem. Soc. Royale des Sci. de Liege, 6(10): 187-200.
- Bowman, M. J. and L. D. Wunderlich. 1977. Hydrographic properties. MESA NY Bight Atlas Monograph No. 2, 78 p., NY Sea Grant Institute, Albany, NY.
- Bumpus, D. F. 1973. A description of the circulation on the continental shelf of the east coast of the United States. Prog. Oceanogr. 6: 111-157.
- Bumpus, D. F. 1976. Review of the physical oceanography of Georges Bank. ICNAF Res. Bull. 12: 119-134.
- Bush, K. A. 1981. Middle Atlantic Bight transports determined from a salinity-heat box model using historical hydrographic and meteorological data. M.S. thesis. Univ. of Delaware, College of Marine Studies. Lewes, Delaware.

- Celone, P. J. and J. L. Chamberlin. 1980. Anticyclonic warm-core Gulf Stream eddies off the northeastern United States in 1978. *Annls. Biol. Copenh.* 35: 50-55.
- Chamberlin, J. L. 1978. Unusual offshore distribution of cold Atlantic Shelf water during the spring and summer of 1978. *Coastal Oceanog. and Clim. News* 1(1): 1-2.
- Charnell, R. L., D. V. Hansen. 1974. Summary and analysis of physical oceanography data collected in the New York Bight Apex. MESA Report No. 74-3. 44 pp.
- Cheney, R. E. 1978. Oceanographic observations in the western North Atlantic during FOX 1, May 1978. Tech. Note 3700-79-78, V. 5 U.S. Naval Oceanographic Office, Washington, D.C.
- Colton, J. B., R. Marak, S. Nickerson and R. Stoddard. 1968. Physical, chemical and biological observations on the continental shelf, Nova Scotia to Long Island, 1944-66. U.S. Fish and Wildlife Service Data Report No. 23. 189 pp.
- Colton, J. B. and R. R. Stoddard. 1972. Average monthly sea water temperatures - Nova Scotia to Long Island, 1940-1959. Folio 21 - Serial Atlas of the Marine Environment. American Geographic Society.
- Cook, S. K. and C. E. Gardner. 1978. An example of rapid change in the summertime water column over the continental shelf southeast of Sandy Hook, N.J. *Gulfstream* 4(5): 6-7.
- Cresswell, G. M. 1967. Quasi-synoptic monthly hydrography of the transition region between coastal and slope water south of Cape Cod, Massachusetts. WHOI Tech. Rpt. 67-35.
- Christ, R. W. and J. L. Chamberlin. 1979. Bottom temperatures on the Continental Shelf and Slope south of New England during 1977. *Annls. Biol., Copenhagen.* 34-21-27.
- Csanady, G. T. 1973. Wind-induced baroclinic motions at the edge of the continental shelf. *J. Phys. Oceanog.* 3(3): 274-279.
- Csanady, G. T. 1978. Wind effects on surface to bottom fronts. *J. Geophys. Res.* 83(C9): 4633-4640.
- Diaz, H. F. 1979. Chapter 3. Atmospheric conditions and comparison with past records. In *Oxygen Depletion and Associated Benthic Mortalities in New York Bight, 1976*. Swanson, R. L. and C. J. Sindermann (Eds.). NOAA Prof. Paper 11: 51-77.
- EG & G. 1978. Intersection of a Gulf Stream eddy with Georges Bank. New England Outer Continental Shelf Physical Oceanography Program, Appendix D of 8th Quarterly Progress Report to U.S. Dept. Int., Bur. Land Management, V:D-1 to D-56.

- EPA, 1978. Environmental impact statement on the ocean dumping of sewage sludge in the New York Bight - Final - September 1978. U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, N.Y., NY 1007. 26 p. plus Appendices A and B.
- Fairbanks, A., Jr. 1972. Entrainment of shelf water by the Gulf Stream northeast of Cape Hatteras. *J. Geophys. Res.* 77: 3248-3255.
- Fitzgerald, J. and J. L. Chamberlin. 1981. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1979. *Annls. biol., Copenh.* 36: 44-51.
- Flagg, C. N. and R. C. Beardsley. 1978. On the stability of the shelf water/slope water front south of New England. *J. Geophys. Res.* 83(C9): 4623-4631.
- Ford, W. L., J. R. Leonard and R. E. Banks. 1952. On the nature, occurrence and origin of cold low salinity water along the edge of the Gulf Stream. *J. Mar. Res.* 11(3): 281-293.
- Godshall, F. A., R. G. Williams, J. H. Bishop, F. Everdale and S. W. Fehler. 1980. A climatologic and oceanographic analysis of the Georges Bank region of the outer continental shelf. NOAA/EDIS Report to the Bureau of Land Management, USDI - Interagency Agreement AA551-1A8-14 (Sept. 1980). 290 pp.
- Gordon, A. L. and F. Aikman, III. 1981. Salinity maximum in the pycnocline of the Middle Atlantic Bight. *Limnol. Oceanogr.* 26(1): 123-130.
- Gotthardt, G. A. and G. J. Potocsky. 1974. Life cycle of a Gulf Stream anticyclonic eddy observed from several oceanographic platforms. *J. Phys. Oceanogr.* 4(1): 131-134.
- Gunn, J. T. 1979. Variations in the position of the shelf water front off the Atlantic coast between Georges Bank and Cape Romain in 1976. In= *Ocean Variability in the U.S. Fishery Conservation Zone.* J. R. Goulet, Jr. and E. D. Haynes (eds.). NOAA Tech. Rep. NMFS CIRC. 427: 301-314.
- Haight, F. J. 1942. Coastal currents along the Atlantic coast of the United States Coast and Geod. Surv. Spec. Publ. No. 230. 73 p.
- Halliwell, G. R., Jr. 1978. The space-time structure and variability of the shelf water/slope and Gulf Stream surface thermal fronts and warm-core eddies off the Northeast United States. M.S. Thesis, Univ. of Delaware, Newark, DE. 195 pp.
- Han, G., D. V. Hansen and J. A. Gault. 1980. Steady-state diagnostic model of the New York Bight. *J. Phys. Oceanogr.* 10(12): 1998-2020.
- Han, G. C. and D. A. Mayer. 1981. Current structure on the Long Island inner shelf. *J. Geophys. Res.* 86: 4205-4214.

- Han, G. and T. Niedrauer. 1981. Hydrographic observations and mixing processes in the New York Bight, 1975-1977. *Limnol. Oceanogr.* 26(6): 1126-1141.
- Hansen, D. V. 1970. Gulf Stream meanders between Cape Hatteras and the Grand Banks. *Deep-Sea Res.* 17(3): 495-511.
- Hansen, D. V. 1977. Circulation, MESA NY Bight Atlas Monograph No. 3. N.Y. Sea Grant Inst., Albany, NY. 23 p.
- Hardy, C. C., E. R. Baylor and P. Moskowitz. 1976. Sea surface circulation in the northwest apex of the New York Bight - with appendix: Bottom drift over the continental shelf. NOAA Tech. Memo. ERL MESA-13. 132 p.
- Hayes, R. M. 1975. Oceanographic observations Nova Scotia to Cape Hatteras, North Carolina October-November 1969 and May-June 1970. Oceanographic Report No. CG 373-66. U.S. Coast Guard Oceanographic Unit, Washington, DC. 13 pp.
- Hicks, D. C. and J. R. Miller. 1980. Meteorological forcing and bottom water movement off the northern New Jersey coast. *Est. & Coast. Mar. Sci.* 1980 II: 563-571.
- Hilland, J. E. and R. S. Armstrong. 1980. Variation in the shelf water front position from Georges Bank to Cape Romain in 1978. *Annls. Biol. Copenh.* 35: 46-50.
- Hopkins, T. and N. Garfield. 1977. Physical oceanography. Chapter 4. In Summary of Environmental Information - Continental Shelf - Bay of Fundy to Cape Hatteras (1977). U.S. Dept. of Interior, Bur. of Land Management.
- Hopkins, T. S. and N. Garfield. 1979. Gulf of Maine Intermediate Water. *J. Mar. Res.* 37(1): 103-139.
- Ingham, M. C. 1976. Variations in the shelf water front off the Atlantic coast between Cape Hatteras and Georges Bank. In J. R. Baseline Rep. of Environmental Conditions in Deepwater Dumpsite 106. NOAA Dumpsite Eval. Rep. 77-1, U.S. Dept. of Comm. pp. 29-54.
- Ingham, M. C., R. S. Armstrong, J. L. Chamberlin, S. K. Cook, D. G. Mountain, R. J. Schlitz, J. P. Thomas, J. J. Bisagni, J. F. Paul and C. E. Warsh. 1982. Summary of the physical oceanographic processes and features pertinent to pollution distribution in the coastal and offshore waters of the Northeastern United States, Virginia to Maine. NOAA Technical Memorandum NMFS-F/NEC-17. 166 pp.
- Keller, G. H., D. Lamberg, G. Rowe and N. Staresinic. 1973. Bottom currents in the Hudson Canyon. *Science* 180: 181-183. April 1973.
- Ketchum, B. H. and N. Corwin. 1964. The persistence of "winter" water on the continental shelf south of Long Island, New York. *Limnol. Oceanogr.* 9(4): 467-475.

- Ketchum, B. H. and D. J. Keen. 1955. The accumulation of river water over the continental shelf between Cape Cod and Chesapeake Bay. *Deep-Sea Res. Suppl. to 3*: 346-357.
- Kupferman, S. L. and N. Garfield. 1977. Transport of low-salinity water at the slope water-Gulf Stream boundary. *J. Geophys. Res.* 82(24): 3481-3486.
- Lettau, F., W. A. Brower, Jr. and R. G. Quayle. 1976. *Marine Climatology. MESA New York Bight Atlas Monograph 7.* N.Y. Sea Grant Inst., Albany, NY. 239 p.
- Limeburner, R. 1979. Hydrography and circulation about Nantucket Shoals. M. S. Thesis, Massachusetts Institute of Technology. 113 pp.
- Limeburner, J. A., J. Vermersch and R. Beardsley. 1978. Hydrographic station data obtained in the vicinity of Georges Bank, May and August, 2976. WHOI Tech. Rept. 78-82. 116 p.
- Mayer, D. A. and G. C. Han. In press. Circulation in the Hudson Shelf Valley, Part I. *J. Geophys. Res.*
- Mayer, D. A., D. V. Hansen and D. A. Ortman. 1979. Long-term current and temperature observations on the Middle Atlantic Shelf. *J. Geophys. Res.* 84(CA): 1776-1792.
- Mayer, D. A., D. V. Hansen and S. M. Minten. 1979. Water movement on the New Jersey shelf, 1975-1976. In *Oxygen Depletion and associated Benthic Mortalities in New York Bight, 1976.* Swanson, R. L. and C. J. Sindermann (eds.). NOAA Prof. Pap. 11. 149-163.
- McClennen, C. E. 1973. New Jersey continental shelf near bottom current meter records and recent sediment activity. *J. Sed. Petrol.* 43(2): 371-380.
- Meserve, J. M. 1974. U.S. Navy marine climatic Atlas of the World. Vol. 1 - North Atlantic Ocean. Naval Weather Service Detachment, U. S. Naval Weather Service Command, Washington, DC. 371 pp.
- Mizenko, D. and J. L. Chamberlin. 1979. Anticyclonic Gulf Stream eddies off the northeastern United States during 1976. J. R. Goulet, Jr. and E. D. Haynes (Eds.). NOAA Tech. Rep. NMFS CIRC 427: 259-280.
- Mooers, C. N. K., R. W. Garvine and W. W. Martin. 1979. Summertime synoptic variability of the Middle Atlantic shelf/slope water front. *J. Geophys. Res.* 84(C8): 4837-4853.
- Morgan, C. W. and J. M. Bishop. 1977. An example of Gulf Stream eddy-induced water exchange in the Mid-Atlantic Bight. *J. Phys. Oceanogr.* Vol. 7: 472-479.
- Naval Weather Service Detachment. 1976. Climatic study of the near coastal zone - east coast of the United States. Published by Director, Naval Oceanography and Meteorology. Wash., DC. 133 pp.

- Nelson, T. A., P. E. Gadd and T. L. Clarke. 1978. Wind-induced current flow in the upper Hudson Valley. *J. Geophys. Res.* 83(C12): 6073-6082.
- Ou, H. W., R. C. Beardsley, D. Mayer, W. C. Boicourt and B. Butman. 1981. An analysis of subtidal and current fluctuations in the Middle Atlantic Bight. *J. Phys. Oceanogr.* 11(10): 1383-1392.
- Pape, E., III. 1981. A drifter study of the Lagrangian mean circulation of Delaware Bay and adjacent shelf waters. Master's thesis, University of Delaware. Del. - SG-18-81. Delaware Sea Grant College Program, Newark, Delaware 19711.
- Patchen, R. C., F. F. Parker and E. E. Long. 1976. Analysis of current meter observations in the New York Bight apex August 1974-June 1974. ERL 368-MESA 5, 08/73-06/74. Environmental Res. Lab., Boulder, CO, 24 pp.
- Robinson, A. R., J. R. Luyten and F. C. Fuglister. 1974. Transient Gulf Stream meandering. Part I: an observational experiment. *J. Phys. Oceanogr.* 4(3): 237-255.
- Saila, S. B., D. F. Bumpus, R. E. Lynde, D. M. Shaw, D. R. Kester, R. A. Courant, T. J. Smayda, H. P. Jeffries, W. C. Johnson, S. D. Pratt, M. E. Q. Pilson, E. Goldstein, F. H. Heppner and L. L. Gould. 1973. Coastal and offshore environmental inventory - Cape Hatteras to Nantucket Shoals. Marine Publication Series No. 2. University of Rhode Island. 702 pp.
- Saunders, P. M. 1971. Anticyclonic eddies formed from shoreward meanders of the Gulf Stream. *Deep Sea Res.* 18: 1207-1219.
- Schmitz, W. J., Jr., A. A. Robinson and F. C. Fuglister. 1970. Bottom velocity observations directly under the Gulf Stream. *Science* 170: 1192-1194.
- Schroeder, E. H. 1966. Average surface temperatures of the Western North Atlantic. *Bull. Mar. Sci.* 15(2): 302-323.
- Scott, J. T. and G. T. Csanady. 1976. Nearshore currents off Long Island. *J. Geophys. Res.* 81-5401-5409.
- Shonting, D. H. 1969. Rhode Island Sound square kilometer study 1967: Flow patterns and kinetic energy distribution. *J. Geophys. Res.* 74:P 3386-3395.
- Steimle, F. W. and C. J. Sindermann. 1978. Review of oxygen depletion and associated mass mortalities of shellfish in the Middle Atlantic Bight in 1976. *Mar. Fish. Rev.* 40(12): 17-26.
- Stommel, H. and A. Leetmaa. 1972. Circulation on the continental shelf. *Proc. Nat. Acad. Sci.* 69(11): 3380-3384.

- Swift, D. J. P., G. L. Freeland, P. E. Gadd, G. Han, J. W. Lavelle and W. L. Stubblefield. 1976. Morphologic evolution and coastal sand transport, New York-New Jersey Shelf. In Special Symposia, Vol. 2, Middle Atlantic Continental Shelf and the New York Bight. (M. Grant Gross, Ed.). Am. Soc. Limnol. Oceanogr. p. 69-89.
- U.S. Naval Oceanographic Office. 1963. Oceanographic Atlas of the North Atlantic Ocean - Pub. No. 700. Section IV, Sea and Swell. Wash., DC. 227 p.
- Walford, L. A. 1968. Monthly sea temperature structure from the Florida Keys to Cape Cod. Serial Atlas of the Marine Environment Folio 15. Amer. Geogr. Soc.
- Walsh, J. J., T. E. Whitley, F. W. Barvenik, C. D. Wirick, S. . Howe, W. E. Esais and J. T. Scott. 1978. Wind events and food chain dynamics within the New York Bight. Limnol. Oceanogr. 23(4): 659-683.
- Whitcomb, V. L. 1970. Oceanography of the Mid-Atlantic Bight in support of ICNAF, September-December 1967. U.S. Coast Guard Oceanogr. Rep. No. 35. 157 pp.
- Williams, R. G. and F. A. Godshall. 1977. Summarization and interpretation of historical physical oceanographic and meteorological information for the Mid-Atlantic region. U.S. Dept. Commerce, NOAA, Wash., DC. Final report to the Bur. of Land Management, U.S. Dept. of the Interior, Interagency Agreement AA550-IA6-12. 295 pp.
- Wright, W. R. 1964. The limits of shelf water south of Cape Cod, 1941 to 1972. J. Mar. Res. 34(1): 1-14.
- Wright, W. R. 1976a. Physical oceanography - The western slope water. In Summary of Environmental Information on the Continental Slope Canadian/US Border through Cape Hatteras. Manuscript submitted to U.S. Bur. Land Management, Marine Minerals Div. NTIS Publ. 2840000/AS.
- Wright, W. R. and C. E. Parker. 1976. A volumetric temperature/salinity census for the Middle Atlantic Bight. Limnol. Oceanogr. 21(4): 563-571.

# Surficial Morphology and Sediments of the Continental Shelf of the Middle Atlantic Bight

by

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The continental shelf has been shaped largely by sea level fluctuations caused by the ice ages of the past two million years. Some 40-100 m of sediment were deposited during this time (Milliman, 1972a). Structurally, the shelf is related to the coastal plain; both have the same subsurface geologic features (described by Emery and Uchupi, 1972). The surface of the shelf has been shaped primarily during Holocene time, the period from the peak of the last (the Wisconsin) glaciation, at 15,000 years ago, until the present (Milliman, 1972a). The shelf's basic morphology and sediments derive from the retreat of the Wisconsin ice sheet, which had advanced as far south as Long Island and northern Pennsylvania, and from the transgression, i.e., the advance of the sea across the land that followed the deglaciation. Yet, the modern shelf environment, through the movement of sediment by currents and waves, has modified this basic structure, placing its imprint upon the older features.

Physiography. The shelf is a gently sloping terrace that extends 100-200 km from shore (Figure 1). In the middle Atlantic, its gradient varies between 1:1500 and 1:2500 (Uchupi, 1968), a gradient comparable to the coastal plain of New Jersey and Delmarva. The general surface is quite smooth; the maximum gradient rarely exceeds 1:100 and the major features do not vary more than 35 m from the shelf surface.

On its seaward edge, in 100-200 m of water, the shelf is bounded by the shelf break, the point where the gradient increases sharply to 1:100 or more, indicating the change in province to the continental slope (Uchupi, 1968). At the landward edge of the shelf, in 10-15 m of water, the gradient increases again as the wave-dominated shoreface region is reached (Everts, 1968).

Figure 2a and 2b show the primary morphology features of the mid-Atlantic Bight. These include the shelf valleys and channels, shoal massifs, and sand ridges. Except the sand ridges, most of these primary features are relict, in that they were formed during the melting of the ice sheet and the ensuing transgression of 15000-3000 years before the present.

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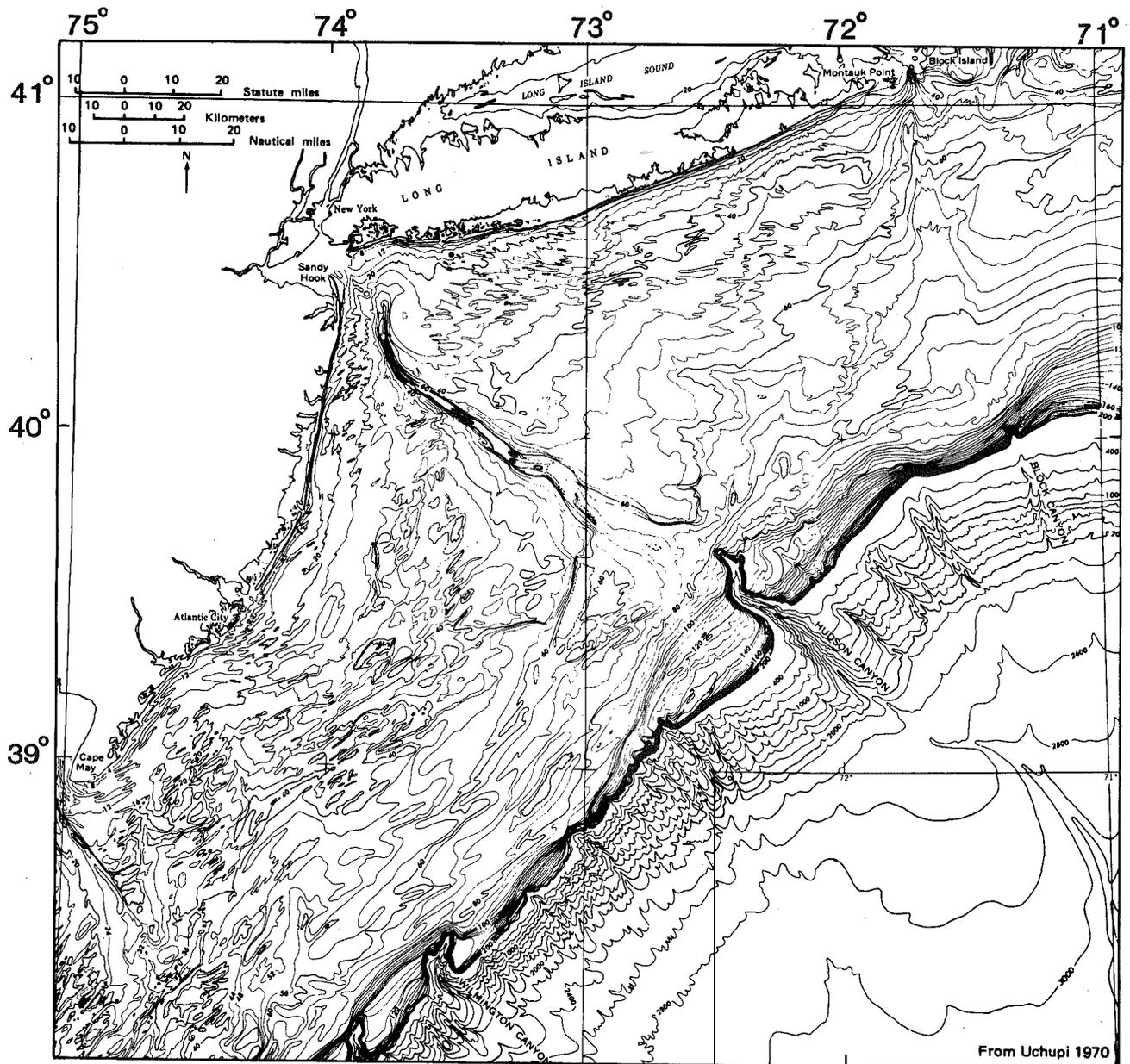


Figure 1. Middle Atlantic Bight bathymetry (from: Freeland and Swift, 1978; after Uchupi 1970)

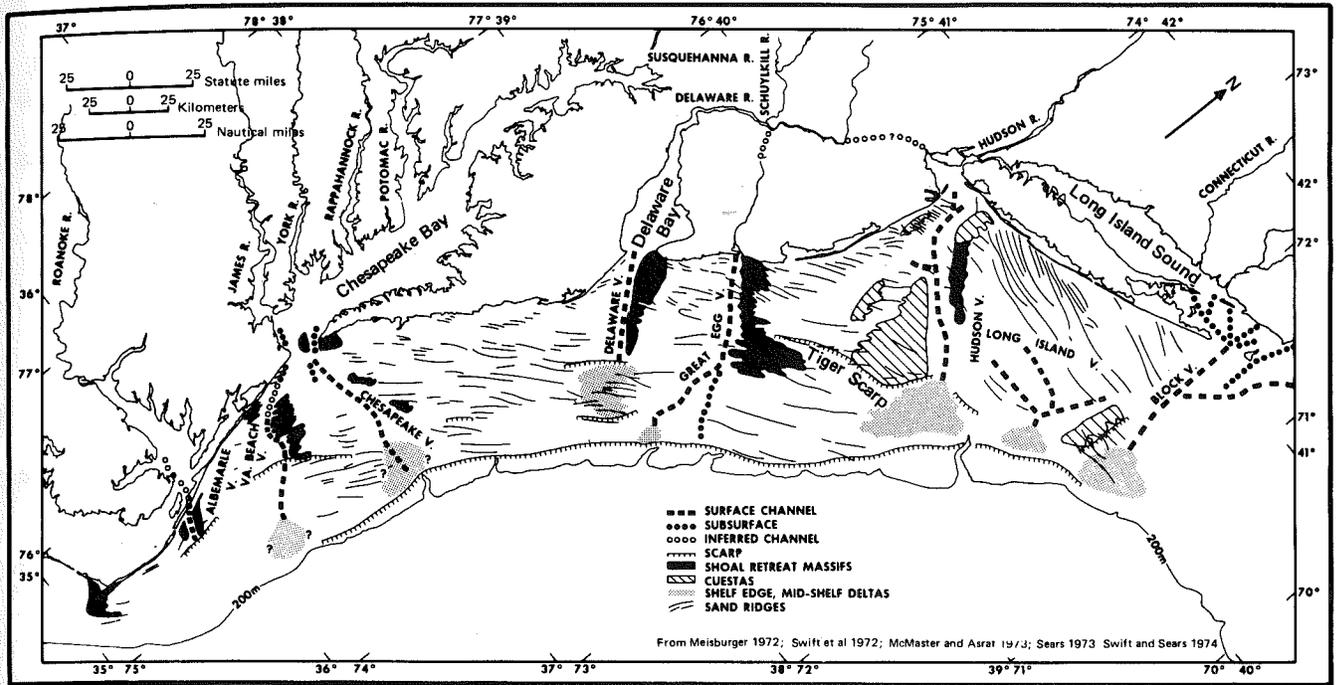


Figure 2a. Middle Atlantic Bight morphology (from: Freeland and Swift, 1978)

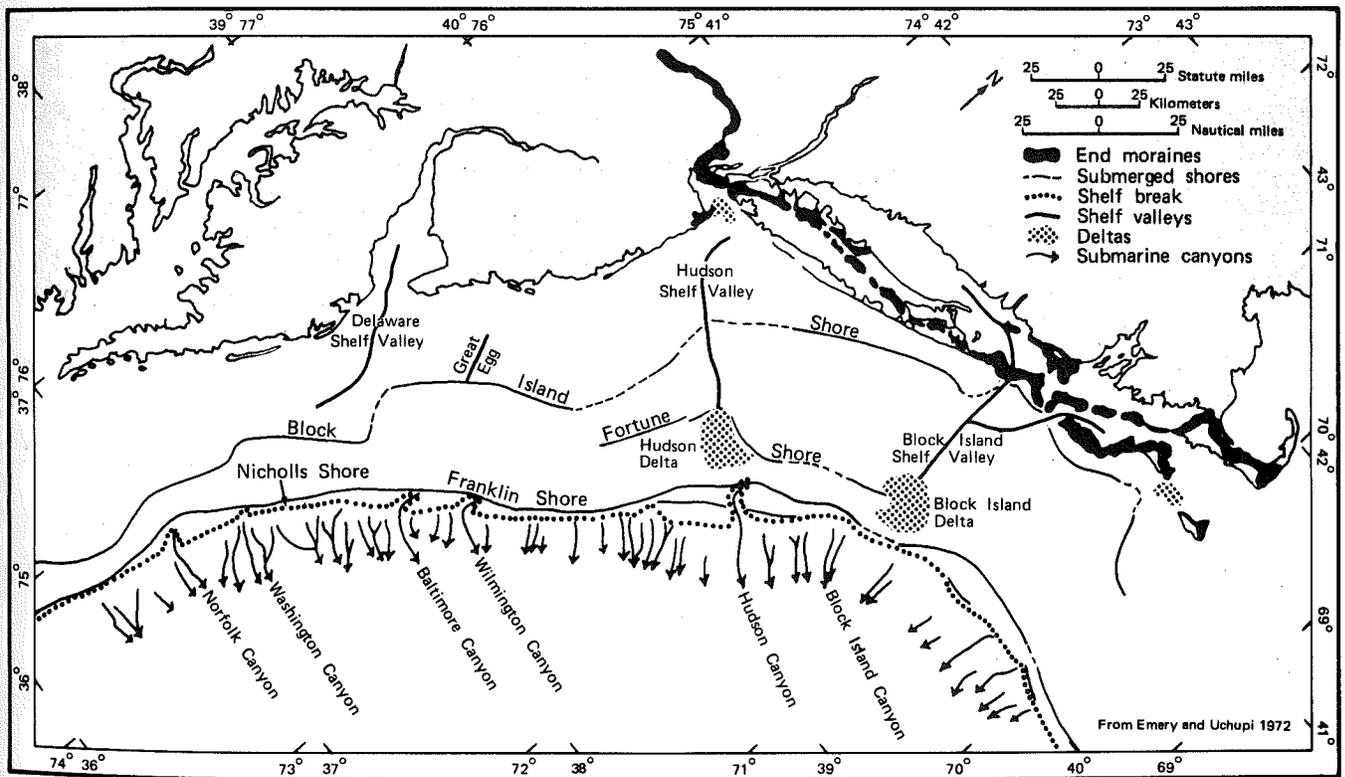


Figure 2b. Major features of the shelf (from: Freeland and Swift, 1978)

As the ice sheet retreated, the streams of the middle Atlantic carried a vast quantity of meltwater and sediment. These swollen streams eroded valleys across the continental shelf and deposited their sediment load on the outer shelf as they entered the ocean. Most of the valleys cut only about 10 m into the shelf surface. However, the Hudson shelf valley is incised over 35 m below the surface (Freeland and Swift, 1978). This difference has been explained by the much larger quantity of water carried by the Hudson River. Veatch and Smith (1939) have suggested that the Hudson River carried the drainage of the Great Lake region until the St. Lawrence River was exposed by the retreating ice sheet, hence the comparatively large Hudson valley. It is worth noting that the Hudson canyon, just below the valley, is the only submarine canyon of the continental slope that has eroded into the shelf.

Variations in the shelf valleys also owe to the redistribution of surface sediments as the sea transgressed the shelf. The original shelf valleys of the Susquehanna, Delaware and Little Egg Rivers have been partially filled with modern sediments and the former river channels have been buried (Swift et al., 1980). The channels we see today off Chesapeake and Delaware Bays are actually outflow channels for the retreating estuaries--channels molded into the depositing sediments (Swift, 1973; Figure 3). Depositional plains appear on the outer continental shelf. These seem to be associated with the river channels, and may have been river mouth deposits formed at lower sea levels (Freeland and Swift, 1978).

The shelf contains several scarps, features indicative of the position of the shoreline during still-stands in sea level. A temporary halt in the rise of sea level would produce a well-developed shoreface extending from sea level to about 10-15 m depth, such as we see at present. As sea level began to rise again, the lower shoreface would be too deep to be eroded by waves, thereby resulting in a scarp. The Nicholls and Franklin scarps at the edge of the shelf (140 m depth) may indicate the shoreline at the peak of the Wisconsin glaciation (Uchupi, 1968).

Shoal retreat massifs are produced by extensive deposition at capes or estuary mouths (Swift et al., 1972). Any sharp change in shoreline orientation, such as occurs at an estuary mouth, will frequently intercept the littoral transport of sediment on the open coast. The change in shoreline orientation may also cause the littoral transport within the estuary to converge on the mouth. This convergence can produce extensive shoals of sand and gravel. Examples of these shoals are found presently at Cape May in Delaware Bay, Cape Charles in Chesapeake Bay, and at the North Carolina capes. With the retreat of the estuary mouth as sea level rose, new shoals continually developed; the older shoals remain stranded in deeper water. The resultant trail of these sandy shoals produced an extensive depositional massif across the shelf.

The ubiquitous sand ridges are most common on the inner shelf and become somewhat rarer and less well-defined on the outer shelf (Duane et al., 1972). The ridges, frequently found in groups, have a spacing of about 2 km, mean height of 10 m and lengths from 10-50 km. The ridges are oriented at a slight angle to the shore (30-50°) and have a NE-SW trend.

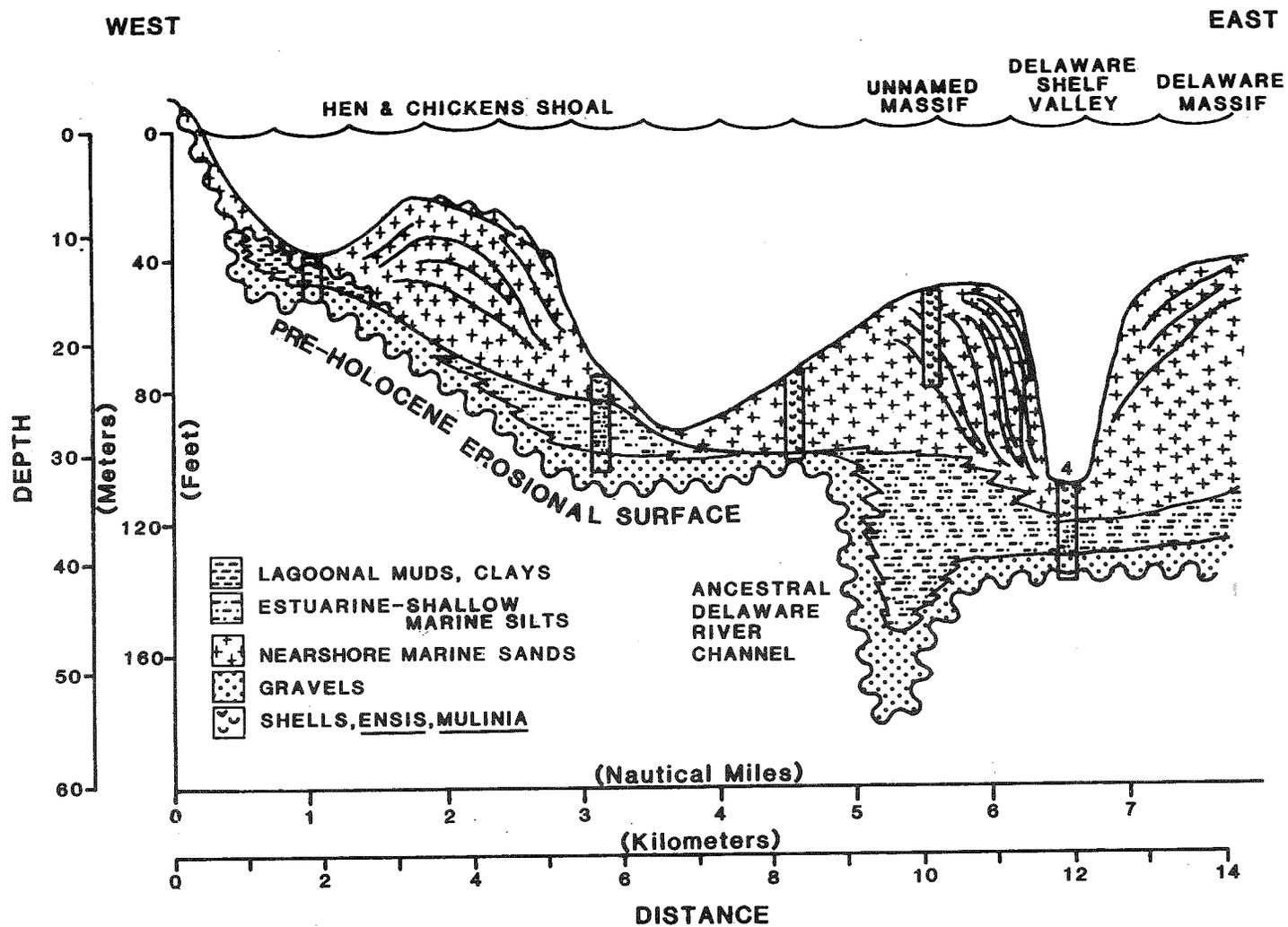


Figure 3. Position of present-day Delaware Shelf Valley and shoal retreat massif as compared to the former Delaware River Valley (from: Sheridan et al, 1974)

Generally their seaward face has the steepest slope. Unlike the other shelf features, which formed during lower sea levels, the ridges are more modern in origin. Their formation is not well understood, but they appear to develop from the sediments that erode from the shore face (Swift and Field, 1981). Because they maintain their shape, the ridges are probably in an equilibrium with the present day storm currents and waves. We will discuss them in more detail later.

Several other smaller bedforms, such as sand waves and megaripples, are also found on the shelf. These are frequently, but not necessarily, found on the sand ridges. They will also be discussed later in context of sediment transport.

Sediments. Taking the shelf as a unit, the transgression has produced remarkably uniform distributions of sediments. A sheet of sand and gravel covers most of the shelf (Schlee, 1973; Hollister, 1973; Figures 4 and 5). This sheet varies from 0-10 m in thickness, the maximum thickness occurs in the sand ridges and the minimum is often found in the swales. Most of the sediment is medium to coarse sand with finer sand found in the Hudson shelf valley and on the outer shelf (Table 1). Gravel is found in abundance on the New Jersey inner shelf. In places it comprises 100% of the bottom sediments.

Mud is rare; it is common only in the Hudson Valley and the Christiaensen Basin at the head of this valley (Freeland and Swift, 1978; Figure 6), and sometimes appears as outcrops of lagoonal or estuarine deposits that have been re-exposed in the swales between sand ridges (Duane *et al.*, 1972). Lenses of mud may also appear in swales or troughs during the summer, but these lenses disperse during storms (Swift *et al.*, 1976). The mud content of the bottom sediments increases rapidly at the shelf break (off eastern Long Island, some mud begins to appear on the outer shelf) and on the slope, the sediments contain 70-100% mud (Figure 6). The change is dramatic enough to warrant being called the "mud line" (Stanley *et al.*, 1983).

The composition of the shelf sediments is quite similar to that of the beach sediments of the region. They consist predominately of quartz and feldspar, 70-95% quartz, and up to 25% feldspar (Milliman, 1972; Freeland and Swift, 1978). The remainder includes heavy minerals--particularly garnet, amphiboles, staurolite, and epidote--and some shell fragments. The variations in heavy minerals result from regional differences in the sources of the material (Ross, 1972). Much of the sediment was carried or eroded by meltwaters coming down the Susquehanna, Delaware, and Hudson rivers. Sediment also derives from the outwash plain produced by the many streams that flowed from the ice sheet as it retreated from Long Island. Thus, the shelf off Long Island contains glacially transported material from southern New England. Garnet and staurolite originate in New England, hence they are found in abundance on the Long Island shelf and beaches. Garnet, carried by the Hudson River, is also dominant off New Jersey (Ross, 1972). Amphibole and epidote supplied from coastal plain and piedmont sediments appear off Delaware and Chesapeake Bays (Milliman, 1972).

The shelf sediments contain only a small proportion (<3%) of calcium carbonate, in the form of shell fragments (Milliman, 1972). The total amount varies little in the bight, however, the source of CaCO<sub>3</sub> changes from echinoid fragments in the north to a mix of molluscan and echinoidal fragments to the

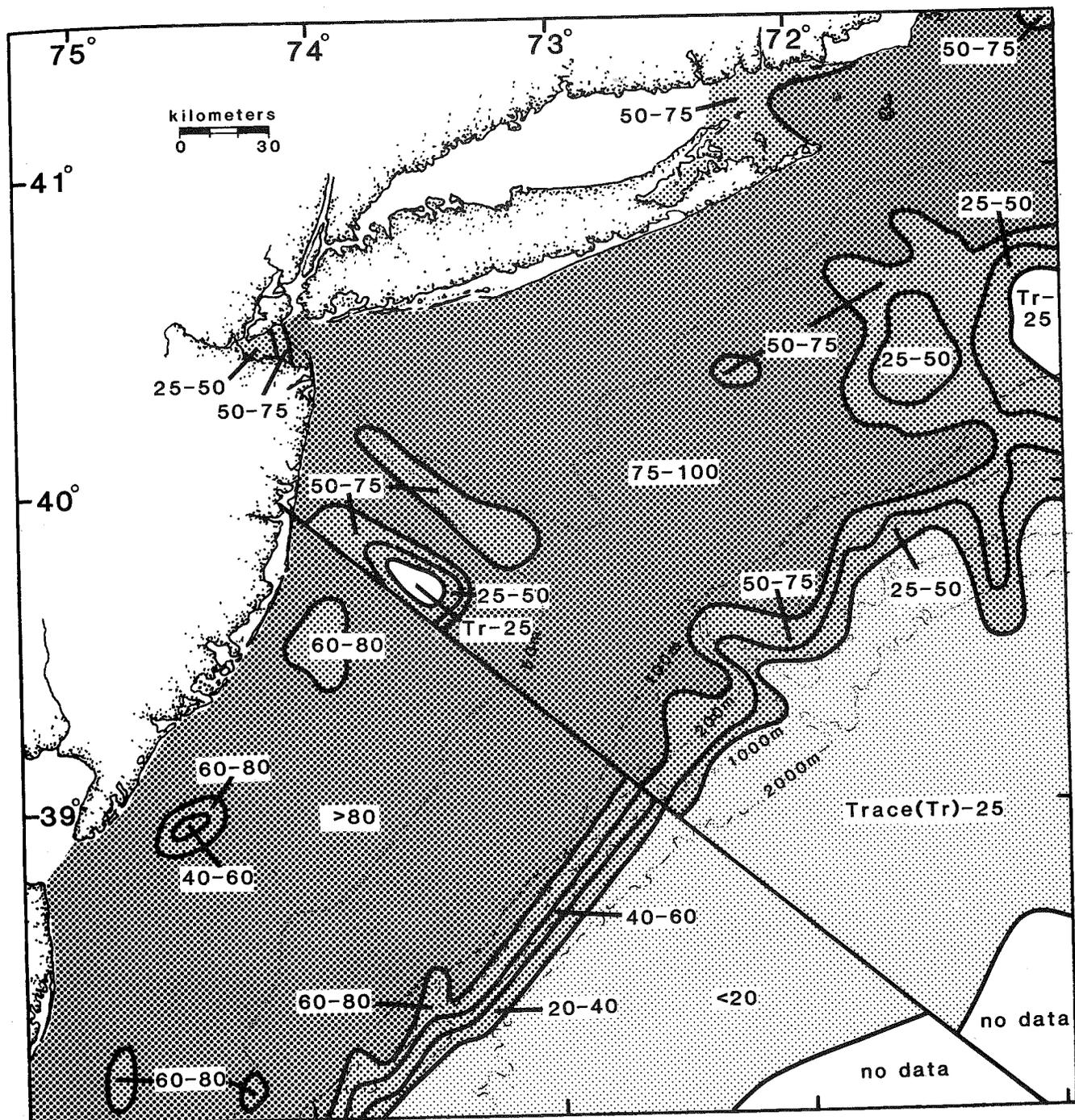


Figure 4. Percentage of sand in the surface sediments (from: Freeland and Swift, 1978)

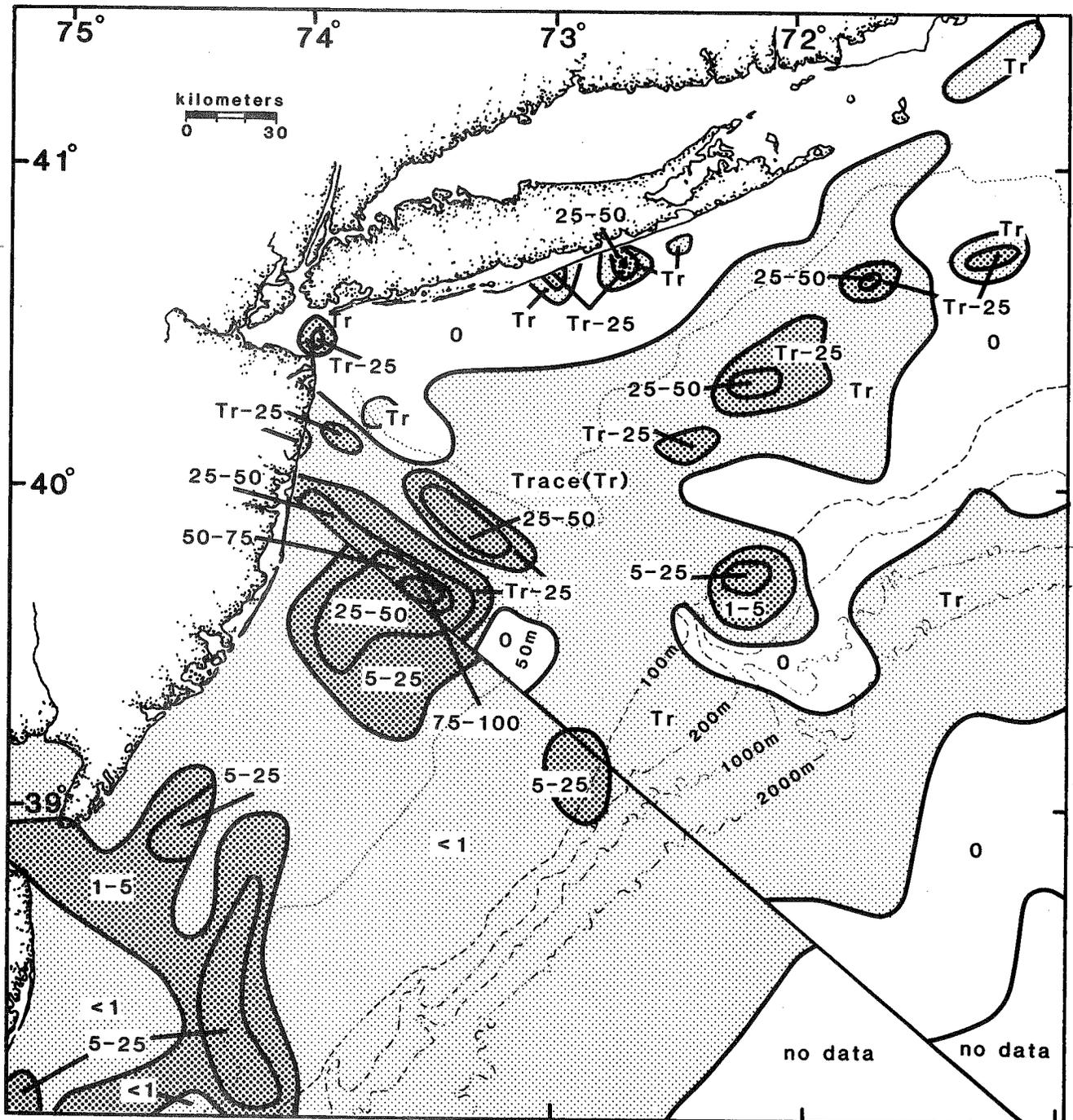


Figure 5. Percentage of gravel in the surface sediments (from: Freeland and Swift, 1978)

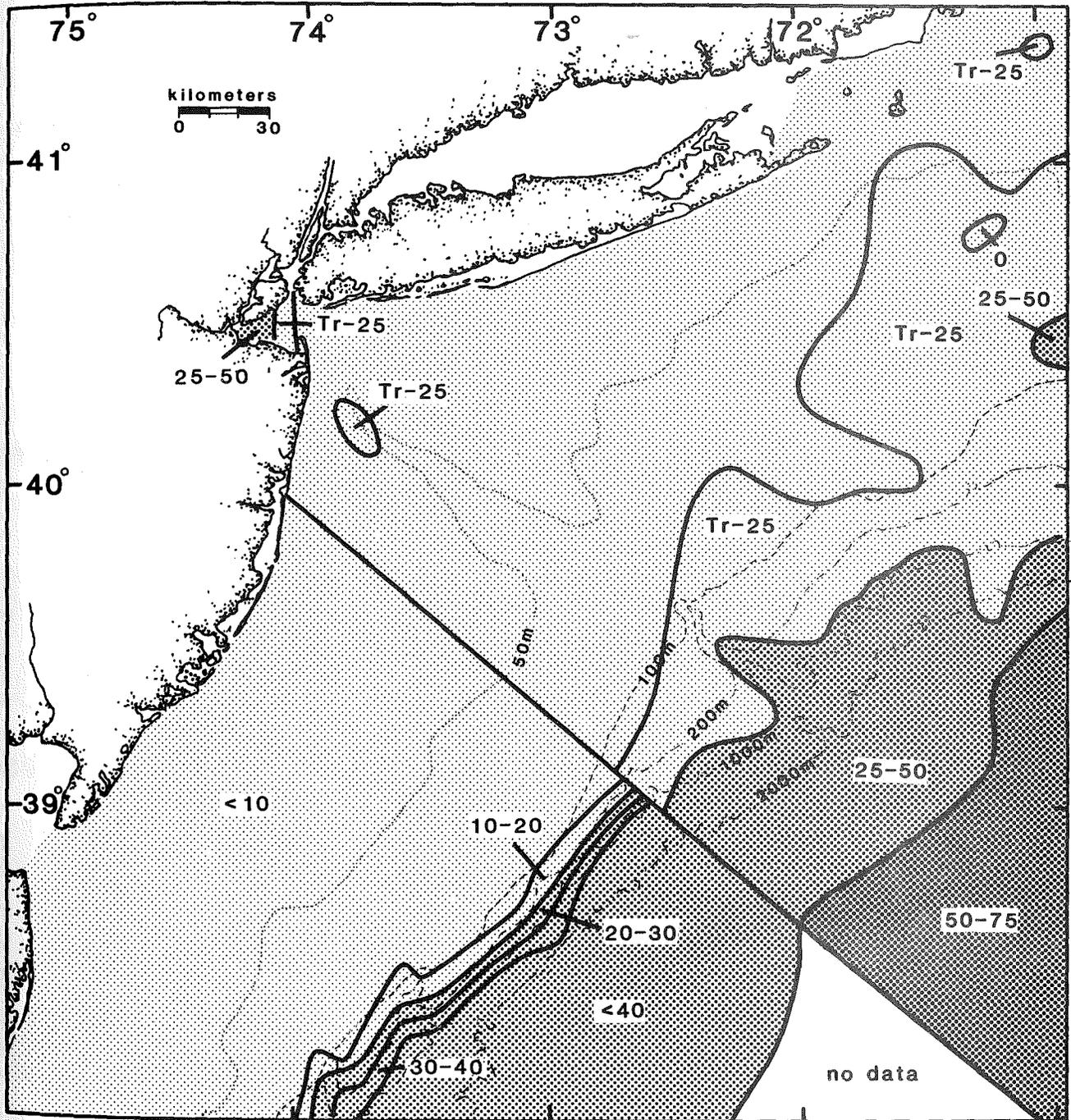


Figure 6. Percentage of clay in the surface sediments (from: Freeland and Swift, 1978)

Table 1. Grain Sizes

Size Description	Phi units $\phi$	Grain Diameter mm
Gravel	-1	2.0
Very Coarse	0	1.0
Coarse	1	0.5
Medium	2	0.25
Sand	3	0.125
Fine	4	0.0625
Very Fine	8	0.0039
Silt	12	0.00024
Clay		
Colloid		

(Mud is undifferentiated silt and clay)

south of Delaware Bay (Figure 7). Echinoids consist primarily of sand dollars, *Echinarchinus parma*, which frequently concentrate on the crests of bedforms. Molluscan fauna includes principally pelecypods. Oyster shells (*Crassostrea virginica*) may occasionally appear when old lagoonal and estuarine deposits are re-exposed and eroded (Freeland and Swift, 1978).

It is important to realize that the sediments on the shelf derive from events that occurred at lower sea level rather than from the addition of new sediments at present (Milliman, 1972a). Most of the sediment carried in streams today is trapped in the upper portion of their estuaries, and little escapes onto the shelf. The lower portions of the mid-Atlantic estuaries all contain sand and gravel sized sediments characteristic of the shelf and not of the rivers (Meade, 1969). Some fine sediment may leave the estuary when the

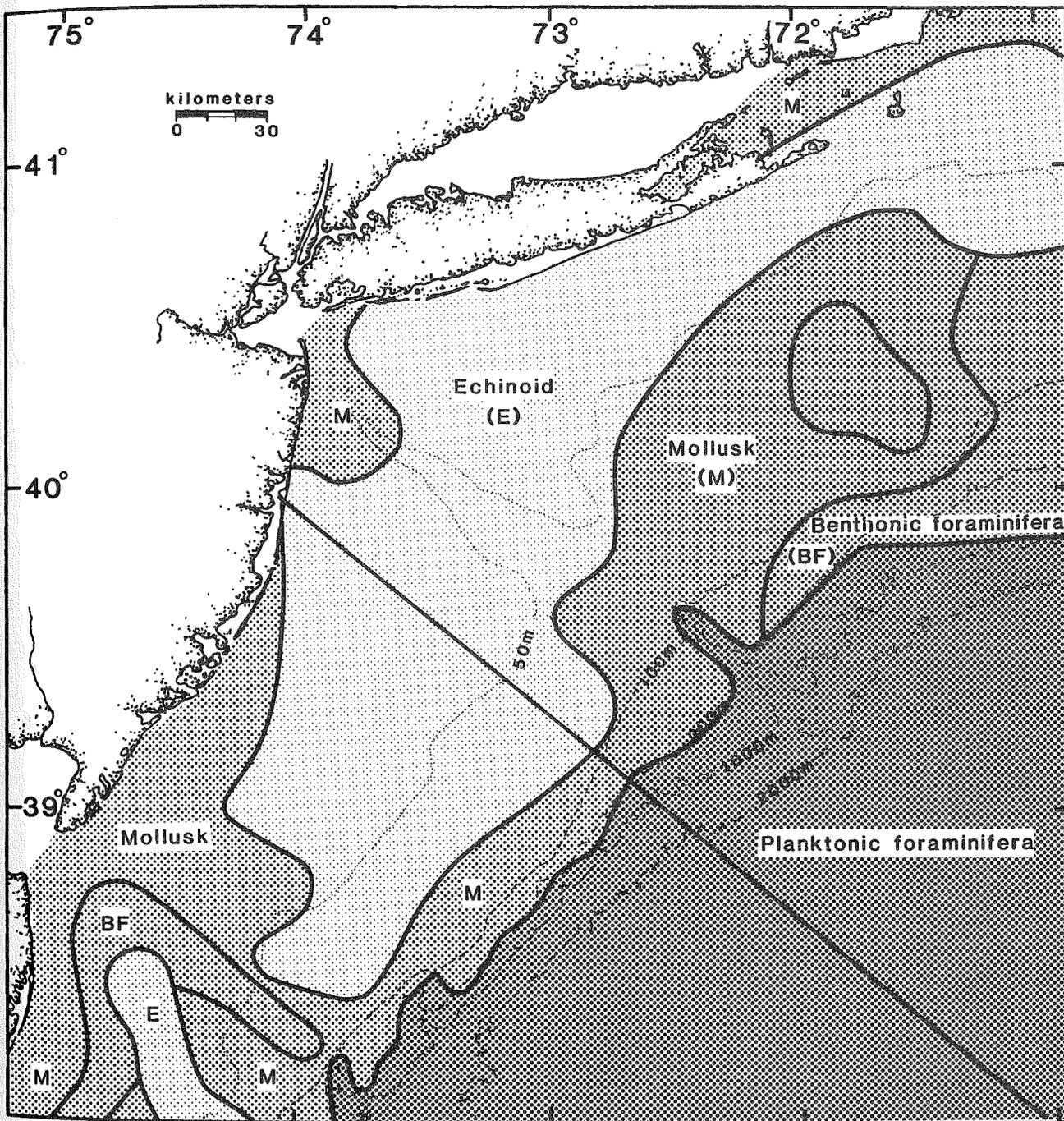


Figure 7. Carbonate assemblages (from: Freeland and Swift, 1978 after Milliman, 1972b)

river has a high discharge, but much of this sediment moves along the coast and is deposited within the coastal lagoons (Kelley, 1982). The small fraction of fine sediment that does escape onto the shelf rarely remains there. Storm waves and currents rework the bottom sediments keeping the fine fraction in suspension until it ultimately settles onto the less energetic continental slope (Knebel, 1981).

The coloration of the sediment indicates a fairly well oxidized environment. The sediments of the inner shelf are in general yellow or brown in color with 25-50% of the grains iron-stained (Milliman, 1972b). On the outer shelf off Long Island, the sediment is more greenish gray. The color change corresponds to the somewhat higher mud content (up to 25%), because the flow of water and oxygen is retarded in muddy sediment (Freeland and Swift, 1978).

Little organic material is found in the sediments (Boesch et al., 1979). Generally, its presence correlates with the presence of mud. Sediments may contain organic carbon in concentrations of 0.2-0.5% at the head of the Hudson Valley and in some mud lenses, but in most areas the concentration is very low (<0.1%). Nitrogen (measured as Kjeldahl nitrogen) is typically less than 0.01% (Milliman, 1972b). The ratio of carbon to nitrogen (C/N) tends to vary between 6-10. In finer grained sediment--fine silty sands and muds--the ratio is higher, about 15-25. This higher ratio suggests a greater proportion of non-living organic material in the finer grained sediments, whereas in the coarser sands the organic carbon may be associated with living organisms (Boesch et al., 1979).

### Secondary Structures and Sediment Transport

Several categories of bedforms are prominent on the shelf. These include sand waves, megaripples, and ripples. These bedforms are identified by both their hierarchy and their structure. In hierarchy, megaripples may be covered with ripples, and sand waves may be covered by either megaripples and/or ripples--but not vice versa. Their structure and formation are described below.

Sand waves are found primarily on the inner shelf, although some have been observed on the shelf break at the head of the Wilmington Canyon (Knebel, 1981). They tend to form in patches of 5-10, with wavelengths of 50-100 m and amplitudes of about 2 m (Swift et al., 1979). Patches may be found 1-2 km apart. The waves strike obliquely to the shoreline and they have a steeper-southwest flank. They, along with megaripples, are often observed on the flanks and troughs of sand ridges. Often, megaripples may cover the sand waves. Individual sand waves have remained intact over several seasons.

Megaripples occur either on sand waves or separately. They are found on the inner and central shelf. Swift et al. (1979) estimated that during the winter they may cover as much as 15% of the inner shelf. They form in large patches and can have wavelengths of 1-40 m, but 3-5 m is more typical. They have an amplitude of 0.5-1.0 m. Megaripples, like sand waves, usually have a steeper southwest flank. They tend to survive for less than a season. However, sand dollars, presumably seeking faster currents, will often cover the crests of the megaripples, helping to armor them and thereby maintain their shape.

Ripples are found everywhere on the shelf (Swift et al., 1977). They have wavelengths of 1-150 cm, the wavelength increasing with grain size, and have amplitudes of a few centimeters. They are ephemeral, appearing and disappearing within hours or days depending on the events that form and destroy them. On the outer shelf, they tend to be represented for several weeks after formation. Two general classes of ripples develop on the shelf: short-crested, asymmetric ripples and long-crested symmetric ripples (Swift et al., 1979). The former develop in unidirectional currents; the latter, which may extend several meters in length, occur in oscillatory (wave) flow (Butman et al., 1979).

The sediment size varies over the bedforms--including the sand ridges. In most cases, particularly for megaripples and sand waves, coarser sediments may include shell fragments and clay balls (Swift et al., 1979). On the sand ridges, sediment size appears to be 90° out of phase with the bathymetry (Figure 8; Niedorada et al., 1984). The coarser (small phi) sediments are found on the seaward slope rather than at the crests. The gentler shoreward slope has the finer (larger phi) sediments. Generally, the finer sediments consist of fine sand, the coarser material includes coarse sand and even some gravel.

Sometimes the sediment size in the troughs or swales is unrelated to the processes. If the surficial deposits lack adequate coarse sediment to armor the bottom, a trough can erode through the surficial sand sheet and expose old lagoonal muds (Figure 9). In this case, the trough will frequently contain a layer of clay balls, shell fragments, and gravel lying over a mud surface. Also, during the summer, when there are few storms, mud layers, 10-15 cm thick, form in the troughs of sand waves or megaripples (Swift et al., 1979). This mud is temporary, lasting only until the next storm. On close inspection, the bottom sediments tend to be somewhat patchy with grain size variations of 0.1-0.2 mm (3-2 phi) within tens of meters (Freeland and Swift, 1978; Swift and Field, 1981).

Bedform Migration and Long-term Sediment Transport. All of the bedforms observed on the shelf--ripples, megaripples, and sand waves--are flow-transverse in nature. That is, their crests lie normal to the dominant direction of sediment transport. Thus, their predominant orientation with the steeper (down-current) slope to the southwest, indicates a south-westerly flow of sediment (Vincent et al., 1981), (Figure 10).

The trend of grain size distributions on the surface of the bedforms is consistent with this flow. Coarser sediment extends from the troughs onto the gentle flank, indicating the exposure of the flank to greater bottom stress and erosion (Swift et al., 1979).

The sand ridges are also clearly migrating in a southerly direction. Ridges off Delaware migrated 100-250 m to the south between 1919 and 1961 (cf. Swift and Field, 1981). During the severe northeast storm of 1962, they shifted as much as 90 m.

Swift and Field (1981) found ridges off Maryland and Virginia migrating up to 300 m in 80 years. On one of these ridges, they estimated up to 3 m of deposition on the southeastern flank of the ridge (from 1933 to 1976), concurrent with 3 m of erosion on the northeastern flank. The flank of

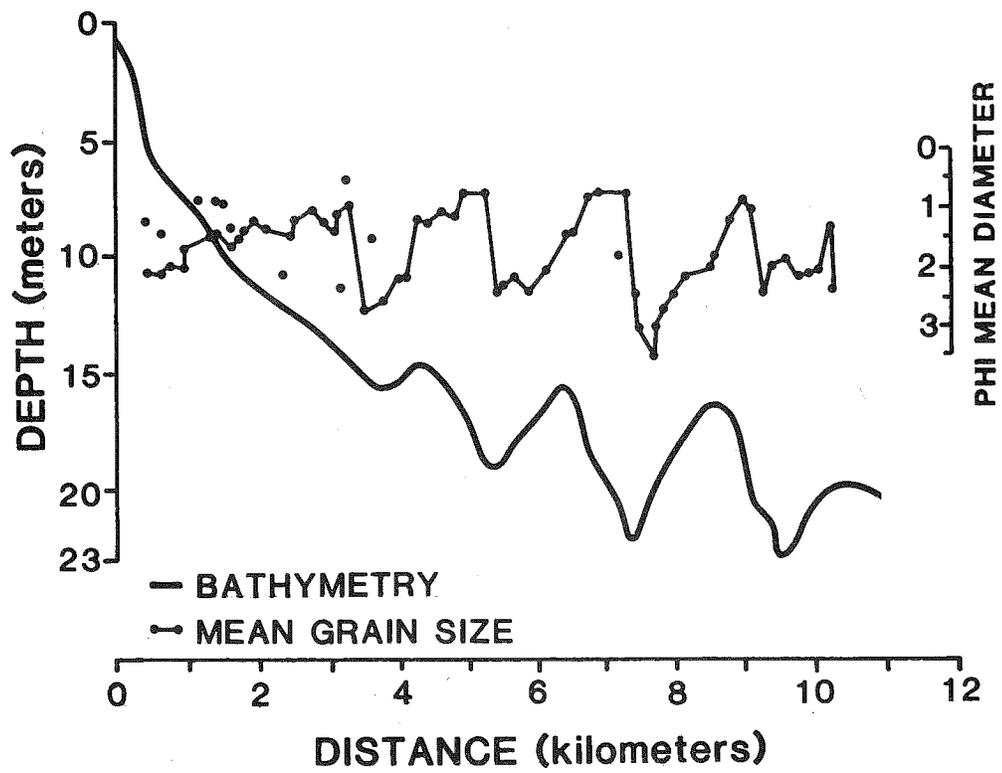
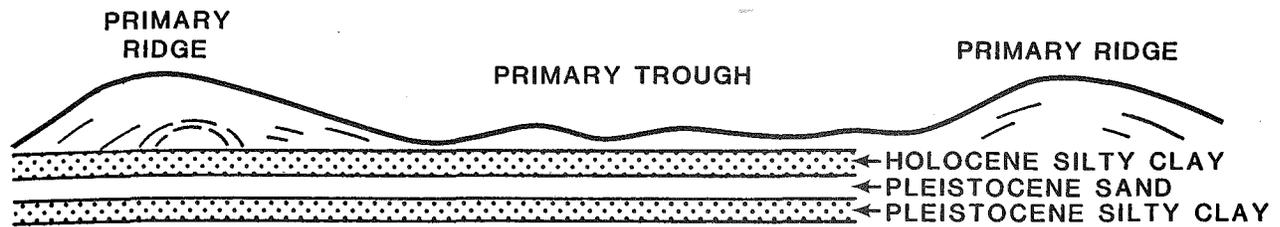
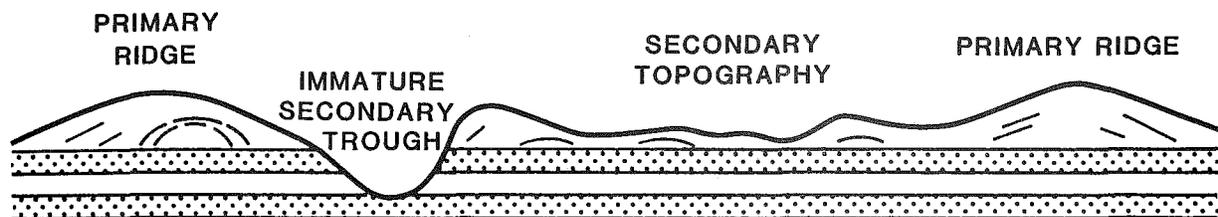


Figure 8. Variation of sediment size with topography over sand ridges (from: Niedoroda, A. W., et al, 1984)

- (A) Retreating shoreline left surficial sand sheet on early Holocene clay; internal stratification of ridges indicates growth by lateral and crestal aggradation.



- (B) Continued scour in troughs results in incision of secondary troughs into upper silty clay layer; secondary ridges may appear as levee-like forms associated with secondary troughs.



- (C) Downward erosion in secondary troughs inhibited by lower silty clay; secondary trough widens by erosion of Pleistocene sand and undermining of upper silty clay.

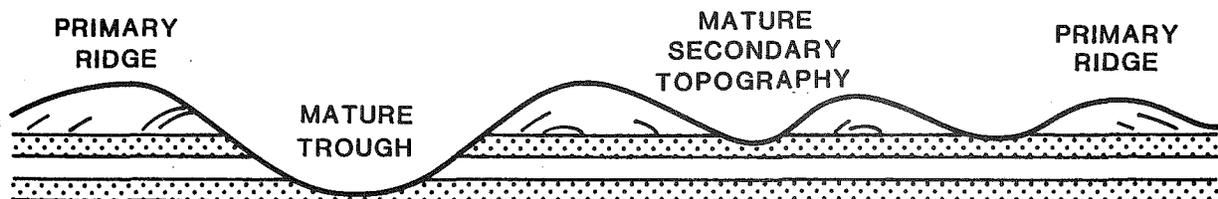


Figure 9. Development of ridge and swale topography (From: Stubblefield and Swift, 1976)

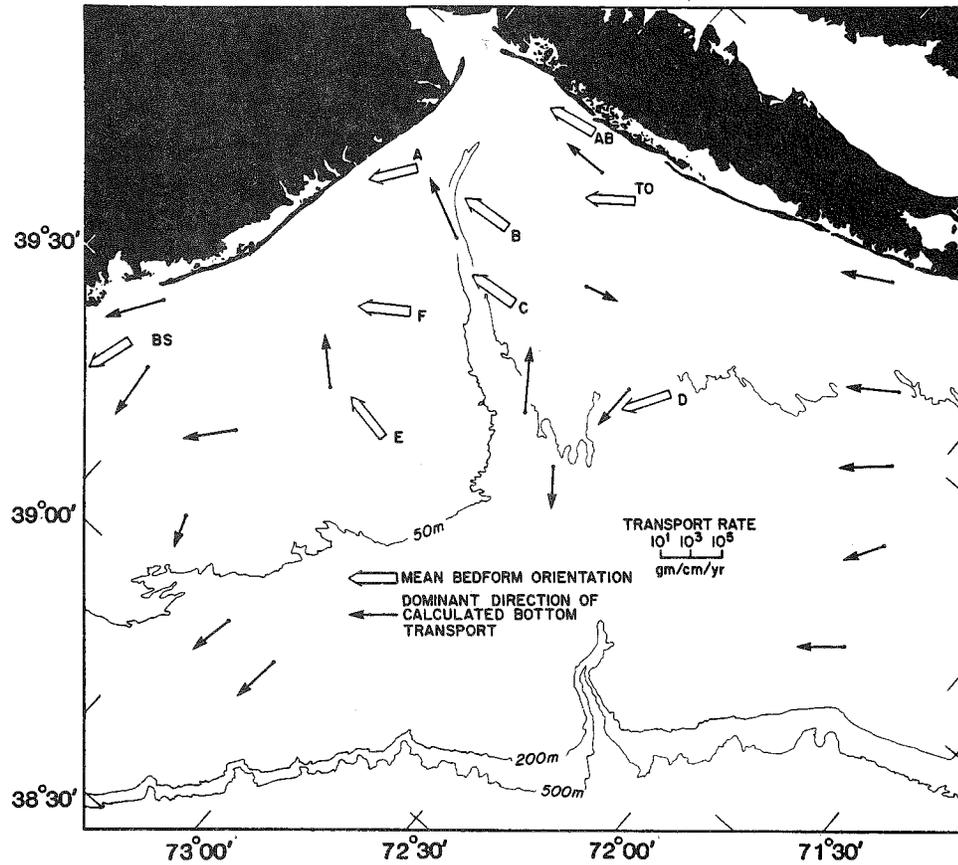


Figure 10. Directions of sediment transport near the Hudson Shelf Valley, calculated and inferred from bedforms (from: Freeland *et al* 1981)

deposition tended to have finer sediment than the eroding flank (fine sand vs. medium sand). Swift and Field suspect that the ridges, regardless of their mode of formation, may have achieved an equilibrium with the present day environment of the inner shelf--otherwise storms would tend to degrade the ridge, rather than tend to promote their migration.

Deposition in the Hudson shelf valley confirms the presumed southerly transport. Freeland *et al* (1981) found that the northeastern side of the valley contains three times as much post-transgression sediment as does the southwestern side. These updrift deposits are substantial, reaching a thickness of 20 m in the upper valley as compared to 5-10 m on the adjacent shelf. Sediment transport in the valley appears to follow the valley axis (Vincent *et al.*, 1981), the result being that the valley interrupts the movement of sediment along the shelf. Downdrift of the valley and off New Jersey, lies the shelf area having the greatest abundance of gravel. This concentration of gravel can be explained by the gradual removal of sand from the surface sediments, sand that cannot be replaced from updrift of the sediment sink in the valley (Vincent *et al.*, 1981).

Mechanisms of Sediment Transport. Identifying the direction of sediment transport on the shelf is somewhat easier than accounting for it. Drifter studies and long-term current moorings show a mean bottom flow of 1-5 cm/s to the southwest (Bumpus, 1973; Mayer *et al.*, 1979). Because currents of this speed cannot move sand, the transport of sediment on the shelf must be a highly episodic process. Research in recent years has shown that sediment transport depends on the interactions of surface waves with tidal currents, wind-driven currents, and possibly internal waves (Knebel, 1981).

Sediment will not move until the bottom stress caused by the flow exceeds some threshold value. For unidirection currents, this threshold stress corresponds to a threshold velocity. Medium sand, for example, will begin to move when the near bottom (100 cm) current is about 25-30 cm/s; gravel will move at 50 cm/s (Komar, 1976). However, in a wave-induced flow, the continual variation of the velocity field produces a greater shear stress for a given velocity than in a unidirection flow. Thus, a maximum bottom velocity in a wave field of only 15 cm/s may produce movement of medium sand (Komar, 1976).

Wave orbital velocities are strongest at the surface and decrease exponentially with depth--the rate of decrease being greatest in short period waves. Accordingly, only long period waves affect the outer shelf, shorter period waves can achieve the necessary velocities on the inner shelf. Komar (1976) also found that for a given velocity, the stress is greater under a short period wave. This implies that wave effects tend to combine synergistically on the inner shelf. Work by Butman *et al.* (1979) on the middle and outer shelf and by Lavelle *et al* (1978) on the inner shelf, show the importance of the interaction of waves with currents for transporting sediment.

Tides and wind induced currents account for equal amounts of the variance in the long shelf current (Han and Mayer, 1981). During fair weather, a near bottom tidal current of 10-15 cm/s is observed. Wind-driven currents greatly augment that current. The mean near bottom current on the outer shelf

during storms typically exceeds 30 cm/s (Butman *et al.*, 1979); on the inner shelf, mean currents of 40 cm/s are common (Lavelle *et al.*, 1978). At these velocities, sediment will also move along the bottom as bedload.

Storm waves have quite a different effect on the sediment. Butman *et al.* (1979) found that resuspension of fine sand on the outer shelf depended principally on the presence of waves. Storm waves would resuspend sediment regardless of the presence of any other current, including currents as low as 5 cm/s. On the inner shelf, Lavelle *et al.* found that the mean sediment concentrations near the bottom increased from 5 mg/l during fair weather to a mean of 70 mg/l during storms. The latter elevated concentrations lasted for 12 hours or more. Instantaneous velocities and sediment concentrations exceeded 100 cm/s and 100 mg/l, respectively, and changes in concentration of more than 50 mg/l within 3-5 seconds were not unusual.

Currents can transport suspended sediment far more effectively than bottom sediment. Calculations by Vincent *et al.* (1981) indicate that suspended transport of fine sand can be twice the bedload transport in the mid-Atlantic. Thus wave resuspension is quite important in moving sediment. Their data also predict a net transport of sediment in a southwesterly direction (Figure 10). This direction results from the tendency of storms in the mid-Atlantic to have northeasterly winds; hence both the bedload and suspended load are directed toward the south.

As both wind currents and wave resuspension increase in importance in shallow water, bedforms logically become more common on the inner shelf. Their presence points toward more extensive reworking of the bottom sediments. The formation of megaripples during a storm may reshape the upper 50-100 cm of the sediments within a few hours (Swift *et al.*, 1979) with significant effects on anything living there.

The effect of depth also explains the presence of finer sediment within the Hudson shelf valley, fewer waves can disturb the sediments there, so that fine sediments may continue to accumulate (Freeland *et al.*, 1981).

Other factors may have some influence on the sediment transport. During the summer, when waters of the outer shelf are well-stratified, Butman *et al.* (1979) found bottom currents of 10-20 cm/s induced by internal waves. It is not known how important internal waves are, but their interaction with tidal flow has been suggested as an explanation for the sand waves found at the shelf break near the Wilmington Canyon (Knebel, 1981).

Several studies have also indicated a net drift onshore in less than 60 m of water (and possibly a net drift offshore on the outer shelf, Butman *et al.*, 1979; Bumpus, 1973). Bumpus (1973) found a residual net flow on the inner shelf into the mid-Atlantic estuaries, later confirmed for Delaware Bay (Pape and Garvine, 1982). The presence of continental shelf type sediments in estuaries is consistent with this observation.

Anthropogenic Sedimentation. The head of the Hudson Valley shows the effects of dumping of dredge spoil and sewage sludge. The dredge spoil site has the greatest visible effect. The area has shoaled over 10 m in the past 40 years (Figure 11). Around this "bank" lies a shallow depression in which

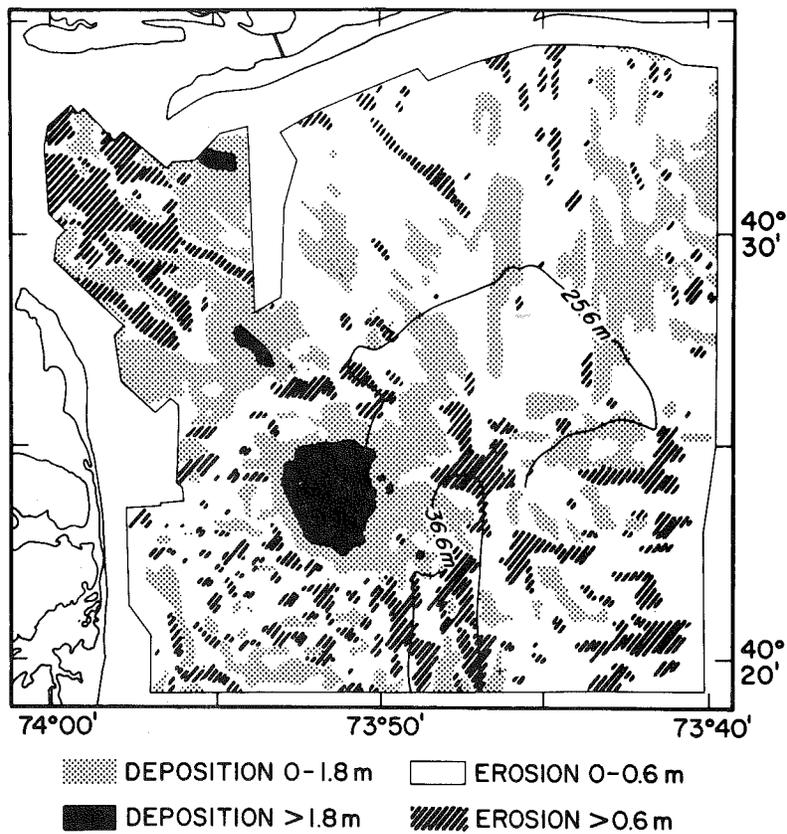


Figure 11. Changes in bathymetry on the New York inner shelf, 1936-1973 (from: Freeland and Swift, 1978)

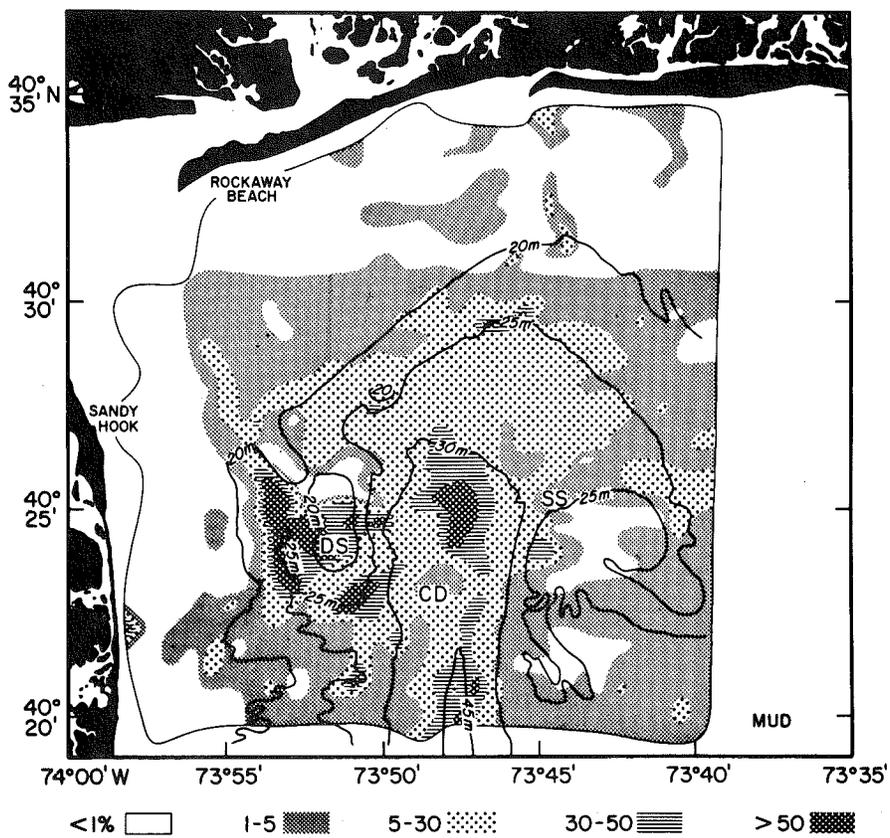


Figure 12. Percentage of mud on the New York inner shelf (from: Freeland and Swift, 1978)

unusually fine sediments have accumulated. These sediments apparently have derived from the dredge spoil (Freeland et al., 1979).

In contrast, the shelf floor at Cholera Bank, where sewage sludge was dumped, has shown negligible accretion and still consists of sand. The adjacent Christiaensen Basin does contain muddy sands (Figure 12). This sediment is probably contaminated by the components of the sludge. However, contamination is not revealed by the gross physical properties and organic carbon content of the sediment, suggesting that the sludge is probably diluted and dispersed by storm currents (Freeland et al., 1979, 1981).

### Summary

The shelf sediments were supplied during the deglaciation of the early Holocene. Few sediments enter the mid-Atlantic Bight now, most are trapped in estuaries. Yet, the shelf is a highly energetic environment. A combination of storm waves, storm currents and tidal currents continually rework and locally redistribute the available sediments, often developing bedforms a meter high and a kilometer in length. The energy does not allow permanent deposition of muds, mud lenses often appear in depression during calm weather but they are dispersed again during storms. The net movement of sediment on the inner and central shelf is southwesterly, consistent with the mean flow of bottom water. Perhaps two-thirds of this transport results from sediment resuspended by storm waves, then transported in storm and tidal currents. Thus, it appears that the inner shelf surface is highly mobile, and the sediments bedforms and ridges are capable of substantial motion, factors which must be considered in any use of the shelf bottom.

### REFERENCES

- Boesch, D. F., D. J. Hartzband, R. J. Ellison. 1979. Bottom sediments and sedimentary framework. In Middle Atlantic outer continental shelf environmental studies, Vol. IIB: Chemical and biological benchmark studies. Virginia Institute of Marine Sciences, Gloucester, Point, VA.
- Bumpus, D. F. 1973. A description of the circulation on the continental shelf of the East Coast of the U.S. *Progr. Oceanogr.* 6: 111-157.
- Butman, B., M. Noble, D. W. Folger. 1979. Long-term observations of bottom current and bottom sediment movement on the Mid-Atlantic continental shelf. *J. Geophys. Res.* 84(C3): 1197-1205.
- Duane, D. B., M. E. Field, E. P. Meisburger, D. J. P. Swift and S. J. Williams. 1972. Linear shoals on the Atlantic inner Continental Shelf, Florida to Long Island. In *Shelf Sediment Transport: Process and Pattern*. D. J. P. Swift, D. B. Duane and O. H. Pilkey, Eds. Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA.
- Emory, K. O. and E. Uchupi. 1972. Western North Atlantic Ocean: Topography, rocks, structure, water, life, and sediments. *AAPG Memoir* 17, 532 pp.
- Everts, C. H. 1978. Geometry of Profiles Across Continental Shelves of the Atlantic and Gulf Coasts of the United States. U.S. Army Corps of Engineers, CERC Tech. Paper 78-4.

- Freeland, G. L. and D. J. P. Swift. 1978. Surficial Sediments: MESA New York Bight Monograph 10, New York Sea Grant Institute, Albany, NY.
- Freeland, G. L., D. J. P. Swift and R. A. Young. 1979. Mud deposits near the New York Bight dumpsites: origin and behavior. In Ocean Dumping and Marine Pollution. HG. D. Palmer and M. G. Gross, Eds. Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA. pp. 73-95.
- Freeland, G. L., D. J. Stanley, D. J. P. Swift, D. N. Lambert. 1981. The Hudson shelf valley: its role in shelf sediment transport. Marine Geology 42: 399-427.
- Han, G. C. and D. A. Mayer. 1973. Current structure on the Long Island inner shelf. J. Geophys. Res. 86(C5): 4205-4214.
- Hollister, C. D. 1973. Atlantic continental shelf and slope of the U.S.- texture of surface sediments from New Jersey to southern Florida. USGS Prof. Paper 529M.
- Kelley, J. T. 1982. Composition and origin of the inorganic fraction of southern New Jersey coastal mud deposits. Geol. Soc. Amer. Bull. 94: 689-699.
- Knebel, H. J. 1981. Processes controlling the characteristics of the surficial sand sheet, U.S. Atlantic outer continental shelf. Marine Geology 42: 349-368.
- Komar, P. D. 1976. The transport of cohesionless sediments on continental shelves, chapter 8. In Marine Sediment Transport and Environmental Management. D. J. Stanley and D. J. P. Swift, Eds. John Wiley and Sons, Inc., NY.
- Lavelle, J. W., R. A. Young, D. J. P. Swift, T. L. Clarke. 1978. Near bottom sediment concentration and fluid velocity measurements on the inner continental shelf, New York. J. Geophys. Res. 83(C12): 6052-6062.
- Mayer, D. A., D. V. Hansen, D. A. Ortman. 1979. Long-term current and temperature observations on the middle Atlantic shelf. J. Geophys. Res. 84: 1776-1792.
- Meade, R. H. 1969. Landward transport of bottom sediments in estuaries of the Atlantic coastal plain. J. Sed. Petrology 39: 222-234.
- Milliman, J. D. 1972. Atlantic continental shelf and slope of the petrology of the sand fraction of sediments, northern New Jersey to southern Florida. USGS prof. Paper 529J.
- Niedorada, A. W., D. J. P. Swift, A. G. Figueiredo, Jr., G. L. Freeland. 1986. Barrier island evolution, Middle Atlantic Shelf, USA. Part II. Evidence from the shelf floor. Marine Geology, Vol. 63, Special Issue, Barrier Islands.
- Pape, E. and R. Garvine. 1982. The subtidal circulation in Delaware Bay and adjacent shelf waters. J. Geophys. Res. 87(C10): 7955-7970.

- Ross, D. A. 1970. Atlantic continental shelf and slope of the U.S.--heavy minerals of the continental margin from southern Nova Scotia to northern New Jersey. USGS Prof. Paper 529G.
- Schlee, J. S. 1973. Atlantic continental shelf and slope of the U.S. -- sediment texture of the northeast part. USGS Prof. Paper 529L.
- Sheridan, R. E., C. E. Dill, Jr. and J. C. Kraft. 1974. Holocene sedimentary environment of the Atlantic inner shelf off Delaware. Geol. Soc. Amer. Bull. 85: 1319-28.
- Stanley, D. J., S. K. Addy, E. W. Behrens. 1983. The mud line: variability of its position relative to shelfbreak. In *The Shelfbreak: Critical Interface on Continental Margins*. D. J. Stanley and G. T. Moore, Eds. Soc. Econ. Paleon. Min. Special Pub. 33: 279-299.
- Stubblefield, W. L. and D. J. P. Swift. 1976. Ridge development as revealed by sub-bottom profiles on the central New Jersey shelf. *Marine Geology* 20: 315-334.
- Swift, D. J. P. 1973. Delaware Shelf Valley: Estuary retreat path not drowned river valley. Geol. Soc. Amer. Bull. 84: 2743-2748.
- Swift, D. J. P. and M. E. Field. 1981. Evolution of a classic sand ridge field: Maryland sector North American inner shelf. *Sedimentology* 28: 461-482.
- Swift, D. J. P., J. W. Kofoed, F. P. Saulsbury and P. Sears. 1972. Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America. *Shelf Sediment Transport: Process and Pattern*. D. J. P. Swift, D. B. Duane and O. H. Pilkey, Eds. Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA.
- Swift, D. J. P., R. Moir, G. L. Freeland. 1980. Quaternary rivers on the New Jersey shelf relation of seafloor to buried valleys. *Geology* 8: 276-280.
- Uchupi, E. 1968. Atlantic Continental Shelf and Slope of the United States-Physiography. USGS Prof. Paper 529C. 30 pp.
- Uchupi, E. 1970. Atlantic Continental Shelf and Slope of the U.S. -- shallow structure. USGS Prof. Paper 529C.
- Veatch, A. C. and P. A. Smith. 1939. Atlantic submarine valleys of the United States and the Congo Submarine valley. GSA Spec. Paper 7.
- Vincent, C. E., D. J. P. Swift, B. Hillard. 1981. Sediment transport in the New York Bight. North American Atlantic Shelf. *Marine Geology* 42: 369-398.

# Middle Atlantic Bight Nutrient Availability

by

A. Matte<sup>1</sup> and R. Waldhauer<sup>2</sup>

## INTRODUCTION

Continental shelves, representing approximately 10% of the world's ocean areas, yield 99% of the global fish harvest. Their shallow depths concentrate fish and promote the recycling of nutrients. Being at the bottom of the food chain, nutrients play a fundamental role in determining the biological potentials and relative health of coastal areas.

Nutrient distributions in the Middle Atlantic Bight (MAB) are subject to a variety of physical and biological controlling mechanisms. These interacting processes result in an area continuously changing on several spatial and temporal scales. Superimposed on distribution resulting from large influences are small-scale events which, under certain circumstances, can intensify and alter overall patterns.

### Nutrient Importance and Role in Productivity

Fisheries production is dependent on phytoplankton productivity, which is largely controlled by the availability of nutrients (nitrogen, phosphorus, and silicon), light, and temperature. The interaction of these elements on the continental shelf of the northwest Atlantic results in one of the most productive ecosystems in the world (O'Reilly and Busch, 1984).

Photosynthesis, or food production by phytoplankton, is limited to the illuminated surface layers of the sea and is dependent on the presence of substances such as nitrogen, phosphorus, and silicon. The utilization of these nutrients by plankton in this photosynthetic (euphotic) zone reduces water column nutrient concentrations and limits further growth of plankton populations. Some nutrients can be regenerated as planktonic organisms die or are grazed upon by zooplankton, with the resultant nutrients recycled within the euphotic zone. There can, however, also be a continuous, seasonal loss of nutrients as phytoplankton sink, or are consumed by zooplankton and lost via zooplankton fecal pellets which sink. Nutrients, therefore, tend to accumulate in the deeper, darker layers of the water column where

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photosynthesis is minimal. Level of production in the euphotic zone depends in part upon the return rate of nutrients from enriched deeper waters to the productive euphotic layer by mixing.

A distinction is often made between "new" and "old" primary production. "New" has nitrogen in the form of nitrate, and "old" has nitrogen in the form of ammonium. Remineralization of dissolved and particulate organic matter to ammonium can occur above and below the euphotic zone. During periods of poor vertical water exchange (summer in the MAB) when nutrient accumulations in deeper waters from previous seasons do not usually reach light active layers, "old" production, based on upper water column nutrient recycling, may be the prevalent mechanism for maintaining productivity levels. Winter and spring mixing of the water column in the MAB make nitrate from deeper layers available to phytoplankton in the euphotic zone, resulting in a significant increase in "new" production.

Temperature affects productivity by influencing nutrient availability through water density as well as directly affecting photosynthetic rates. Density distribution can inhibit the vertical mixing processes which restore nutrients to depleted surface layers. Summer warming of surface waters establishes a relatively stable vertical density distribution. Below the warmed surface layer, waters are progressively cooler and therefore heavier, as depth increases. The summer is also associated with decreased storm activity which, at other times of the year, can contribute to the breakup of any layering. This water layering or stratification impedes vertical mixing and the exchange of nutrients between deeper nutrient-rich waters and the warmed nutrient poor surface layer.

Changing light and temperature regimes and changing nutrient availability result in a seasonal cyclic pattern of primary production in the MAB. In early spring, the water column is well mixed and contains sufficient nutrients to support increased primary production as the intensity and availability of light increases, resulting in a spring bloom of phytoplankton. As surface water temperatures rise, the summer stratification of the water column develops and begins to retard nutrient transfer from deeper waters, phytoplankton concentrations increase next to the thermocline (the gradient in the water column of maximum temperature change with depth) and nutricline (the region in the water column of maximum change in nutrient concentrations with depth) and decrease in surface layers. The breakup of these stratified conditions in autumn, due to surface cooling and increased storminess, gives rise to a small phytoplankton bloom before the decreased light availability and temperature begin to severely limit the relative size of the plankton population. The effects of upwelling, water mass movements, estuarine discharge, and organic waste disposal are superimposed on this seasonally changing productivity pattern and can alter the expected nutrient regime both temporally and spatially.

In other shelf areas the interactions among the elements driving phytoplankton production (light, temperature, and nutrient availability) can be quite different. At tropical latitudes where elevated temperature and sufficient light exist year-round, nutrient resupply from below the euphotic zone is the main factor regulating primary production. An example is the Peruvian shelf system where resupply is heavily dependent upon wind-induced upwelling. In the western English Channel, strong tides result in permanently

mixed waters and seasonal primary production cycles deviate from those on the Northwestern Atlantic Shelf (Wafer et al., 1983), which is subject to seasonal water column stratification and injections of nutrient richer slope water having a high nutrient content year-round. Sutcliffe et al. (1983) have attributed the yearly variation of cod on the Labrador Shelf to the variation of nutrient supply controlled by the Hudson Bay freshwater discharge. They suggest that here, high discharge rates of fresh (i.e., less dense) water, act as stratifying influences and suppress mixing. The result is reduced nutrient availability to surface layers on the Labrador Shelf, with a push of high nutrient offshore waters out of Hudson Strait further limiting nutrient availability.

#### DATA COLLECTION

Data reported are from ongoing monitoring and assessment programs, conducted by the National Marine Fisheries Service Northeast Fisheries Center (NEFC), to characterize the northwest Atlantic continental shelf. The survey area extends from Cape Hatteras to Nova Scotia, encompassing some 258,000 km<sup>2</sup>. Over 18,000 measurements of dissolved inorganic nutrient concentrations were extracted from this larger data set and reviewed in relation to nutrient variability in the MAB. Values were determined from filtered seawater samples collected on 11 cruises between April 1979 and March 1980. Horizontal distributional maps of nutrient values were generated for the deepest sampling level (bottom water for all stations, except those where station depth exceeded 200 m), and for a weighted mean for the upper quarter of the water column (but not exceeding 30 m depth). Figure 1 depicts the distribution of station locations. Surveys were usually limited to continental shelf waters less than 200 m deep. Two cross-shelf transects fall within the area of concern (Figures 2 and 3). Transect 2 begins at the mouth of Delaware Bay and Transect 3 begins at the mouth of Hudson River estuary, both run southeast. Samples were processed using procedures outlined in Matte et al. (1983).

#### NUTRIENT SPATIAL AND TEMPORAL VARIABILITY

##### Dissolved Inorganic Nitrate

Bottom water nitrate concentrations in the region remained higher than surface concentrations throughout the year except for local influence of estuarine plumes, such as in April 1979, when integrated surface layer concentrations were 5 to 10 times higher than bottom water (Figure 4) at the mouth of the Hudson River estuary. Nitrate concentrations in bottom waters generally increase seaward, with isopleths of nitrate generally paralleling isobaths. Bottom water nitrate concentrations ranged from the limit of detection (cf. Matte et al., 1983) to over 50  $\mu\text{M}$  (micromoles) in the southeast region of the MAB. Values of from 0.1 to 10  $\mu\text{M}$  were more common to the central region of the shelf.

The seasonal location of the 1 and 5  $\mu\text{M}$  nitrate isopleths, which generally paralleled the coast, varied by about 100 km east to west over the year (Figures 2 and 3). Vertical profiles of nitrate concentration along Transects 2 and 3 demonstrated this movement, the expected stratification of the water column during warmer months, and well-mixed uniform conditions in early spring (Figures 5 and 6). The average location of the summer 0.2  $\mu\text{M}$

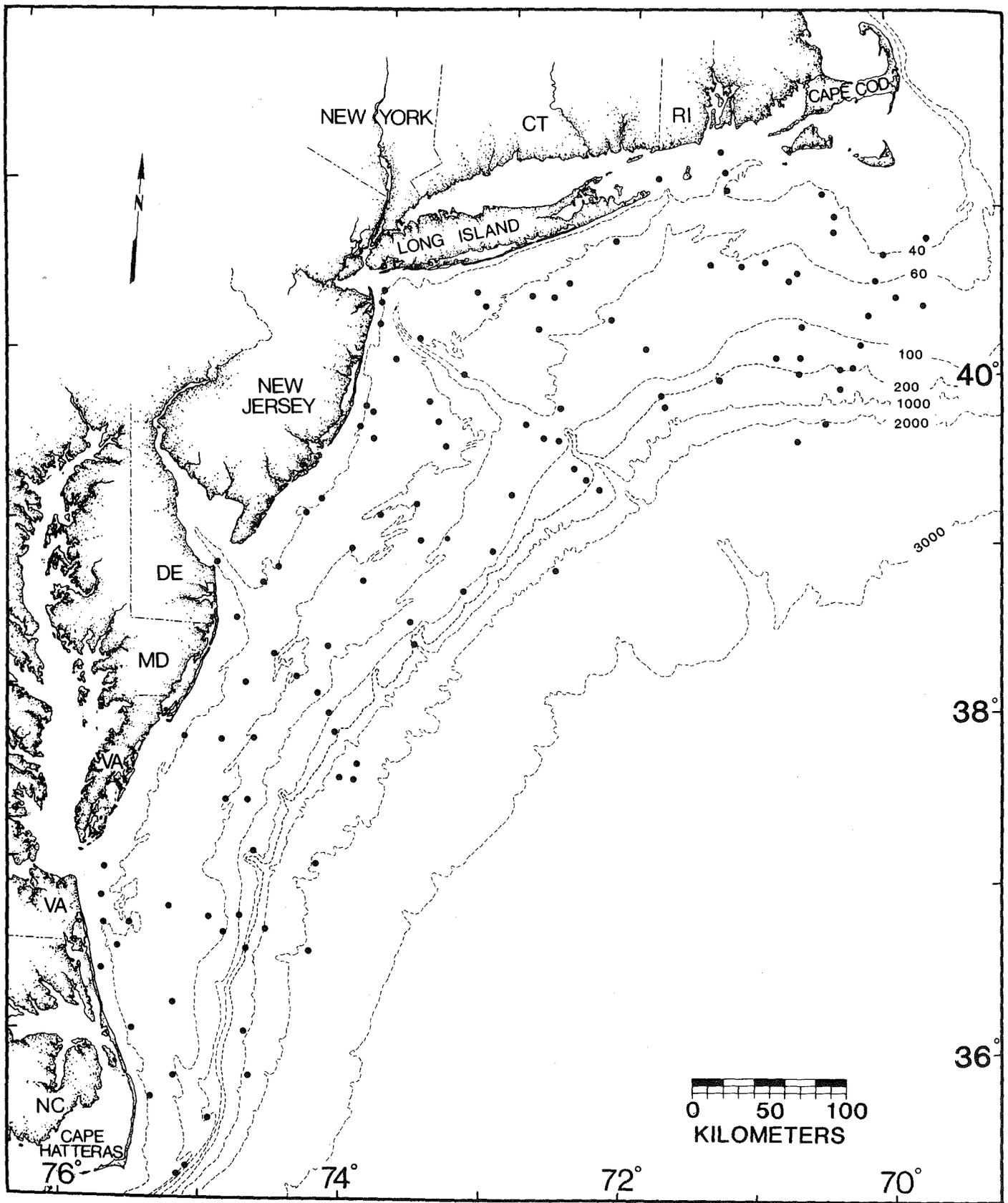


Figure 1. Distribution of station locations sampled between May 1979 and March 1980.

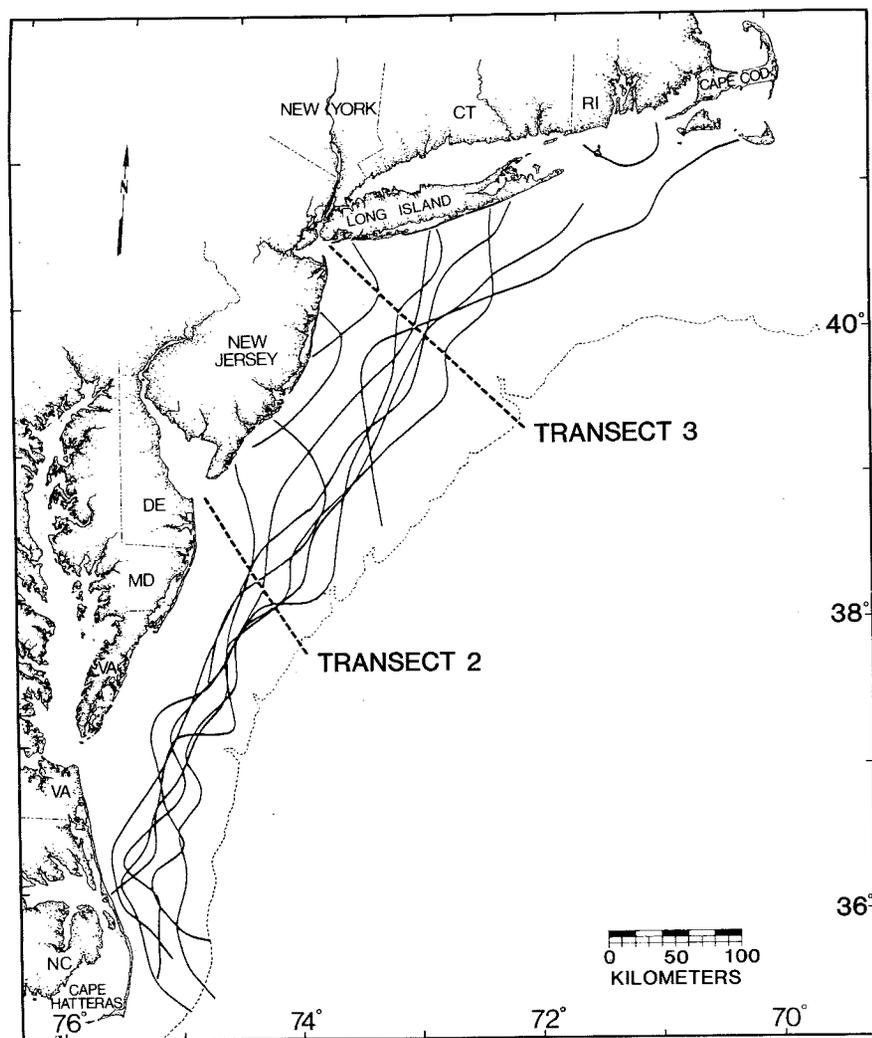


Figure 2. Location of the  $1 \mu\text{M NO}_3$  bottom water contour, April 1979 to March 1980.

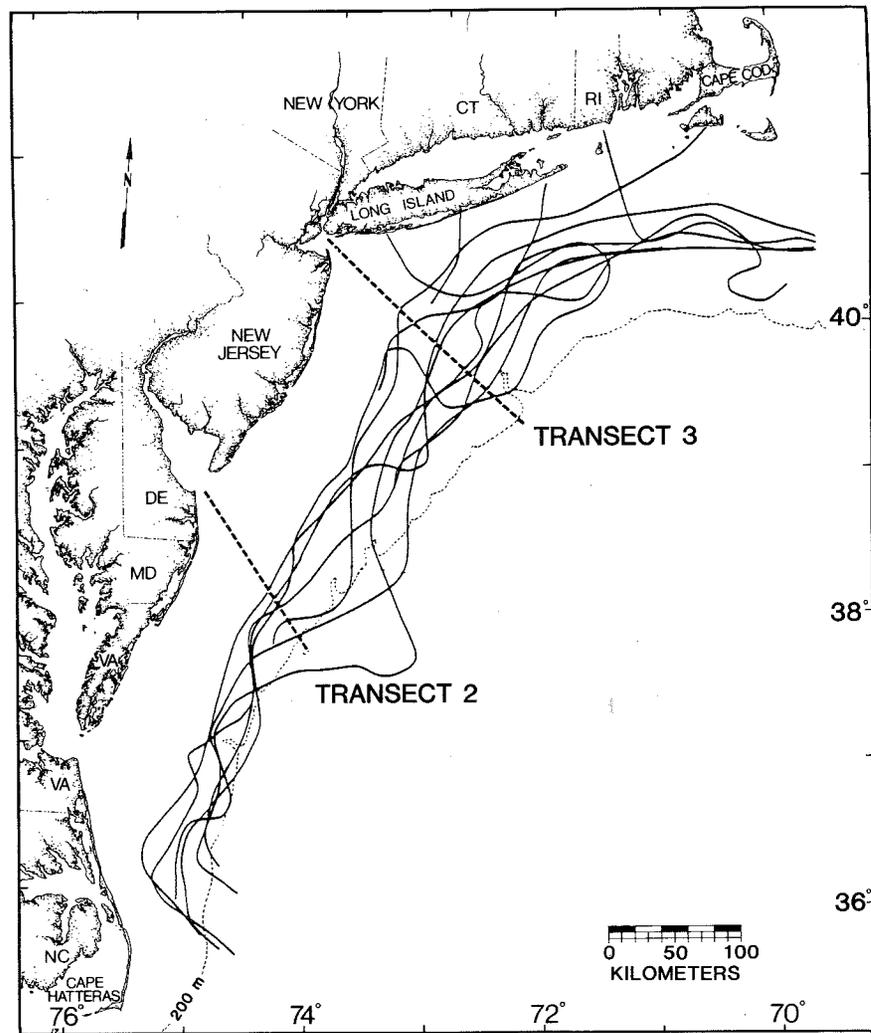


Figure 3. Locations of the  $5 \mu\text{M NO}_3$  bottom water contour, April 1979 to March 1980.

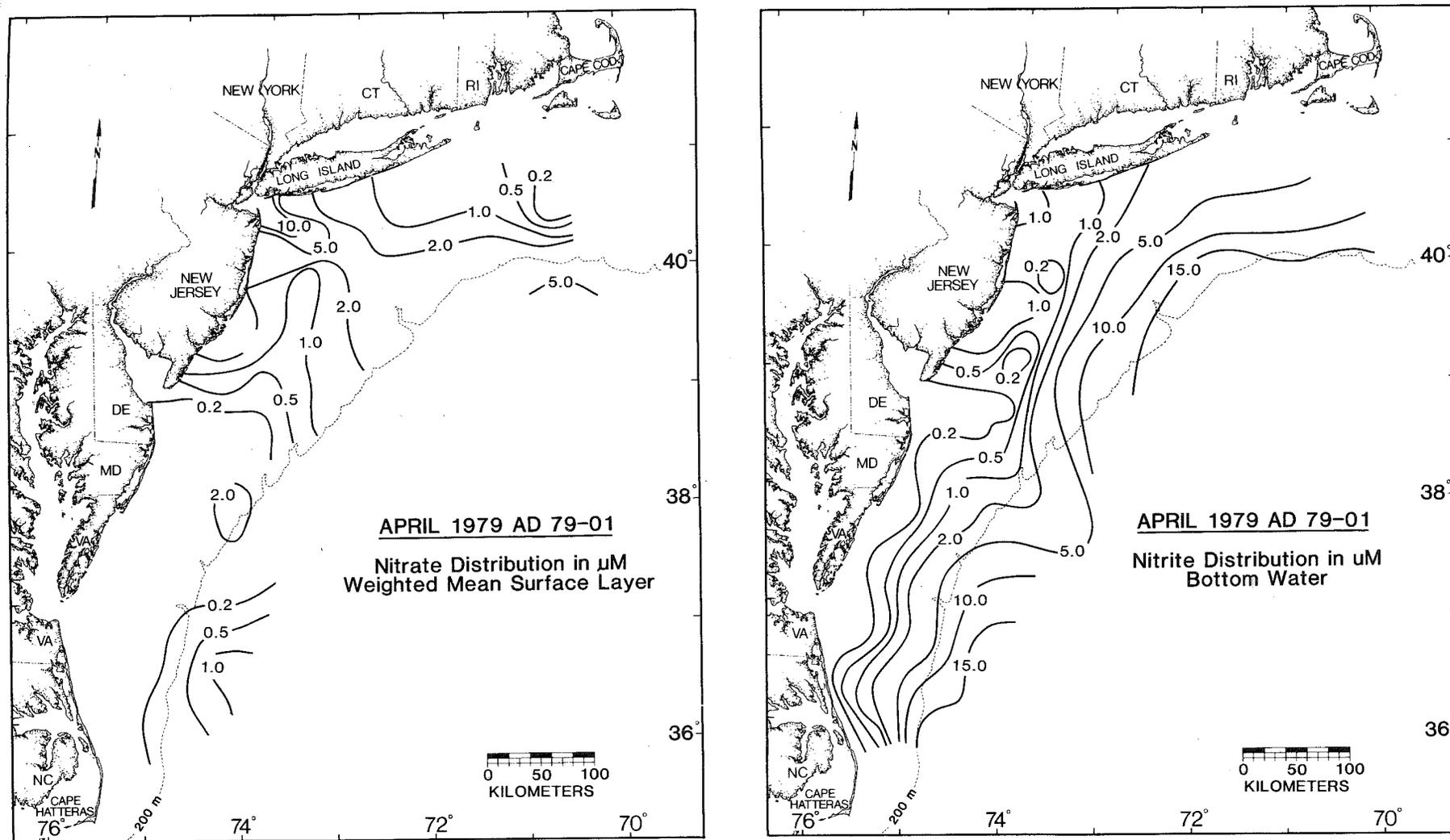


Figure 4. Distribution of dissolved inorganic nitrate in the surface layer and in bottom water in April 1979.

contour line on these profiles generally corresponds with the mean depth of the euphotic zone (O'Reilly et al., 1981) indicating nitrate depletion by phytoplankton in the euphotic zone.

A tongue of nutrient-rich water extending along the bottom and up into the depleted surface layer is indicated in the August 1979 nitrate profile along Transect 2 (Figure 5). This may be evidence of upwelling which can occur during periods of southwesterly winds, and can be responsible for some replenishment of nutrient-depleted surface layers.

Integrated surface layer concentrations of  $\text{NO}_3$  ranged from the limit of detection to 12  $\mu\text{M}$  with values routinely ranging between 0.2 and 2  $\mu\text{M}$ . Highest overall concentrations occurred in the spring and lowest in summer with instances of estuarine influence indicated at the mouths of the Hudson, Delaware, and Chesapeake (Figure 7).

#### Dissolved Inorganic Nitrite

Bottom water nitrite distributions were not as uniform as those of nitrate and did not parallel isobaths as well as nitrate concentrations. Concentrations ranged from the limit of detection to 8.4  $\mu\text{M}$  nitrite in June at a station approximately 250 km southeast of the mouth of the Hudson River estuary. Values of 0.05 to 0.2  $\mu\text{M}$  were more characteristic of the MAB throughout the year. In July a strong gradient from the mouth of the Hudson seaward (2 to 0.05  $\mu\text{M}$  nitrite) was reflected in both bottom and surface layer distributions (Figure 8). Surface layer nitrite values ranged from the detection limit to 0.8  $\mu\text{M}$  with most values falling between 0.05 and 0.2  $\mu\text{M}$ , as in the case of bottom waters. In August there was evidence of a weak gradient in the integrated surface layer extending from the Delaware River seaward which was not strongly reflected in the bottom water nitrite distribution.

#### Ammonium Nitrogen

Ammonium nitrogen concentrations in bottom waters ranged from the detection limit to 9  $\mu\text{M}$  with most observations falling between 0.2 and 1.5  $\mu\text{M}$ . Elevated values were often associated with estuaries or spot sources. A gradient in ammonium nitrogen distribution was associated with the Delaware River estuary during August, September, and October (Figure 9). Gradients associated with the mouth of the Hudson River estuary were also observed in April, September, and October as reported by Waldhauer et al., 1980. Integrated surface layer concentrations ranged from the detection limit to 16.5  $\mu\text{M}$  with most values between 0 and 2  $\mu\text{M}$ .

#### Dissolved Inorganic Phosphate

Bottom water values for phosphate in the MAB were as high as 1.7  $\mu\text{M}$ . Generally, concentrations remained less than 0.6  $\mu\text{M}$  inshore and increased seaward. Surface layer concentrations ranged up to 1.5  $\mu\text{M}$  at the mouth of the Hudson River estuary in October. Most observations throughout the year, however, were between 0.1 and 0.4  $\mu\text{M}$ . Both surface layer and bottom water isopleths were most uniform (i.e., parallel) to the coast in May. Surface layer waters does not exhibit the general increase in concentration seaward as did bottom waters. In October a renewal occurred with reverse; highest phosphate concentrations inshore and decreasing concentrations seaward

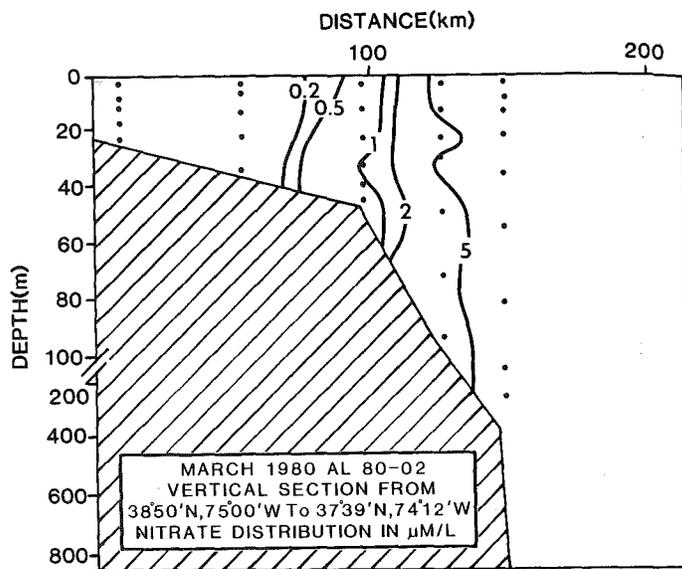
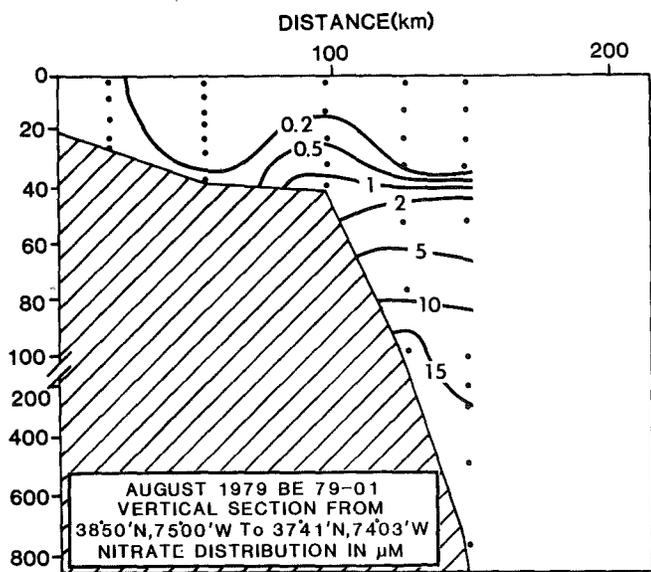


Figure 5. Cross-shelf profile of dissolved inorganic nitrate distribution along Transect 2.

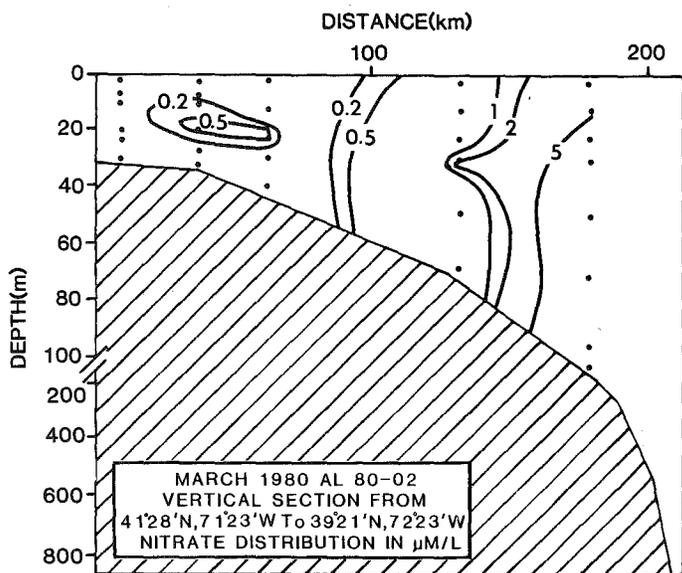
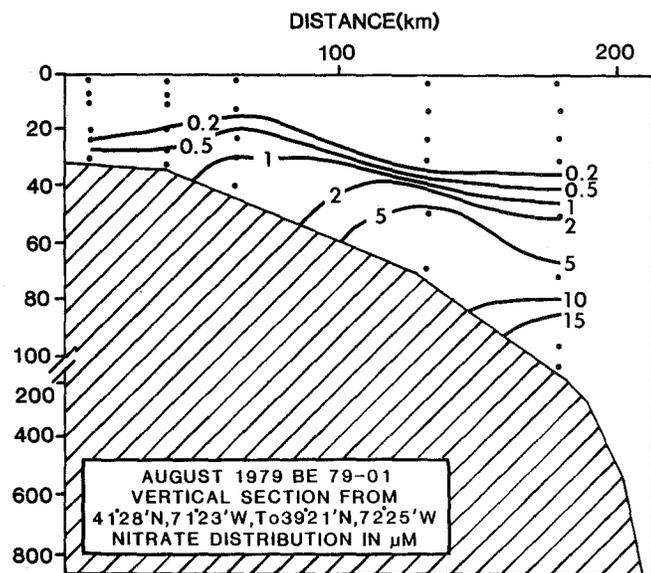


Figure 6. Cross-shelf profile of dissolved inorganic nitrate distribution along Transect 3.

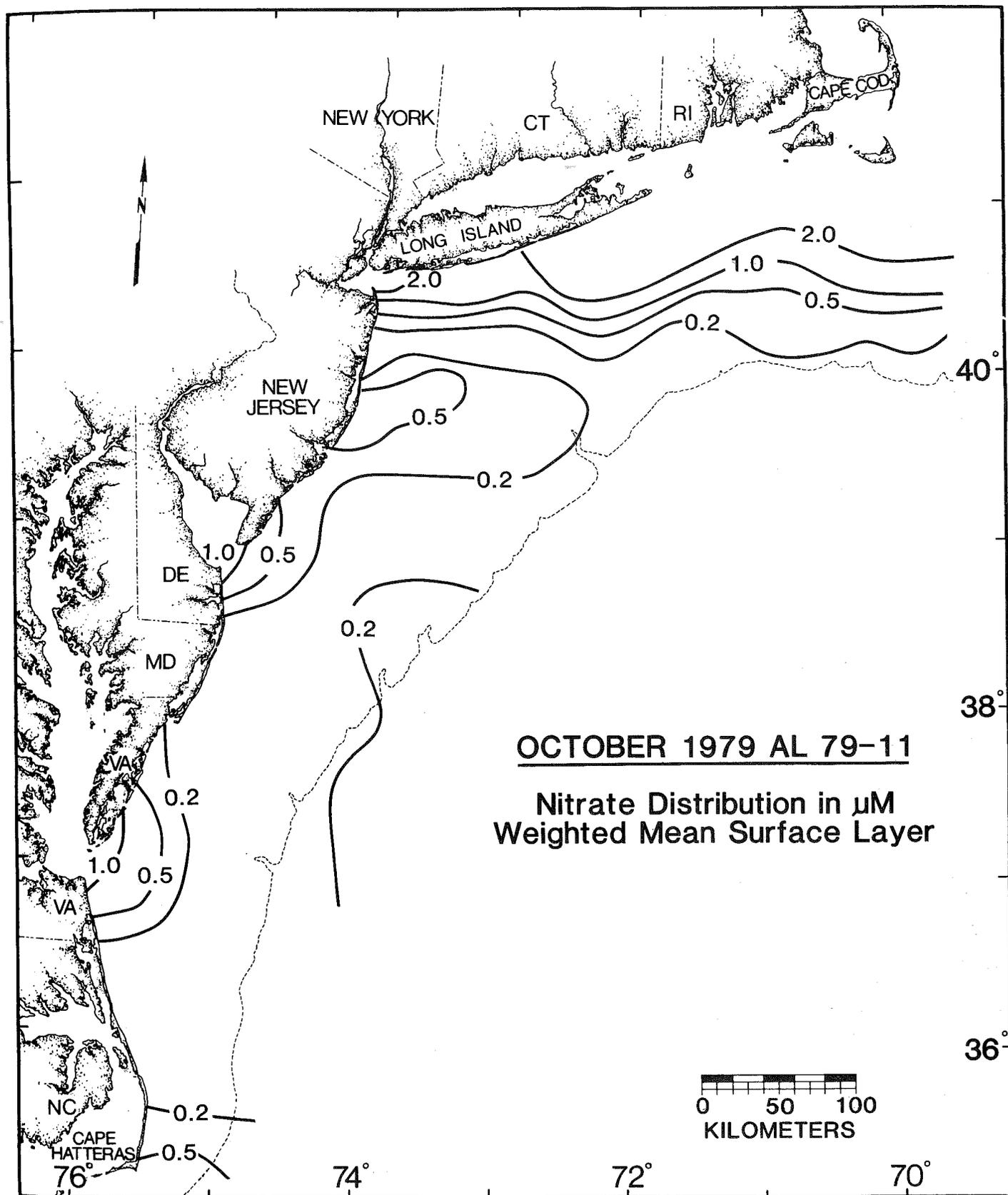


Figure 7. Distribution of dissolved inorganic nitrate in the surface layer, weighted mean, of the Middle Atlantic Bight in October 1979.

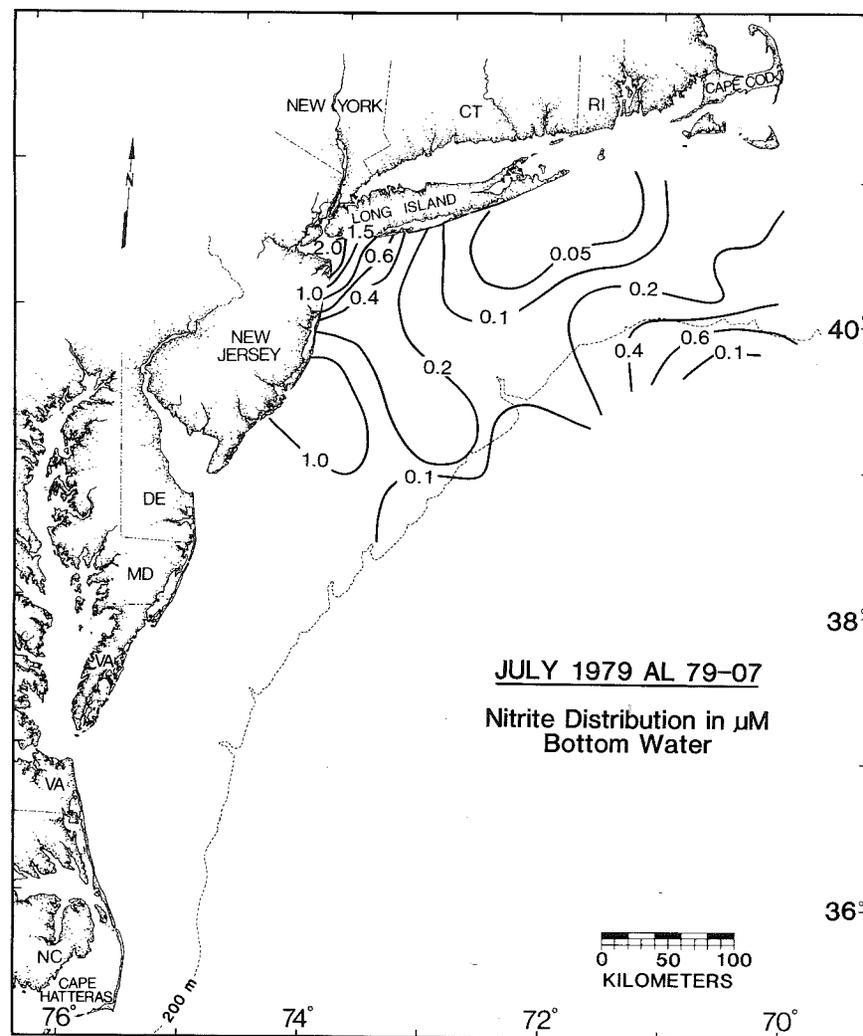
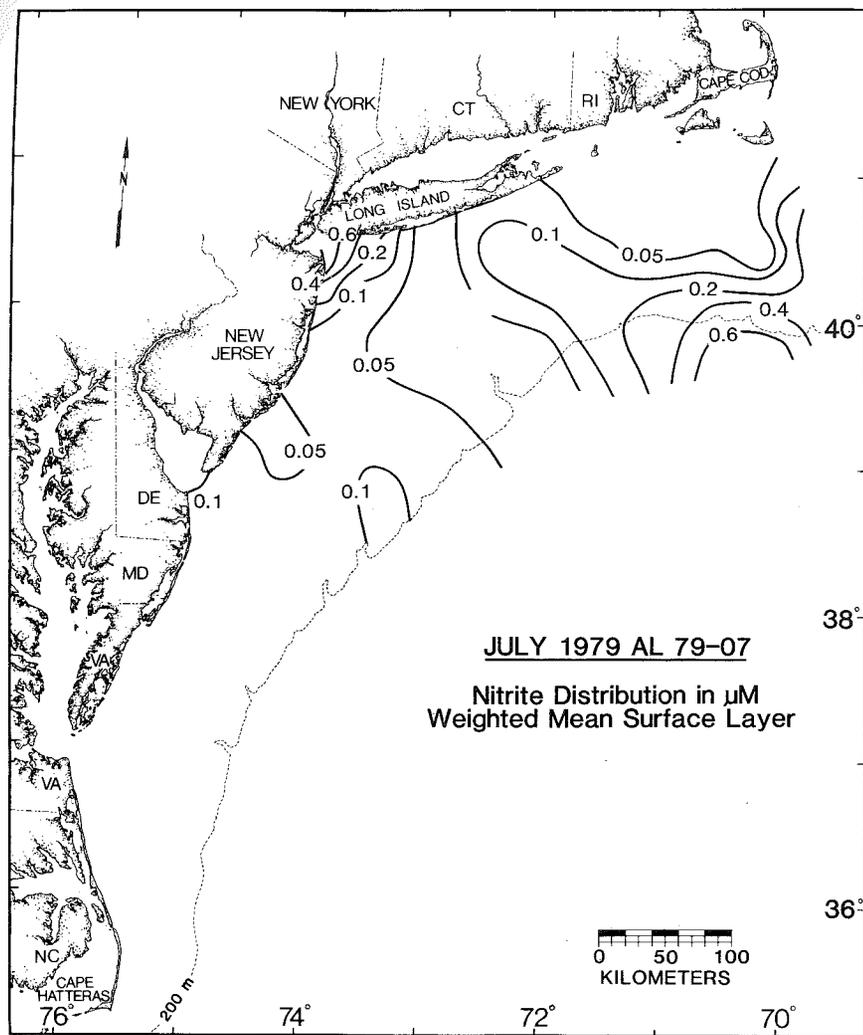


Figure 8. Distribution of dissolved inorganic nitrite in the surface layer, weighted mean, and in bottom water in July 1979.

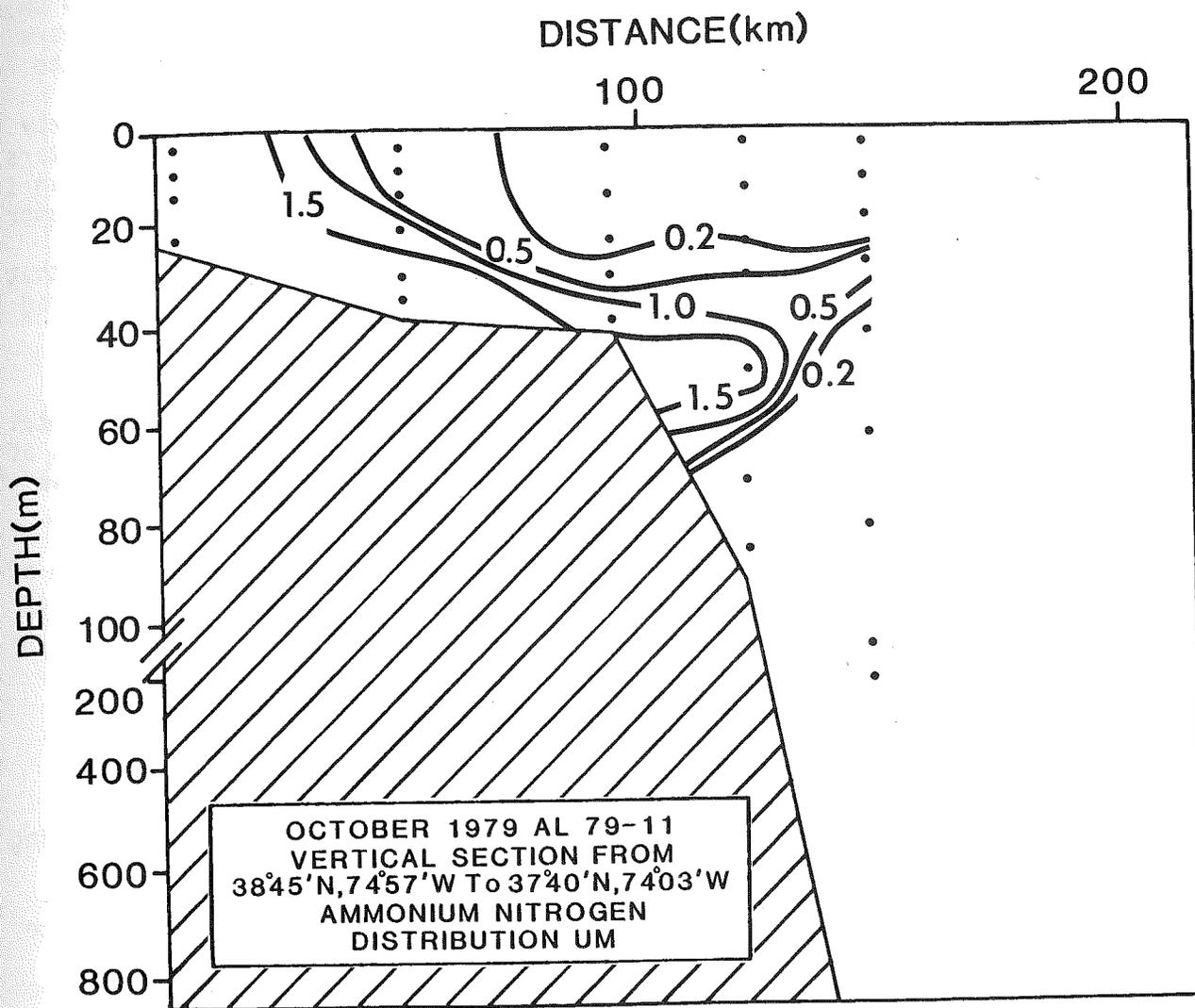


Figure 9. Cross-shelf profile of dissolved ammonium nitrogen along Transect 2, October 1979.

(Figure 10). Vertical profiles along both transects demonstrated expected mixed conditions in March, the onset of stratification in May continuing through September, and the breakup of stratification in October.

### Dissolved Inorganic Silicate

Observed bottom water silicate concentrations ranged from 0.3 to 24.4  $\mu\text{M}$ , with lowest values generally in March, being less than 1  $\mu\text{M}$  in coastal waters and between 1 and 5  $\mu\text{M}$  mid-shelf. Observed year-round bottom water silicate concentrations were typically between 1 and 10  $\mu\text{M}$ . The March silicate distribution, usually indicating a well-mixed water column, was also the only time period without an area of reduced silicate concentration in bottom waters off the mouth of Delaware Bay. Surface layer values of silicate ranged from 1 to 10.5  $\mu\text{M}$ , more typically being between 2 and 5  $\mu\text{M}$  in spring and early summer and less than 1  $\mu\text{M}$  from mid-summer into the fall when increases in overall concentrations were again indicated. Malone et al. (1980) have indicated that the end of the spring phytoplankton bloom in the New York Bight is controlled by this silicate depletion.

It should be kept in mind that surface layer values reported here represent an integrated portion of the water column and smaller areas of total nutrient depletion, particularly in summer months, may be masked. An atlas of nutrient distributions over the continental shelf from Cape Hatteras to Nova Scotia is being prepared by NEFC's Environmental Chemistry Investigation at Sandy Hook. It will contain specific data on which these observations are based, individual figures for each nutrient species, and a longer time span of observations. This source should provide the best available determination of the timing and nature of change in shelf nutrient distributions and relationships to phytoplankton production.

### CONCLUSION

Data indicate the presence of several different processes influencing nutrient distributions and, therefore, primary production in waters of the MAB. The seasonal stratification of the water column is reflected in changing nitrate distributions (Figure 11) with the resultant summer depletion of surface layer nitrate concentrations by phytoplankton. Tongues of nutrient-rich water can be extended along the bottom and up into this depleted surface layer by upwelling, and can cause some replenishment of these nutrient-depleted surface layers during periods of southwesterly winds. Discharge from estuaries can also modify general nutrient distributions locally.

The seasonal variation in the location of 1 and 5  $\mu\text{M}$  bottom water nitrate isopleths further indicates a large temporal variability in nutrients, seemingly slightly less in extent in the southern portion of the MAB than in its northern reaches. Total water column variability seems slightly greater in its southern portion. Total scale of these variations (60 to 100 km) agrees well with the variations in the surface location of the shelf/slope front (50 km around the mean position) found by Gunn (1979) from satellite-derived thermal interpretations of frontal position (Ingham, 1976). From vertical profiles of nitrate distribution along Transects 2 and 3, we can project a zone on the shelf where the 1  $\mu\text{M}$  nitrate isopleth can be expected to be present at some depth in the water column, regardless of season (Figure 12). The scale of this zone (10-20 km) and the shoreward-seaward migrations

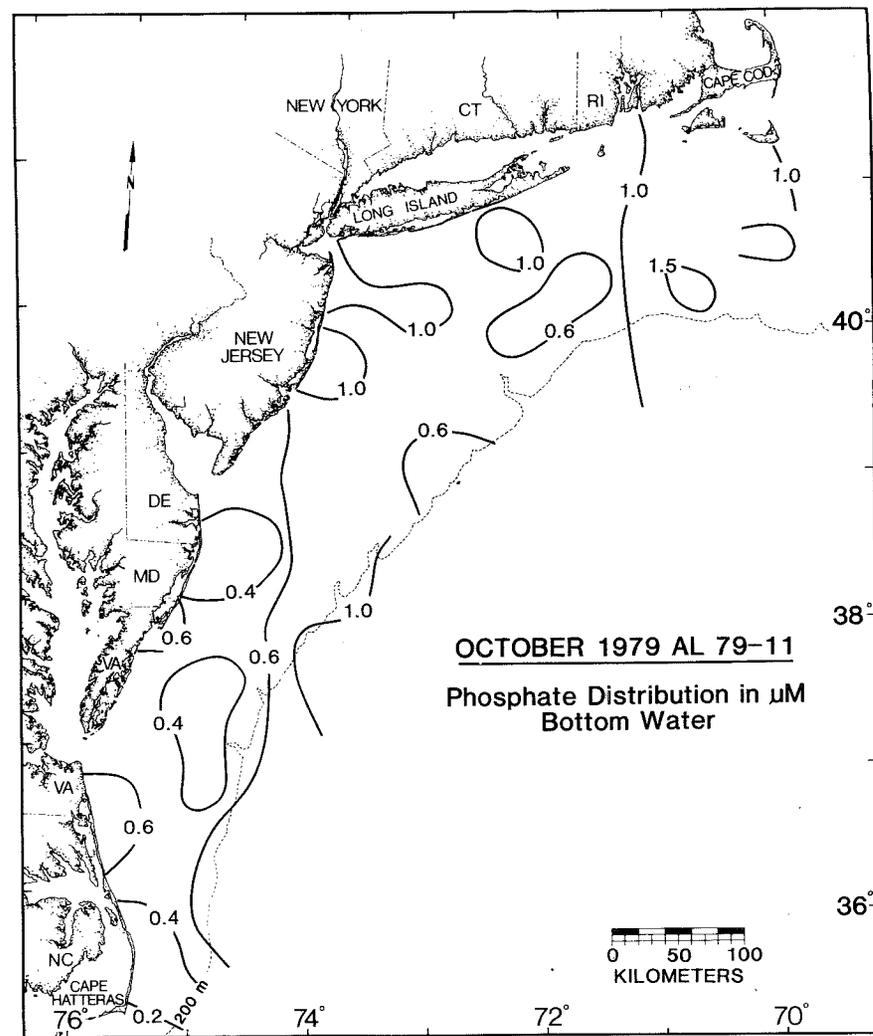
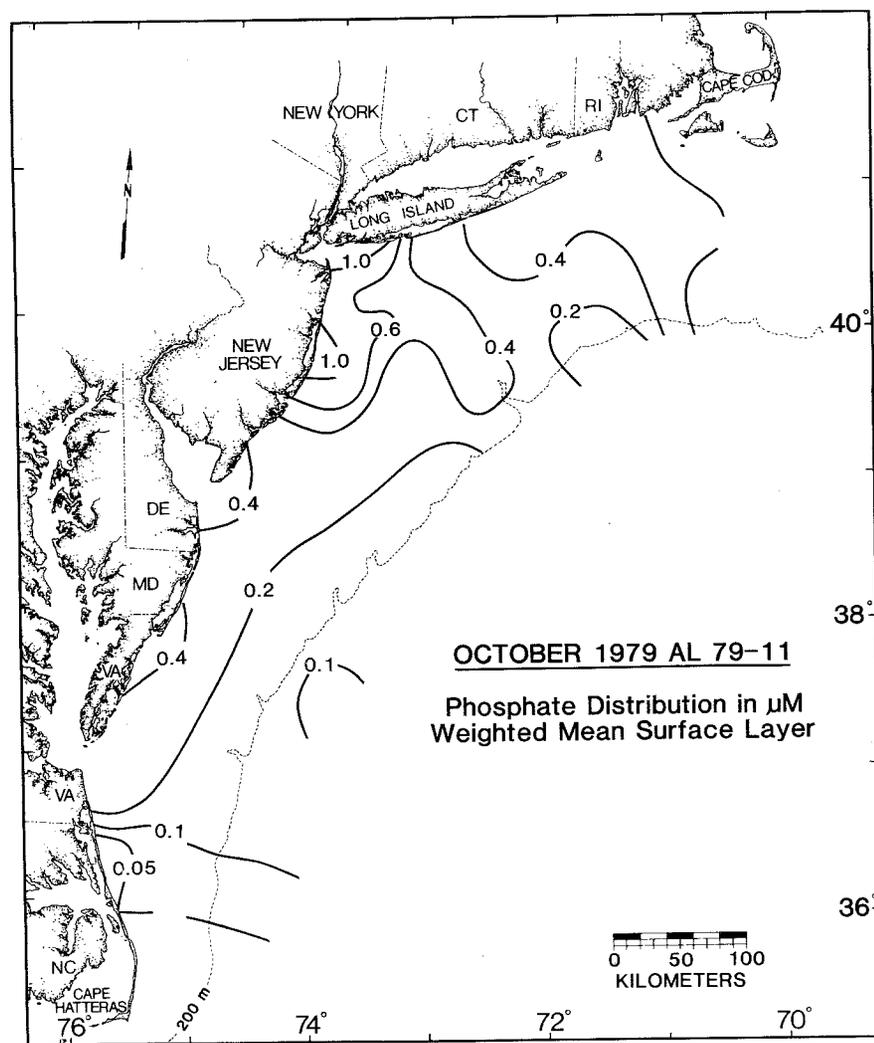
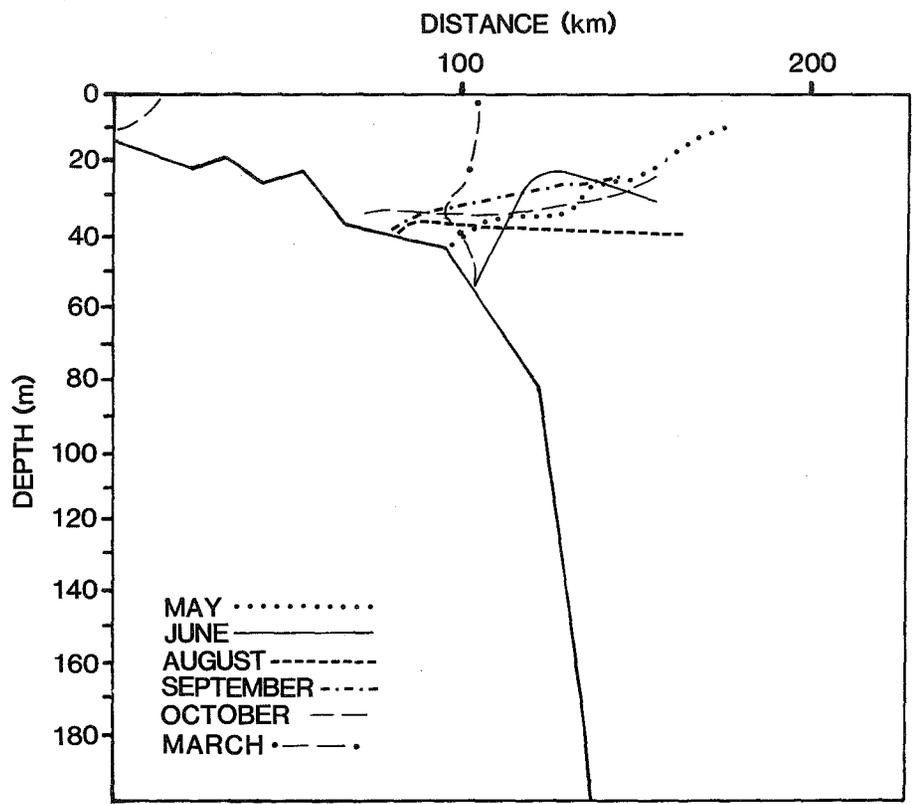
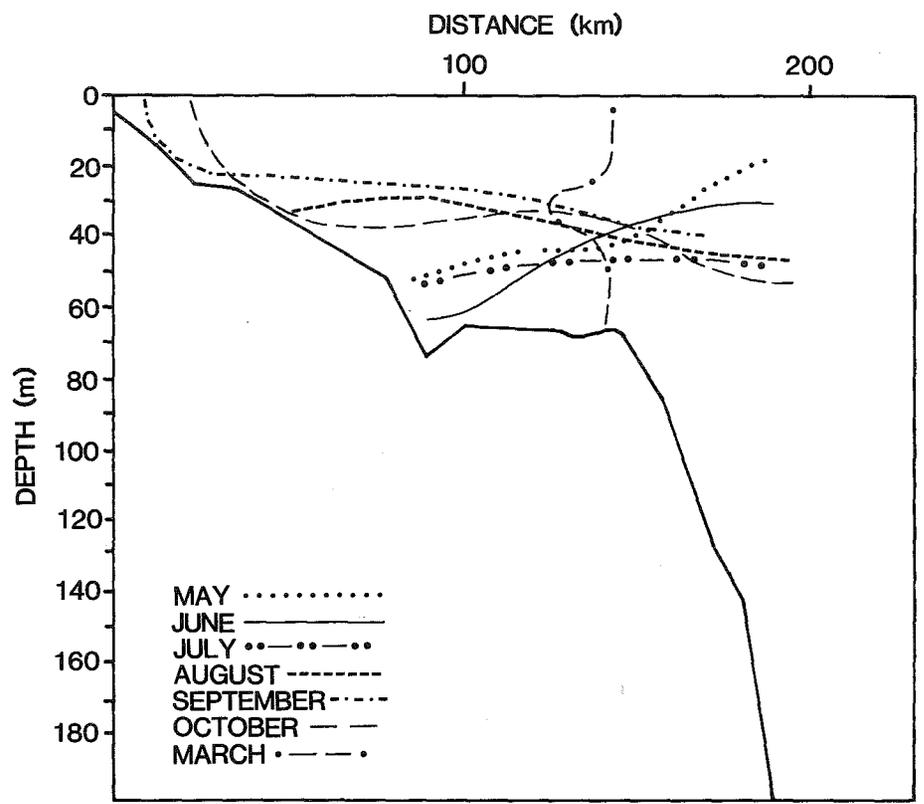


Figure 10. Distribution of dissolved inorganic phosphate in the surface layer, weighted mean, and in bottom water in October 1979.



SEASONAL MOVEMENT OF 1 μM NO<sub>3</sub> CONTOURS  
ALONG TRANSECT 2



SEASONAL MOVEMENT OF 1 μM NO<sub>3</sub> CONTOURS  
ALONG TRANSECT 3

Figure 11. Movement of NO<sub>3</sub> contours

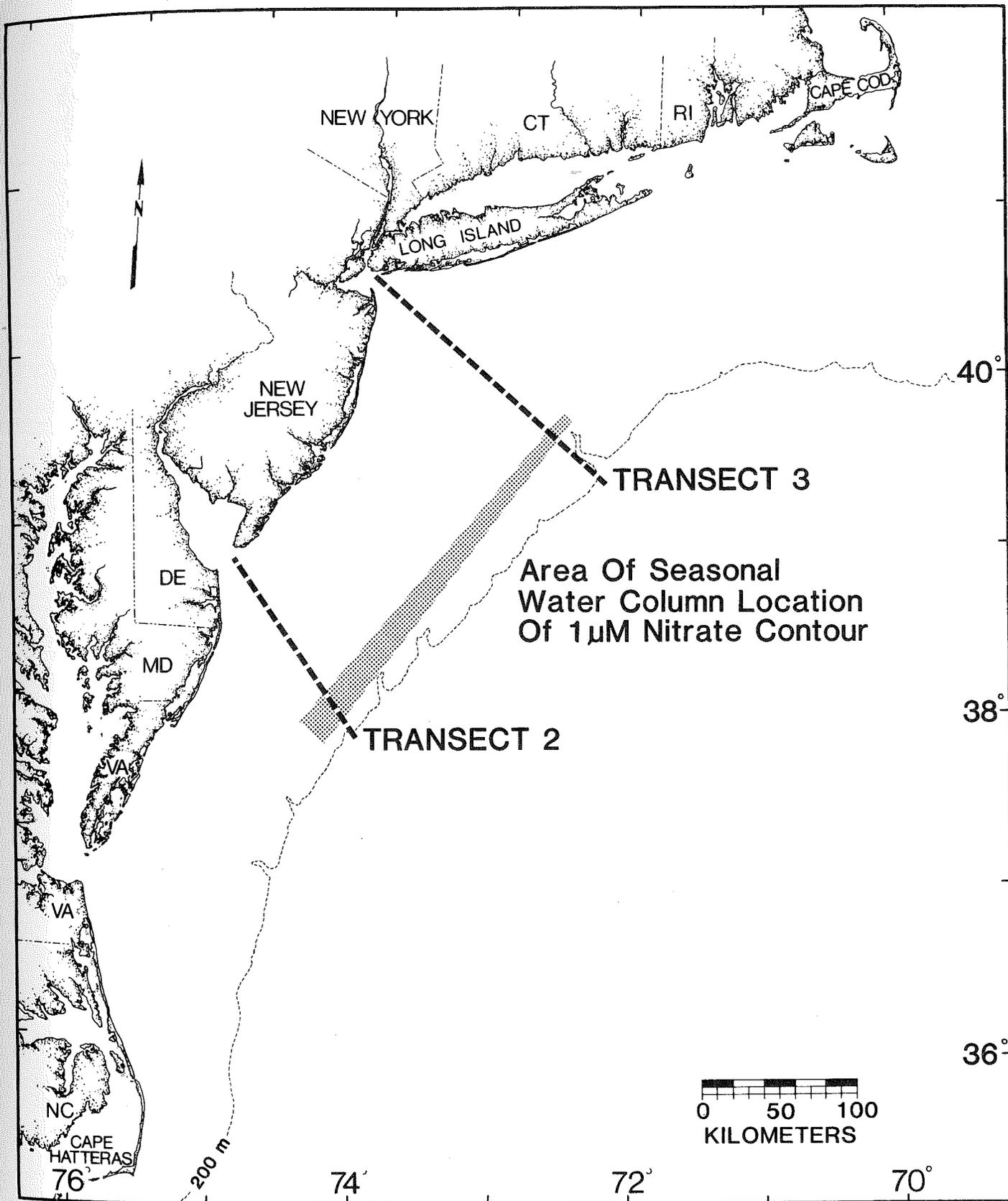


Figure 12. Zone of seasonal location of the 1 $\mu$ M water column nitrate contour.

are characteristic of the scale of movement reported by Wright (1976) for the seasonal change in location of the average bottom water position of the shelf/slope front. Frontal influences are therefore indicated in the nutrient data and it appears that bottom waters on the shelf are strongly influenced by cross-shelf transport of slope water rich in nutrients.

Relatively high levels of primary productivity are sustained shelf-wide throughout the summer despite the formation of a nutrient-depleted surface layer (O'Reilly and Busch, 1984). Stratification of the water column at this time of year can be expected to greatly reduce supply from nutrient-rich bottom waters and replenishment of nutrient-depleted surface layers. Nutrient regeneration by zooplankton, fish, and/or bacteria in the upper water column, at this time, may therefore be the crucial process for the maintenance of phytoplankton stocks and productivity rates in the region resulting in a prevalence of "old" production. Walsh (1981) has suggested that 46% of the New York Bight annual primary production nitrogen demand may be supplied by recycling, indicating a closer association between shelf pelagic and demersal food webs than those of some other shelf ecosystems. Significant production also takes place deeper in the subsurface chlorophyll maximum layer next to the thermocline where chlorophyll concentrations may be 2 to 10 times greater than at the surface (O'Reilly, Zetlin, and Busch, 1987). Nutrient availability here is probably greater than in surface waters. While available light at the thermocline is limited, it is still adequate for growth, its relative limiting effect being offset, to an extent, by phytoplankton abundance and nutrient availability. At other times of the year and in the case of upwelling and onshore movement of nutrient-rich waters, water mass transport may be the dominant factor in regulating primary production and determining the quantities of nutrients available for assimilation by phytoplankton. Walsh et al. (1978) have, in fact, observed a doubling of phytoplankton standing crop as a response to storm-initiated nutrient injection at the shelf slope break. They have postulated that storm-induced mixing and upwelling of nitrate may satisfy at least 30 percent of the productivity demand of the New York Bight system.

Such nutrient limitation or stimulation of phytoplankton populations can be expected to have significant effects up the food chain, as well as in critical summer situations when a population explosion of a specific phytoplankton species can contribute to an anoxic event with associated drastic alteration and marine life mortality (Swanson and Sindermann, 1984).

#### SUMMARY

Nutrient distributions in the MAB exhibit a high degree of spatial and temporal variability. They are characterized by a seasonal cycle with a summer stratified water column producing a surface layer, extending to the depth of the mean euphotic zone, depleted of nutrients by phytoplankton activity. Primary production rates, however, remain high because of rapid nutrient recycling in the upper water column and high phytoplankton biomass and photosynthetic phytoplankton activity in the area of the nutricline. Fall breakup of stratified conditions results in a vertically well-mixed water column throughout winter and spring months, and makes possible the resupply of nutrient-rich waters to the upper light receiving and active layers of the water column. In general, nutrient concentrations in bottom waters are higher than in surface layers. Inshore waters undergo relatively larger changes in

concentration than bottom waters over the eastern extent of the shelf. Offshore bottom waters tend to have high nutrient concentrations year-round reflecting their proximity to nutrient-rich continental slope waters. Nitrate distributions, in particular, show a general increase seaward year-round. Slope waters rich in nutrients are an ever-present reservoir of nitrogen which can replace nitrogen utilized and/or lost from inshore waters. Cross shelf transport of this water, upwelling, and estuarine discharge influence the distribution of specific nutrient species, with resultant effects on productivity, energy transfers to higher trophic levels, and fishery production.

#### REFERENCES

- Gunn, J. T. 1979. Variation in the shelf water front position in 1977 from Georges Bank to Cape Romain. *Annls. Biol. Copenh.* 34: 36-39.
- Ingham, M. C. 1976. Variations in the shelf water front off the Atlantic coast between Cape Hatteras and Georges Bank. pp. 17-1-17-21. In: J. R. Goulet, Jr. (compiler). NOAA/NMFS MARMAP Contribution 104.
- Malone, T. c., G. Garside and P. J. Neals. 1980. Effects of silicate depletion on photosynthesis by diatoms in the plume of the Hudson river. *Mar. Biol.* 58: 197-204.
- Matte, A., R. Waldhauer, J. E. O'Reilly and A. F. J. Draxler. 1983. Quality assurance: Inorganic nutrients. NMFS, NEFC, Sandy Hook Laboratory Report No. 83-13.
- O'Reilly, J. E. and D. A. Busch. 1984. Phytoplankton primary production (netplankton, nannoplankton and release of dissolved organic carbon) on the northwestern Atlantic shelf. *Rapp. P.-v. Reun. Cons. int. Explor. Mer*, 1983: 255-268.
- O'Reilly, J. E., C. Evans-Zetlin and J. P. Thomas. 1981. The relationship between surface and average water column concentrations of chlorophyll a in northwestern Atlantic shelf water. *ICES, C.M.* 1981/L: 17.
- O'Reilly, J. E., C. Zetlin and D. A. Busch. 1987. Primary productivity. pp. 220-233. In: Georges Bank. R. H. Backus and D. W. Bourne (eds.). MIT Press, 593 pp.
- Sutcliffe, W. H., Jr., R. H. Loucks, K. F. Drinkwater and A. R. Coote. 1983. Nutrient flux onto the Labrador Shelf from Hudson Strait and its biological consequences. *Can. J. Fish. Aquat. Sci.* 40: 1692-1701.
- Swanson, R. L. and C. J. Sindermann. 1979. Oxygen depletion and associated benthic mortalities in New York Bight, 1976. U.S. Dept. of Commerce, NOAA Professional Paper 11.
- Wafer, M. V. M., P. LeCorre and J. L. Birrien. 1983. Nutrients and primary production in permanently well-mixed temperate coastal waters. *Estuarine Coastal and Shelf Science* 17: 431-446.

- Waldhauer, R., A. Matte, A. F. J. Draxler and J. E. O'Reilly. 1980. Seasonal ammonium-nitrogen distributions across the New York Bight shelf. In: Water Conference Proceedings of the Water Conference held at Ramapo College of New Jersey, May 1 and 2, 1980. Ciaccio, L. L. and A. Cantelmo (eds.). [1983].
- Walsh, J. J. 1981. Shelf-Sea Ecosystems. pp. 159-196. In: Analysis of Marine Ecosystems. A. R. Longhurst (ed.). Academic Press.
- Walsh, J. J., T. E. Whitledge, F. W. Barvenik, C. D. Wirick, S. O. Howe, W. E. Essaias and J. T. Scott. 1978. Wind events and food chain dynamics within the New York Bight. *Limnology and Oceanography* 23: 659-683.
- Wright, W. R. 1976. The limits of shelf water south of Cape Cod, 1941 to 1972. *Journal of Marine Research* 34(1).

# Phytoplankton Abundance and Community Size Composition in the Middle Atlantic Bight

by

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## INTRODUCTION

As the base of the marine food chain, phytoplankton are important in shelf productivity. Their importance is particularly notable when examining their relationship with species important to man. Report of phytoplankton and its importance in the nutrition and survival of higher trophic levels are numerous. As early as 1914 Hjort proposed a relationship between the timing of spring bloom, the spawning of Norwegian spring-spawning herring and the success of year-class recruitment (May, 1974). Zooplankton in the St. Lawrence Estuary, particularly herbivorous copepods, is a critical link in the food web "between phytoplankton and larger animals of economic importance" (Steven, 1975). On the Labrador Shelf nutrient availability affects primary production which in turn affects the food chain development from phytoplankton to zooplankton to small fish to cod (Sutcliffe, et al., 1983). On Georges Bank the high level of fish production is, in part, traceable to the high level of primary production (Cohen and Grosslein, 1987). In some areas the ratio of phytoplankton production to fish production is used to estimate size of fish stock which can be related to fish catch to determine the percentage of the community taken through fishing (Steven, 1975). Studies on the west coast of the United States report the importance of phytoplankton to the northern anchovy. The dinoflagellate Gymnodinium splendens is a nutritionally important food source for first feeding northern anchovy larvae and the success of the year class may be partly dependent upon the availability of this organism or other nutritionally comparable dino-flagellates (Lasker 1981, 1978, 1975). Moffatt (1981) found that northern anchovy larvae grown on low zooplankton densities are able to survive and grow in the presence of a dense Chlorella bloom and suggested that the algae provided additional nutrition needed for larval survival and growth.

Abundance of zooplankton which are food for larvae or fish can be affected by phytoplankton availability. Most marine fish larvae feed on young stages of copepods (Hunter, 1981) and copepods feed on phytoplankton. In the Norwegian Sea the number of copepods and nauplii increased as "spring bloom" developed and "the copepods became so numerous that the increase in phytoplankton population undoubtedly was checked because of grazing" (Sverdrup, 1955). In the Davis Strait and the Labrador Sea, Huntly et al. (1983) concluded increases in zooplankton biomass resulted from consumption of

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"spring bloom". In the North Sea and northeast Atlantic herbivore (except for *Calanus*) and phytoplankton abundance were strongly correlated and herbivorous plankton appeared more strongly regulated by food than predation (Koslow, 1983).

The purpose of this report is to characterize the phytoplankton communities in continental shelf and slope water in the Middle Atlantic Bight. The characterization of this area is based on chlorophyll a measurements, an index of phytoplankton biomass, made during 54 Northeast Fisheries Center surveys. Phytoplankton chlorophyll a and community size composition are examined. Phytoplankton are categorized as netplankton (>20  $\mu$ m) and nanoplankton (<20  $\mu$ m) size fractions. Knowledge of the phytoplankton community size structure is "as important and probably more significant than total chlorophyll a in determining modes of transfer between trophic levels" (Steele and Frost, 1976).

Chlorophyll a distribution is described for five regions delineated by their bathymetry. They are designated as 1, 2, 3, 4, and 5 and represent the shelf slope between 0-20, 20-40, 40-60, 60-200, and 200-2000 m respectively (Fig. 1).

#### METHODS

Data on phytoplankton pigments included were collected on 54 cruises from October 1977 through March 1982 as part of an extensive ongoing monitoring and assessment program designed to characterize the principal biological components of the fisheries of the northwest Atlantic continental shelf from Cape Hatteras to Nova Scotia. Generally, at each sampling location, water for pigment analysis was collected from standard depths of 1, 5, 10, 15, 20, 25, 30, 35, 50 and 75 m or bottom, whichever came first. After spring 1980, a 100 m sampling depth was routinely sampled. Aboard the research vessel samples were size-fractionated into netplankton (>20  $\mu$ m) and nanoplankton (<20  $\mu$ m) and analyzed for chlorophyll a using the fluorometric method described in Evans and O'Reilly (1983). The chlorophyll a concentration in the two size fractions was added to generate an estimate of the total chlorophyll a found at each depth sampled. The depth-weighted average chlorophyll a for the water column was calculated for each station sampled and contoured.

To describe the general features of the annual cycle of chlorophyll a and size composition, data were pooled and averaged by month. The total amount of chlorophyll a found in the water column for each region as well as the percentage of total chlorophyll a ( $\text{mg}/\text{m}^3$ ) in the nanoplankton size-fractions were graphed by month. The percentage of the total community chlorophyll a contributed by nanoplankton, the smaller phytoplankton, was determined by dividing chlorophyll a measured in the nanoplankton size fraction by total chlorophyll a. The coefficient of variability (CV) (standard deviation  $\times$  100) was calculated for each bathymetric region. (January data for Regions 3 and 5 are excluded from statistical summaries because the number of samples was small).

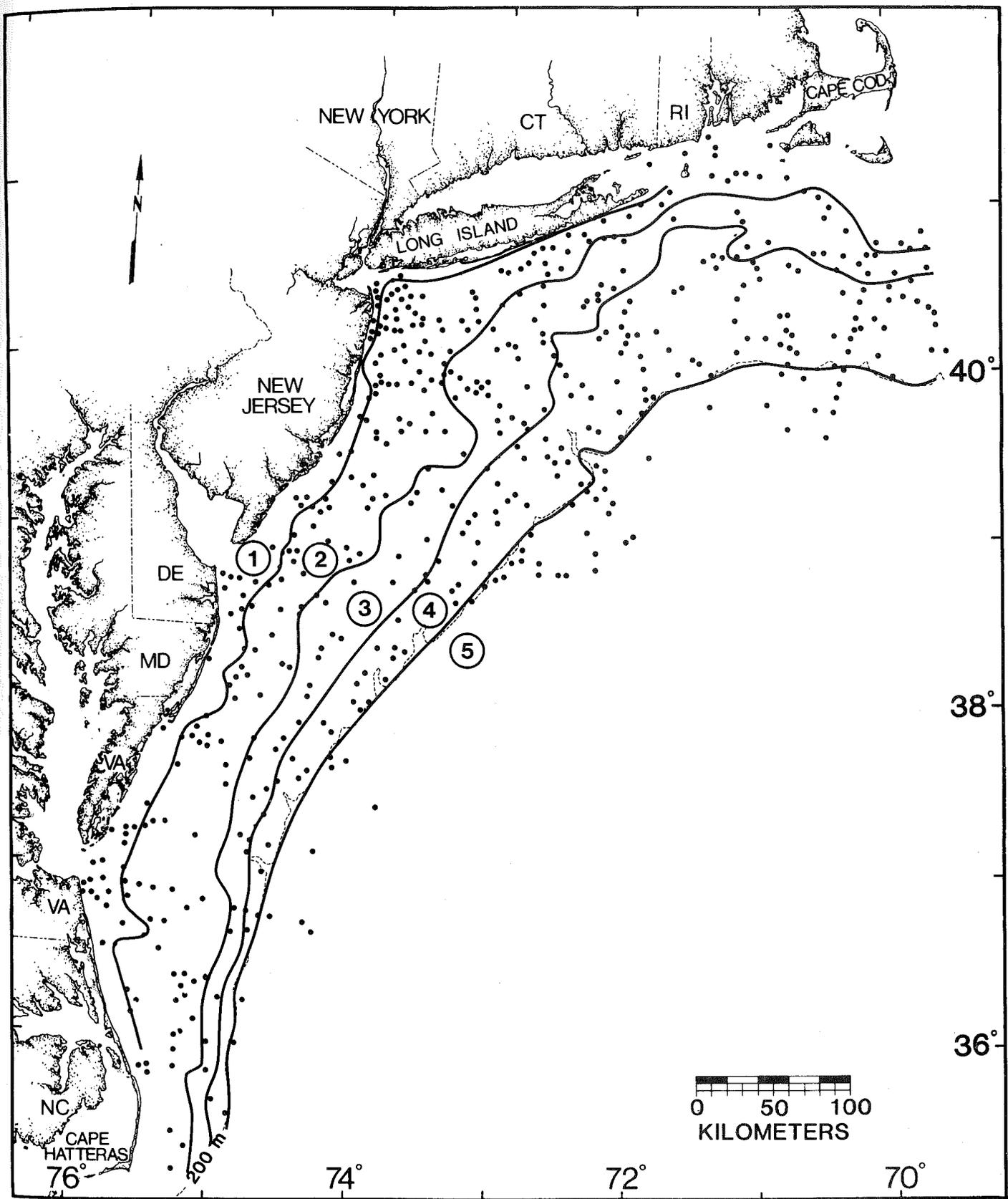


Figure 1. Sampling locations and regions defined by bathymetry.

## RESULTS

### Region 1 (0-20 m)

Distribution of chlorophyll a over the generalized annual cycles was bimodal. The highest concentrations (7.44-7.23 mg/m<sup>3</sup>) were found during the January-February period in the unstratified season. Broad secondary peaks were observed during September (4.97 mg/m<sup>3</sup>) and during fall bloom on November and December (4.78 and 4.34 mg/m<sup>3</sup>, respectively). Generally, chlorophyll a concentrations exceeded 3.00 mg/m<sup>3</sup> except during months when stratification was present (May, June, and July) when the lowest values 1.75, 2.76, and 2.74 mg/m<sup>3</sup> were observed. Chlorophyll a concentrations clearly reached their low point in the annual cycle in May (Figs. 2, 3; Table 1).

Netplankton dominated the communities throughout most of the year. They accounted for 71% of the standing stock during the February spring bloom and for between 55 and 62% of the standing stocks the remainder of the year except during May, June, July, and September when nanoplankton became dominant and accounted for 51-67% of the community chlorophyll a. In general, netplankton dominated during the unstratified season; strongly in February, weakly the remainder of the season. Nanoplankton dominated the stratified season. Netplankton accounted for 54% of the annual chlorophyll a and were dominant eight of 12 months.

Chlorophyll a concentrations in Region 1 were consistently higher than those in all other regions throughout the year (Figs. 2, 3). The lowest concentration (1.75 mg/m<sup>3</sup>) observed in this region was higher than the maximum (1.43 mg/m<sup>3</sup>) observed during spring bloom in Region 5 and was close to the maximum (2.12) observed in Region 4.

### Region 2 (20-40 m)

The generalized annual cycle of chlorophyll a in Region 2 follows the general bimodal pattern seen throughout the shelf. Averaged chlorophyll a concentrations were highest (3.84 mg/m<sup>3</sup>) during the February "spring bloom". During the secondary November to December fall bloom, concentrations averaged 2.96 and 3.38 mg/m<sup>3</sup>, respectively. A relatively high chlorophyll a concentration also occurred in August (2.10 mg/m<sup>3</sup>). Chlorophyll a concentrations were relatively low during late spring and summer months of April, May, June, and July, averaging 1.46, 1.05, 1.34, and 1.56 mg/m<sup>3</sup>, respectively (Table 1.).

As in Region 1, netplankton were responsible for over 50% of the total annual chlorophyll a. They dominated seven of the 12 months, accounting for 58% of the annual chlorophyll a, and, as in Region 1, were slightly dominant over nanoplankton annually. Spring (February), fall (November-December), and late summer (August) maxima were all dominated by netplankton. As with Region 1, netplankton were strongly dominant during the February spring bloom, accounting for 77% of the chlorophyll a. During the November-December fall bloom, netplankton and nanoplankton, accounting for 54 and 60% of the chlorophyll a, respectively. Both February and November-December peaks were associated with the unstratified season.

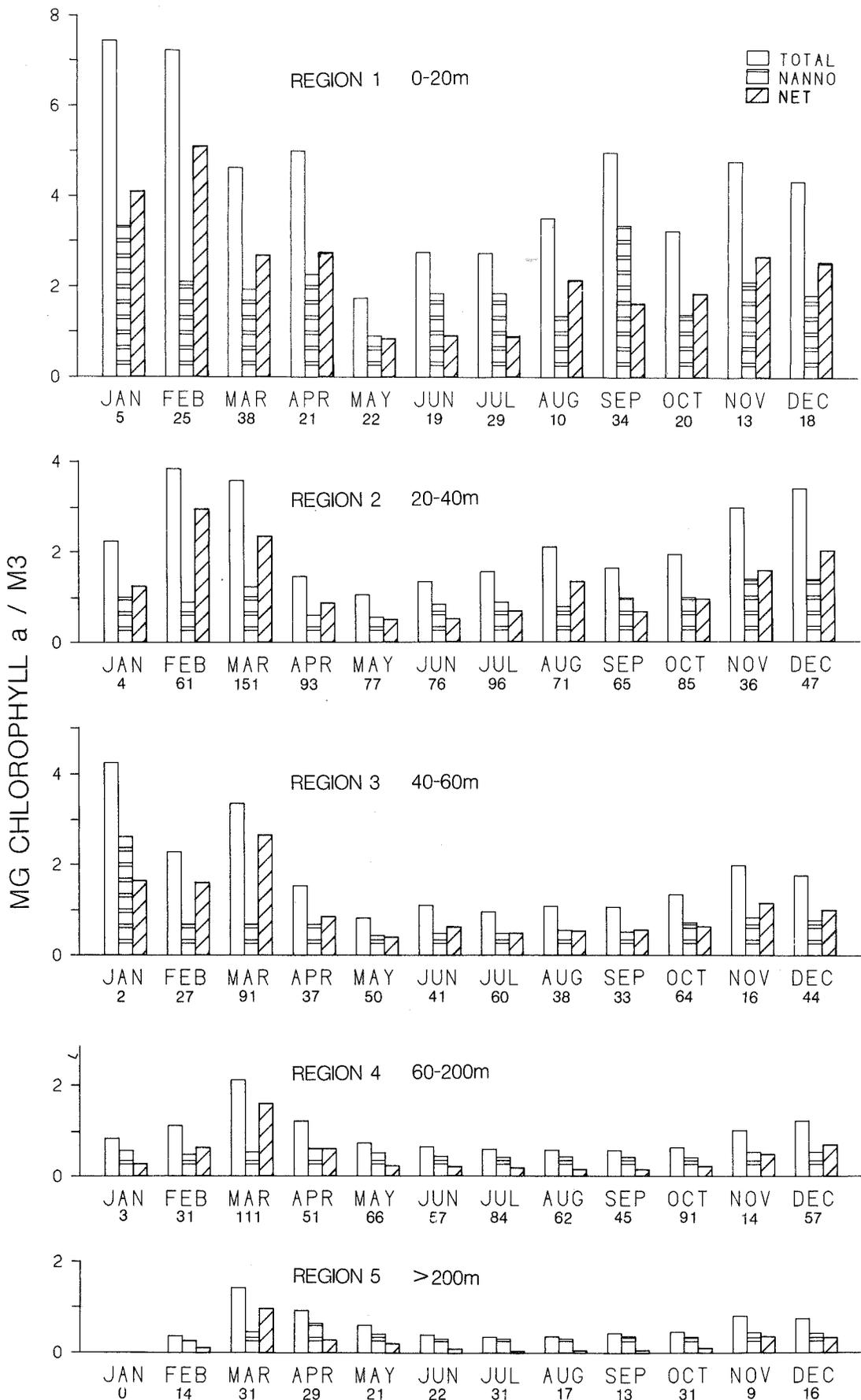


Figure 2. Average monthly chlorophyll a in five bathymetrically defined regions of the Middle Atlantic Bight.

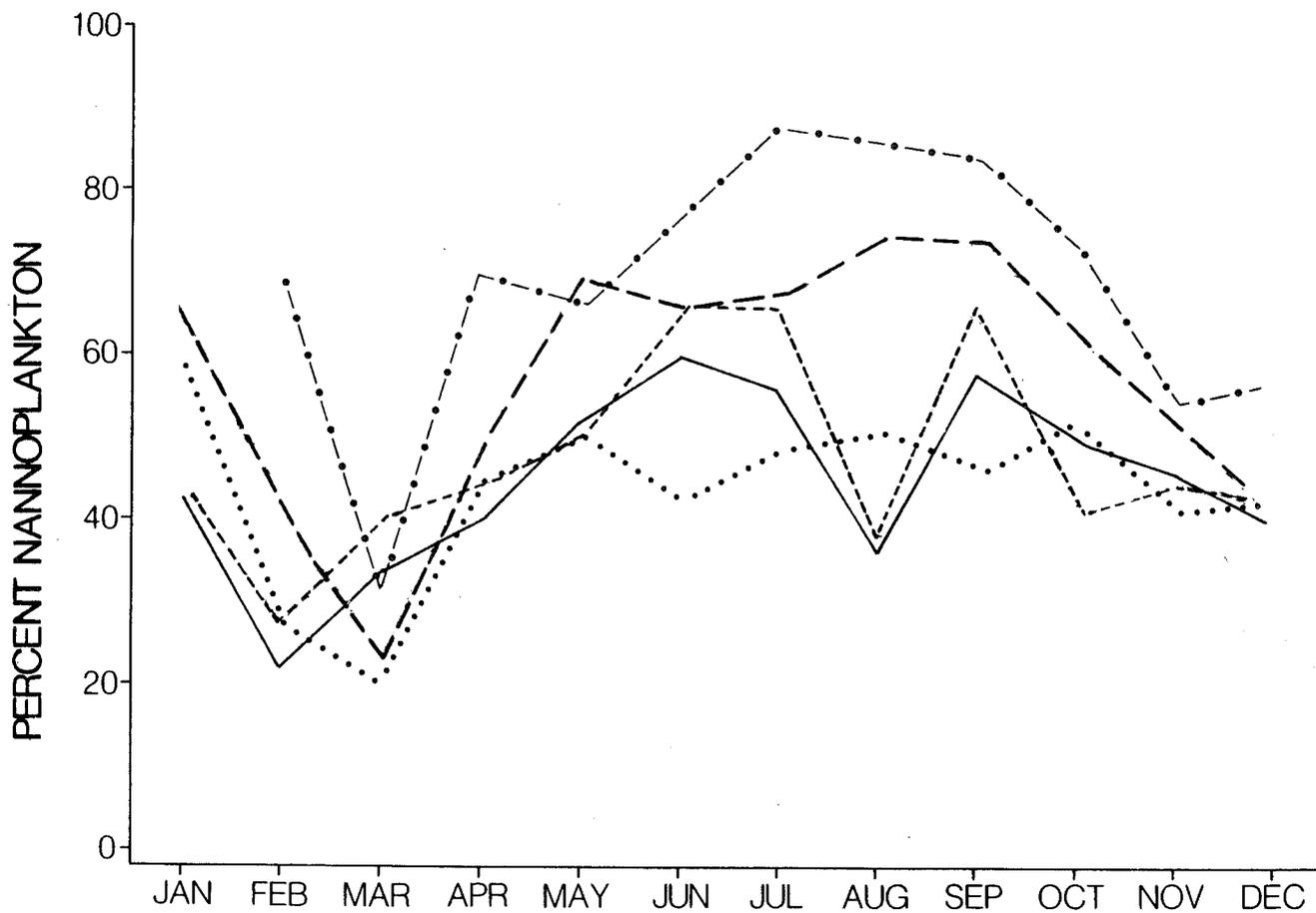
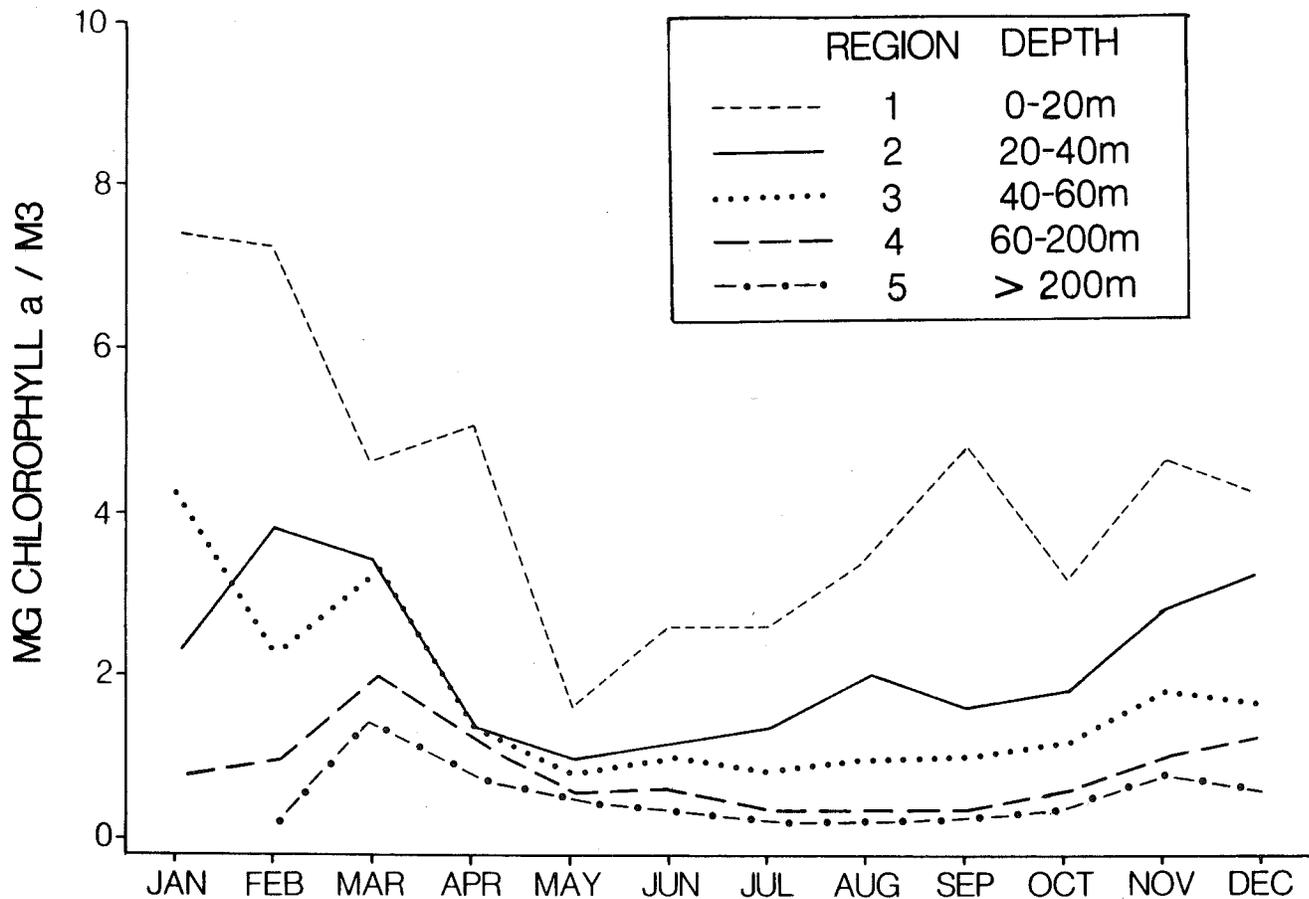


Figure 3. Average community biomass (mg chl  $a/m^3$ ) and community composition (percent nanoplankton) plotted by month for five regions of the Middle Atlantic Bight.

Table 1. Monthly average<sup>1</sup> chlorophyll a concentration<sup>2</sup> and percent nannoplankton<sup>3</sup> in five Middle Atlantic Bight strata adjacent to the Deepwater Dumpsite 106.

MONTH	0 - 20 M				20 - 40 M				40 - 60 M				60 - 200 M				200 - 2000 M			
	CHLA <sup>4</sup>	STD <sup>5</sup>	%NAN <sup>6</sup>	N <sup>7</sup>	CHLA	STD	%NAN	N	CHLA	STD	%NAN	N	CHLA	STD	%NAN	N	CHLA	STD	%NAN	N
JANUARY	7.44	3.34	44	5	2.24	0.86	44	4	4.25	0.88	61	2	0.83	0.02	67	3	0.00	0.00	0	0
FEBRUARY	7.23	4.28	29	25	3.84	2.81	23	61	2.28	1.49	29	27	1.11	0.73	43	31	0.37	0.20	71	14
MARCH	4.64	3.27	41	38	3.58	2.48	34	151	3.35	2.11	20	91	2.12	1.63	25	111	1.43	1.27	32	31
APRIL	5.01	5.39	45	21	1.46	1.31	40	93	1.53	1.49	44	37	1.21	1.05	50	51	0.93	0.37	70	29
MAY	1.75	1.16	51	22	1.05	0.80	52	77	0.82	0.46	52	50	0.73	0.40	70	66	0.61	0.33	67	21
JUNE	2.76	1.76	66	19	1.34	1.11	61	76	1.10	0.63	43	41	0.64	0.34	67	57	0.40	0.23	77	22
JULY	2.74	1.85	67	29	1.56	1.22	56	96	0.96	0.48	49	60	0.59	0.30	69	84	0.35	0.17	88	31
AUGUST	3.51	1.50	38	10	2.10	2.31	36	71	1.08	0.61	50	38	0.57	0.25	74	62	0.36	0.15	86	17
SEPTEMBER	4.97	4.62	67	34	1.63	1.70	59	65	1.06	0.74	47	33	0.56	0.26	74	45	0.44	0.20	85	13
OCTOBER	3.24	2.57	43	20	1.93	1.33	51	85	1.34	0.92	53	64	0.63	0.30	65	91	0.47	0.22	75	31
NOVEMBER	4.78	1.55	44	13	2.96	1.26	46	36	1.98	0.80	42	16	1.01	0.50	52	14	0.82	0.57	55	9
DECEMBER	4.34	2.09	42	18	3.38	1.98	40	47	1.76	0.87	43	44	1.22	0.59	43	57	0.76	0.46	56	16

<sup>1</sup>Weighted average for the upper 100 m of the water column.

<sup>2</sup>mg m<sup>-3</sup>

<sup>3</sup>Nannoplankton (<20 um)

<sup>4</sup>CHLA = chlorophyll a

<sup>5</sup>STD = standard deviation

<sup>6</sup>%NAN = percent of total chlorophyll a in the nannoplankton size fraction

<sup>7</sup>N = number of stations sampled between 1977 and 1982

The "summer maximum" observed in Region 2 differed in time and size composition from the summer maximum in Region 1. In Region 2 the maximum occurred in August, was predominately netplankton-dominated and was less prominent than the maximum observed during "spring" and "fall" blooms. In Region 1, the summer maximum occurred in September, was nanoplankton-dominated, and was comparable in magnitude to the November to December maximum. No summer maxima were observed in Regions 3, 4, and 5.

#### Region 3 (40-60 m)

Chlorophyll a concentrations in Region 3 were distributed in a bimodal pattern (Fig. 2). The highest concentration of chlorophyll a ( $3.35 \text{ mg/m}^3$ ) was found in March during spring bloom. A secondary bloom occurred in the fall during November and December with chlorophyll a concentrations averaging  $1.98$  and  $1.76 \text{ mg/m}^3$ , respectively. No peak was observed during summer.

Low concentrations of chlorophyll a were observed from May through September, the lowest ( $0.82 \text{ mg/m}^3$ ) occurred in May. From June through September, chlorophyll a concentrations averaged roughly  $1 \text{ mg/m}^3$ .

Over the generalized year (excluding the two observations in January), chlorophyll a concentrations in the nanoplankton size fraction did not exceed  $0.83 \text{ mg/m}^3$ . Netplankton concentrations exceeded  $1 \text{ mg/m}^3$  only during "bloom periods" and generally remained below  $0.85 \text{ mg chl a/m}^3$  during the remainder of the year. Netplankton and nanoplankton were present in near equal quantities throughout most of the year but netplankton were often slightly more dominant. In March, during spring bloom, netplankton were strongly dominant and accounted for 70% of the averaged chlorophyll a. Over the annual cycle netplankton accounted for 56% of the total chlorophyll a.

#### Region 4 (60-200 m)

Total chlorophyll a concentrations were distributed bimodally in Region 4. As with Region 3, higher standing stocks were found in March during the spring bloom and during the November to December peak. Averaged concentrations during these months were  $2.12$ ,  $1.01$ , and  $1.22 \text{ mg/m}^3$ , respectively (Figs. 2, 3; Table 1). As in Region 3, netplankton strongly dominated the spring bloom (accounting for 75% of chlorophyll a) and slightly dominated the fall bloom.

Lowest concentrations of chlorophyll a were present during the stratified season from May through September and in October. Nanoplankton clearly dominated the community during this time period and accounted for between 65 and 74% of the total chlorophyll a. This differed from Region 3 where netplankton and nanoplankton were present in near equal quantities during this time.

Over the generalized year, nanoplankton concentrations were fairly consistent, ranging from  $0.41$ - $0.62 \text{ mg/m}^3$ . Netplankton concentrations were not as consistent over the annual cycles as those of the nanoplankton size fraction. They generally ranged between  $0.14$  and  $0.69 \text{ mg/m}^3$ , except for March, when netplankton concentrations reached  $1.59 \text{ mg/m}^3$ . Concentrations less than  $0.25 \text{ mg/m}^3$  occurred during the summer and early fall stratified season.

Nanoplankton were slightly dominant annually in Region 4, their averaged chlorophyll a accounted for 52% of the total. This contrasts to Regions 1, 2, and 3, where netplankton were slightly dominant on an annual basis.

Considering averaged total chlorophyll a on a monthly basis, Region 4 (outer shelf) concentrations were always lower than those in Region 3, and higher than those in Region 5 (slope). This pattern was also observed for monthly averages of netplankton and nanoplankton fractions.

#### Region 5 (200-2000 m)

In Region 5, as in Regions 3 and 4, monthly chlorophyll a concentrations were distributed in a bimodal pattern over the year with the higher chlorophyll a concentrations occurring during March (1.43 mg/m<sup>3</sup>) and November to December (0.82 and 0.76 mg/m<sup>3</sup>, respectively). Over the generalized yearly cycle, nanoplankton dominated and accounted for 63% of the total annual chlorophyll a. However, the spring bloom, as in all other regions, was dominated by netplankton which accounted for 68% of the total average chlorophyll a. The fall bloom was slightly nanoplankton dominated (56%).

The lowest chlorophyll a concentrations occurred over the slope during the stratified season from May through September, and in October. These monthly low values ranged from 0.35-0.61 mg/m<sup>3</sup> and averaged 0.54 mg/m<sup>3</sup>. As in Region 4, nanoplankton dominated the stratified season accounting for 80% of the chlorophyll a during this time period.

Considering the yearly cycle, total chlorophyll a and nanoplankton chlorophyll a concentrations in Region 5 were consistently lower than those found in Region 4. Monthly nanoplankton averages ranged from 0.27 to 0.65, with an average of 0.39 mg/m<sup>3</sup>. Average chlorophyll a in netplankton ranged from 0.04 to 0.36 mg/m<sup>3</sup>, averaging 0.16 for all months except March when chlorophyll a concentrations reach 0.97 mg/m<sup>3</sup> during spring bloom.

## DISCUSSION

### Chlorophyll Distribution over the Middle Atlantic Bight Shelf

Autotrophic phytoplankton need light and nutrients to grow. Often one or the other is limiting and the effect, apparent in chlorophyll a data, increases with distance from shore and with increasing bottom depth. During late spring and summer the system is relatively stable. Few events occur to cause mixing, stratification occurs and a well-defined thermocline forms. During this time solar energy for photosynthesis reaches its maximum; however, nutrient availability regulates phytoplankton production and the averaged water column chlorophyll a mg/m<sup>3</sup> is relatively low compared to other times of the year.

In general, once the thermocline forms, the waters become divided into three layers, euphotic, thermocline, and subeuphotic. The euphotic layer, which has a good supply of light, is regulated by nutrient availability. Here, nutrients are generally supplied through recycling of organic matter and to a lesser extent from diffusion of nutrients across the thermocline (Harrison, 1980). The subeuphotic layer, which is below the thermocline, has a good supply of nutrients but is generally light-limited. Thus, conditions

in neither of the layers surrounding the thermocline are ideal. However, chlorophyll a concentrations in the thermocline sometime exceed 10 times that found in waters above and below and much of the summer productivity occurs in this area of the water column (O'Reilly et al., 1987). In the thermocline, light is generally sufficient for growth to occur and nutrients are supplied through diffusion from nutrient rich water below. Due to the high rate of primary productivity and high standing stocks of phytoplankton the area in and around the thermocline can be very important to larvae and zooplankton as a "feeding ground".

Different species of fish larvae and zooplankton have their own peculiar survival tactics but they all need food. Availability of food is particularly critical for larval survival. Sea bass larvae when fed Artemia nauplii ate 40-60% of their own dry weight per day (Barahona-Fernandes, 1981). When larvae can feed before yolk exhaustion, they show a "substantial increase in growth and difference in morphological development" when compared to larvae starved or unable to feed early in development (Ellertsen et al., 1981). On the west coast, success of anchovy year class is related to the strength of the thermocline, phytoplankton species composition within it, and the stability of the water column. In 1976, when the water column was stable and the major phytoplankter was Gymnodinium splendens, the anchovy year class was exceptional. In years when waters were unstable, the thermocline poorly established and diatoms the dominant phytoplankters, year class recruitment was poor (Lasker, 1981, 1978).

Generally, during the summer the layered distribution described prevails over most of the shelf, particularly in deeper, more stable waters. However, nearshore in shallow waters where the system is more susceptible to mixing events, chlorophyll a distribution can be affected by events that introduce nutrient rich waters that stimulate growth. These events, such as estuarine and coastal runoff, upwelling, downwelling, wind and tidal mixing, lead to variations in the pattern described (Evans-Zetlin et al., 1984). Frequently, in areas where there are high rates of vertical stirring or mixing, high concentrations of phytoplankton are found (McGowan and Hayward, 1978).

In fall the system becomes unstratified. The thermocline breaks down, the water column is mixed to the seabed, plant nutrients are plentiful throughout, and phytoplankton are distributed fairly uniformly throughout the water column. During this time, the mean light intensity in the water column is decreasing, the euphotic zone becomes shallower, and in general light becomes limiting. Since there is constant mixing throughout the water column, phytoplankton are in the euphotic zone part of the time and in the subeuphotic zone out of light the remainder. Seaward, as the bottom depth increases, the amount of time spent in the euphotic zone decreases and phytoplankton spend less time photosynthesizing and more time respiring. Again, as in the nutrient regulated stratified season, the effects are not as severe inshore. Because of the shallowness of the inshore area phytoplankton spend more time in the euphotic zone than their offshore counterparts and higher concentrations of chlorophyll a are observed. During the unstratified season, the highest standing stocks of phytoplankton occur during spring bloom. Spring bloom, composed primarily of netplankton, probably is not eaten and eventually sinks and becomes part of the demersal food chain. During summer, decomposition of phytoplankton on bottom may contribute to increased oxygen consumption and potential hypoxia.

Chlorophyll a ( $\text{mg}/\text{m}^3$ ) is distributed over the shelf in a well-defined gradient. There are high concentrations inshore (Region 1) and low concentrations offshore (Region 5) (Figs. 2, 3, and 4). This pattern is generally present throughout the year with variations occurring in the magnitude of chlorophyll a present. The estimates of the average annual chlorophyll a (excluding January in Regions 3 and 5) for Regions 1-5 were 4.37, 2.26, 1.60, 0.94, 0.63  $\text{mg}/\text{m}^3$ , respectively, and support the generalization that phytoplankton chlorophyll a decreases from the shallow to the deeper areas of the MAB shelf. This pattern is also present in netplankton and nanoplankton data. Mean annual netplankton chlorophyll a concentrations decreased from 2.34  $\text{mg}/\text{m}^3$  in Region 1 to 0.22  $\text{mg}/\text{m}^3$  in Region 5. Nanoplankton concentrations decreased from 2.03  $\text{mg}/\text{m}^3$  (Region 1) to 0.36  $\text{mg}/\text{m}^3$  (Region 5). Despite the seven-fold decrease in total chlorophyll a concentration from nearshore to slope water, the overall month-to-month variability within each of the five regions was similar (coefficient of variability was 40, 42, 59, 48, and 52 for Regions 1-5, respectively). The coefficient of variability for netplankton was more variable and for nanoplankton less variable than that for total community chlorophyll a. Coefficients of variability for netplankton increased with depth and was 55, 60, 71, 91, and 113 for Regions 1-5 respectively. Those for nanoplankton were similar except for Region 4, and were 35, 28, 29, 14, and 28 for Regions 1-5 respectively.

In the Middle Atlantic Bight, the monthly distribution of chlorophyll a was bimodal in all regions with highest concentrations found in the spring and secondary maxima found between November and December. During spring when light intensity increases and nutrients are plentiful, "spring bloom" is observed over the shelf generally between February and April. During this period the highest concentrations of chlorophyll a are observed. In the fall, following breakdown of stratification and subsequent enhancement of the euphotic layer with nutrients trapped below the summer thermocline, light is still sufficient, and a secondary "fall bloom" occurs where chlorophyll a concentrations are lower than those found during spring bloom but higher than those found the remainder of the year. Additional maxima were seen in August and September in the inshore Regions 1 and 2. The lowest chlorophyll a concentrations were found during late spring and early summer at the onset of thermal stratification. In Regions 1 and 2, the lowest chlorophyll a concentrations occurred in May. In Regions 3, 4, and 5, chlorophyll a concentrations were relatively low from May through October.

On an annual basis, there is an onshore to offshore trend in phytoplankton community size composition that parallels the gradient in chlorophyll abundance. Over the annual cycle netplankton slightly dominated in Regions 1, 2, and 3, whereas nanoplankton were slightly dominant in the outer shelf (Region 4) and clearly dominant over the slope (Region 5).

Netplankton are generally favored by extensive vertical mixing, are presumed to adjust well to "rapidly fluctuating irradiance conditions in well-mixed layers and have faster growth rate at lower temperatures (Walsby and Reynolds, 1980). Diatoms generally are dominant in colder, nutrient-rich waters (Smayda, 1980). They strongly dominated phytoplankton chlorophyll a in all regions during the February to March spring bloom. During the November to December secondary maximum netplankton and nanoplankton were present in near equal amounts. Netplankton slightly dominated during the November to December

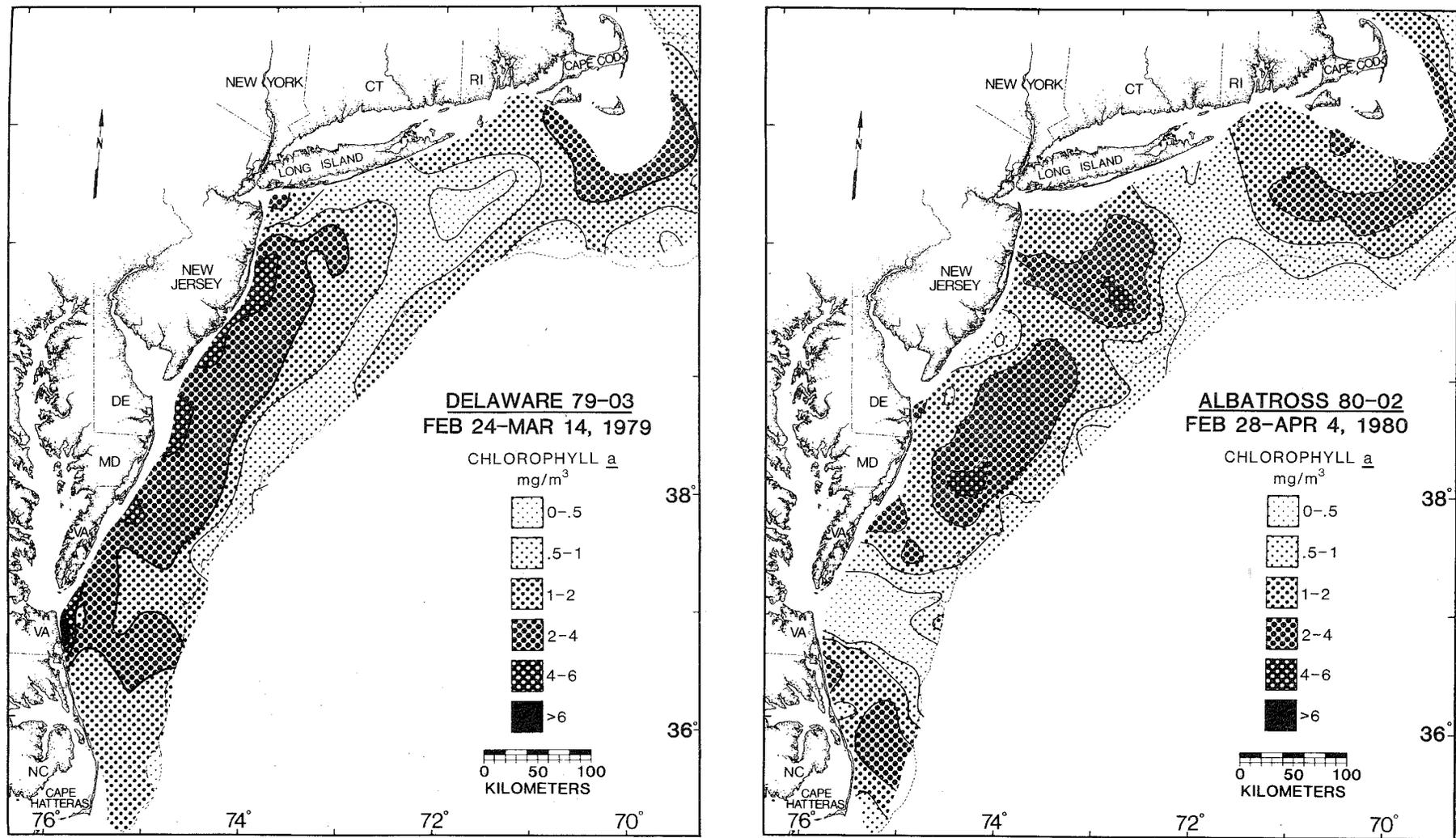


Figure 4. Distribution of chlorophyll a (mg/m<sup>3</sup>) during eight months of the year.

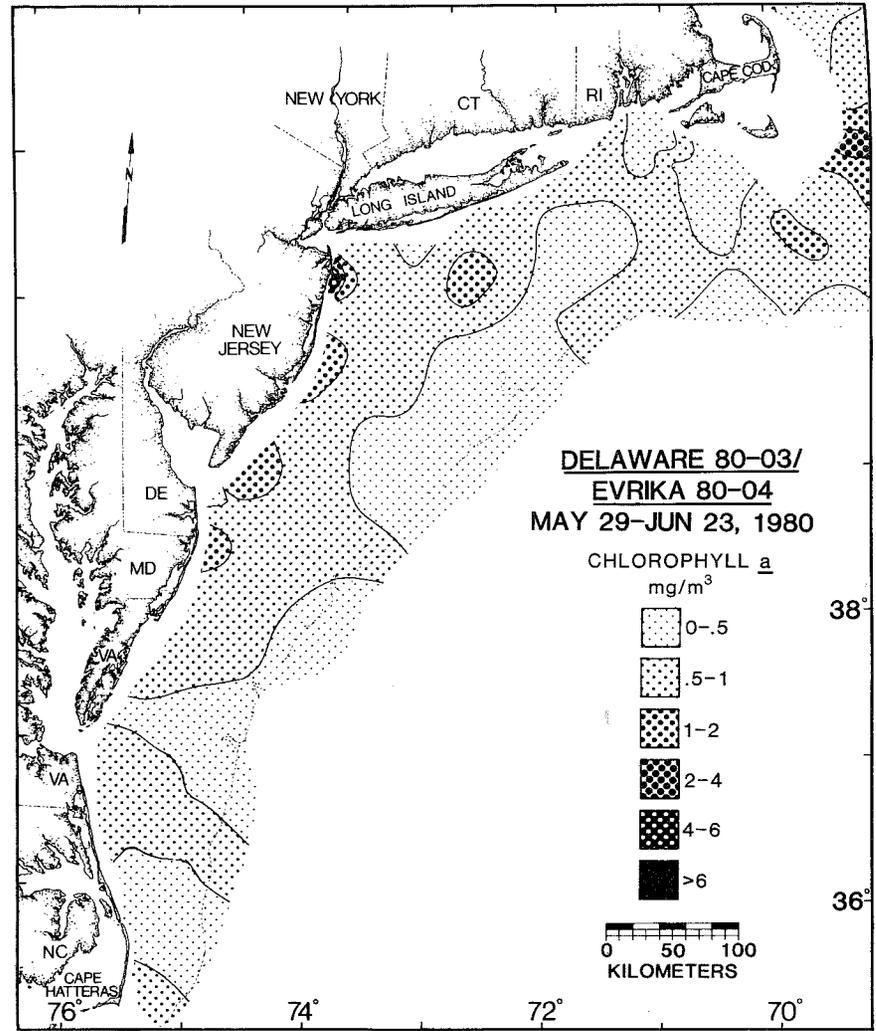
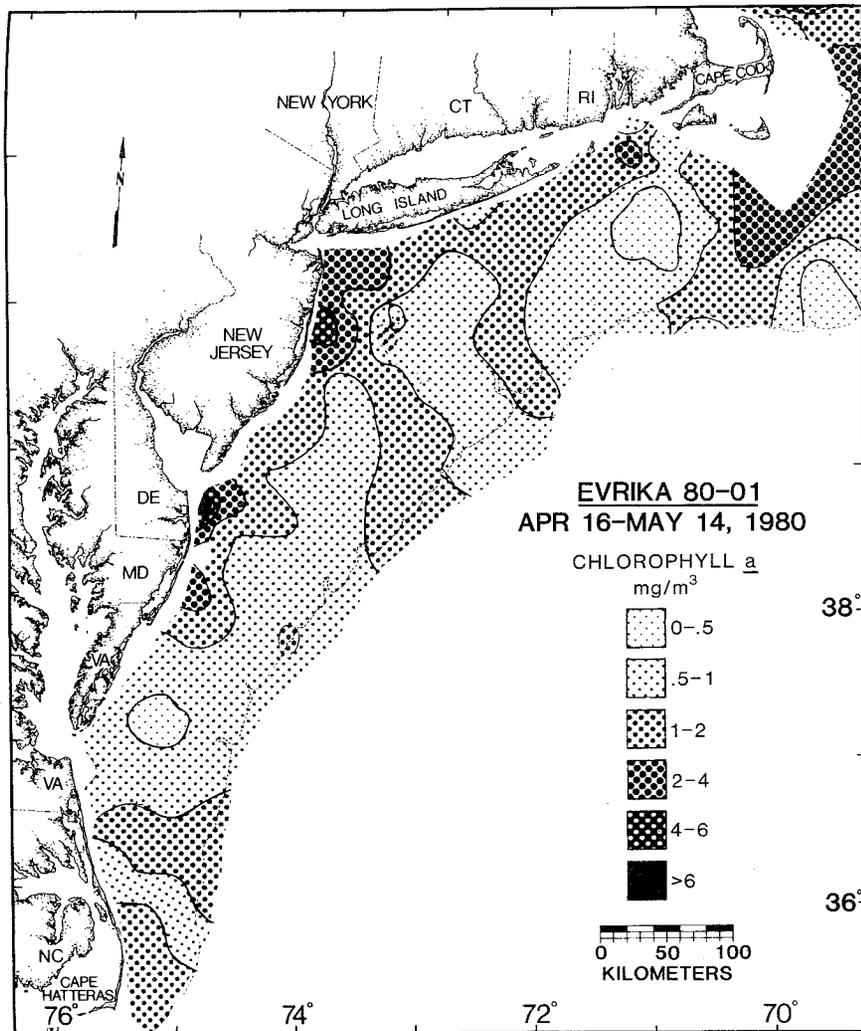


Figure 4. continued

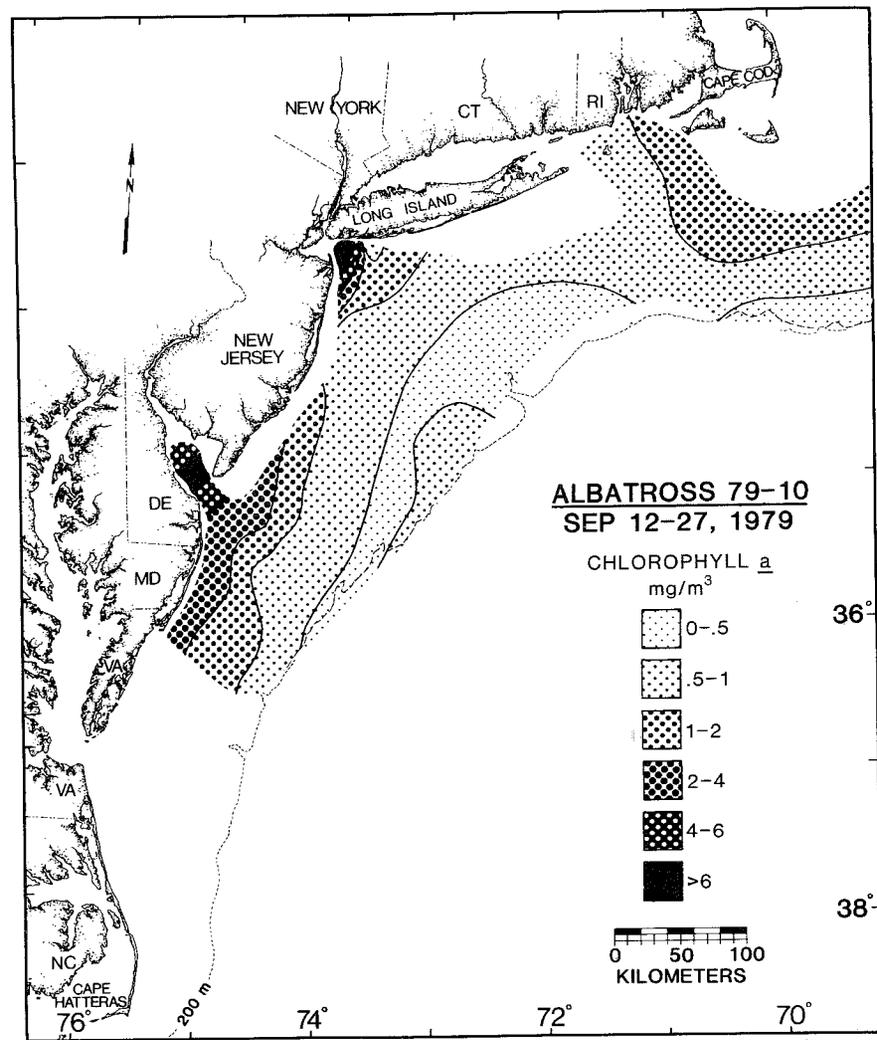
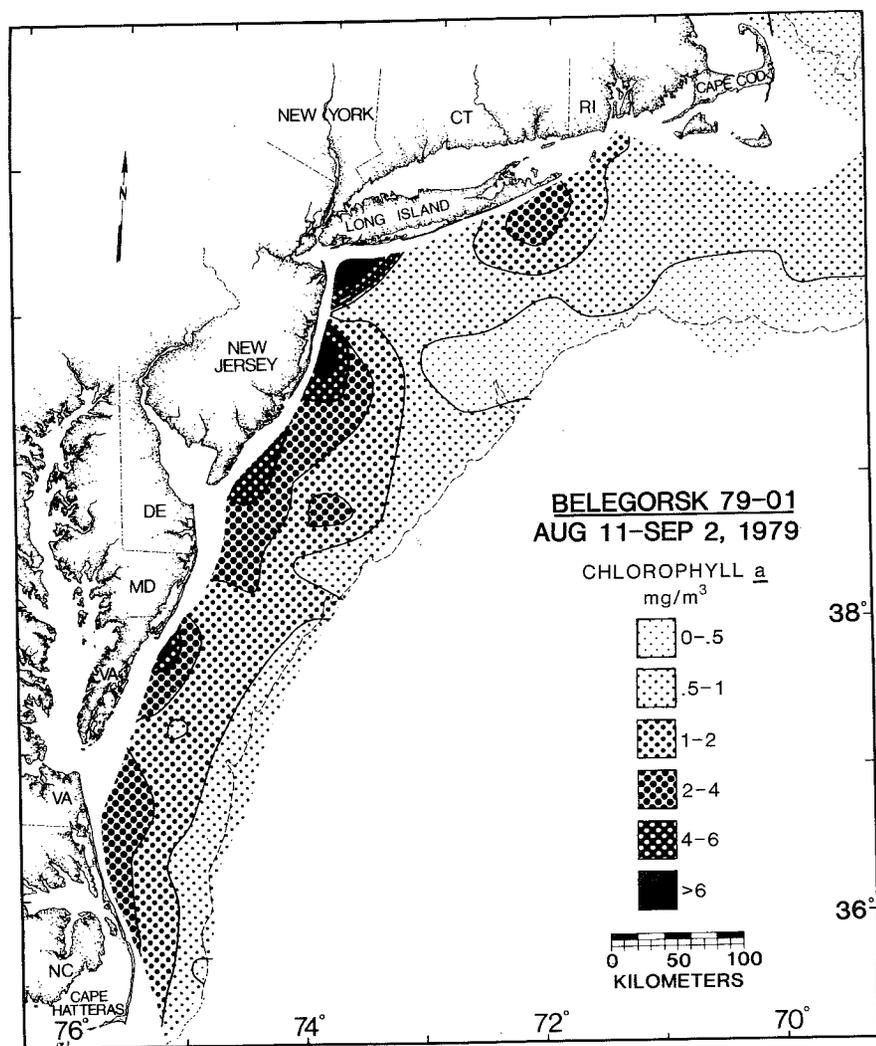


Figure 4. continued

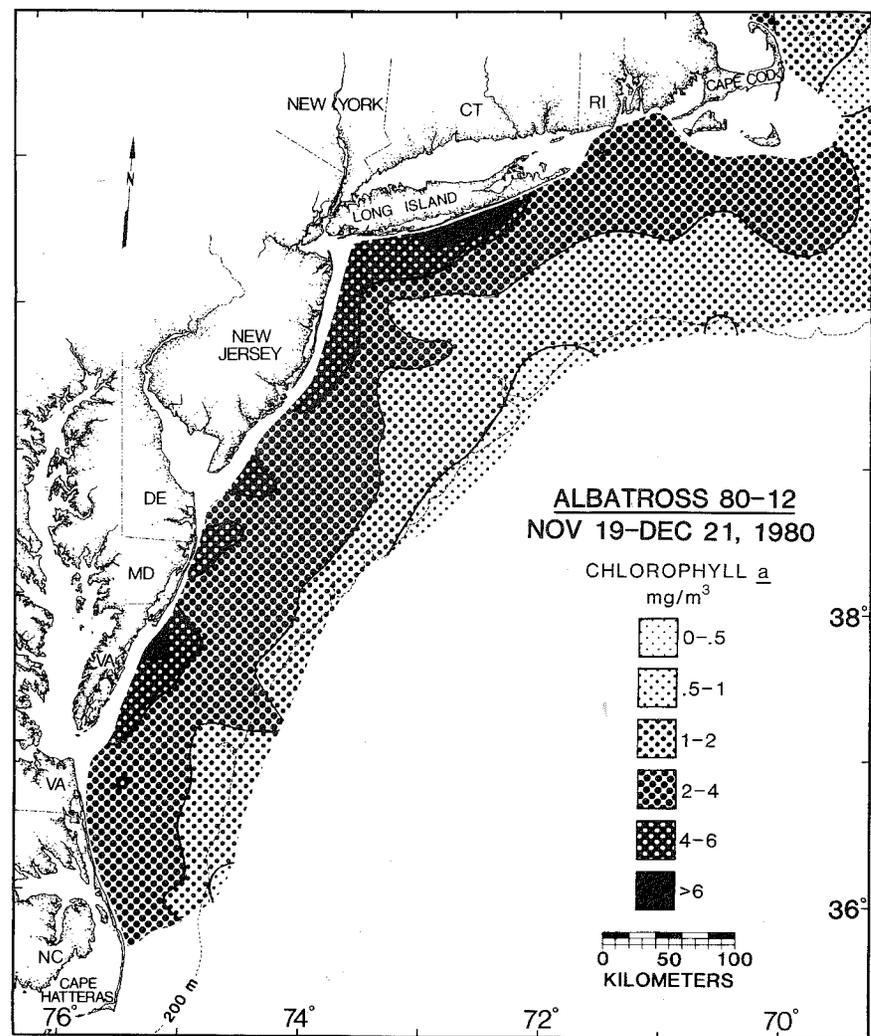
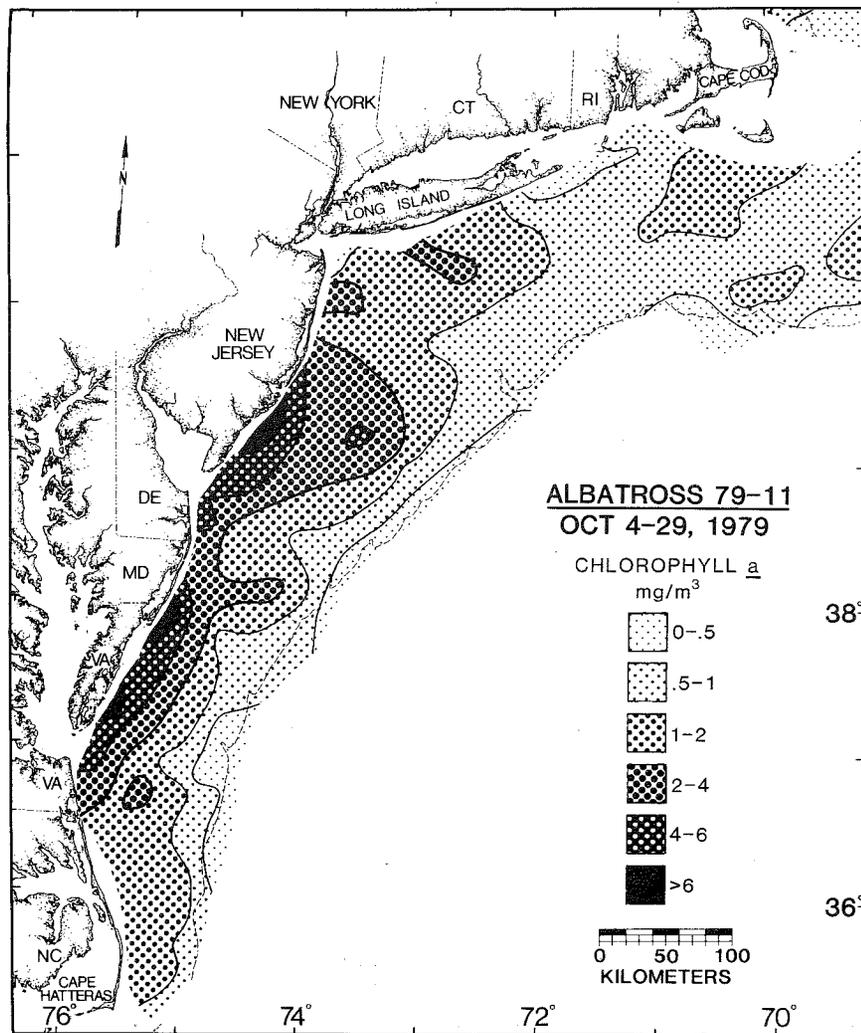


Figure 4. continued

secondary bloom in Regions 1-4 (shelf) while nanoplankton slightly dominated in Region 5, over the slope (Figs. 2 and 4). Generally, nanoplankton dominated during the warmer stratified season. The patterns in phytoplankton size and chlorophyll *a* distribution reported are supported by Smith (1973), Yentsch (1977), Shilling (1981) and Malone (1976).

#### SUMMARY

We have described the phytoplankton community characteristics in waters over the continental shelf and slope of the Middle Atlantic Bight. Average water column chlorophyll *a* estimates from 54 cruises from October 1977 to March 1982 were pooled by area and month, irrespective of year, to form a synthetic year of averaged water column chlorophyll *a* estimates. The area was divided into five bathymetric regions based on bottom depth to examine chlorophyll *a* distribution: 1) 0-20, 2) 20-40, 3) 40-60, 4) 60-200, and 5) 200-2000 m (the slope seaward of the shelf break). NMFS phytoplankton data are not available for the region beyond the 2000 m isobath.

The annual cycle of chlorophyll *a* was generally bimodal in all five regions. The highest chlorophyll *a* concentrations were consistently observed during the spring bloom during February (depths <40 m) and March (depths >40 m). The lowest concentrations were consistently observed from May through July in waters <40 m (Regions 1 and 2). At depths >40 m (Regions 3, 4 and 5), corresponding to mid to outer shelf and slope, chlorophyll *a* concentrations were consistently low from May through October. A secondary peak in chlorophyll *a* was observed during November and December across the entire shelf. Additional peaks of abundance were also observed in late summer for the two nearshore regions; during September, at depths <20 m and in August at depths between 20-40 m. During the stratified season in and around the thermocline a subsurface chlorophyll *a* maximum is present, where relatively high concentrations of phytoplankton are available as food for zooplankton. During the unstratified season chlorophyll *a* and phytoplankton generally are distributed evenly throughout the water column.

A consistent gradient in chlorophyll *a* concentration occurred within the monthly and annual chlorophyll *a* averages. Highest chlorophyll *a* concentrations were inshore (0-20 m) and the lowest were found at depths >200 m (Region 5).

Phytoplankton community size composition also varied over the year. Netplankton strongly dominated the February-March spring bloom over the entire shelf generally and accounted for 70% of the standing stock. In contrast, nanoplankton generally dominated communities during the mid-year stratified periods when chlorophyll *a* concentrations were at a low. During the fall bloom, netplankton and nanoplankton contributed to the phytoplankton community chlorophyll *a* in near equal amounts. In waters less than 200 m (Regions 1-4) netplankton slightly dominated, but these differences probably are not statistically significant.

At depths <60 m (Regions 1-3) netplankton was slightly more abundant than nanoplankton over the annual cycle. Nanoplankton was slightly more abundant between 60-200 m and clearly dominated the annual chlorophyll *a* at depths >200 m.

## REFERENCES

- Barahona-Fernandes, M. 1981. Daily food intake of reared larvae of the European Seabass (*Dicentrarchus labrax* L.) statistical analysis and modelling. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 178: 41-44.
- Cohen, E. B. and M. D. Grosslein. 1987. Total ecosystem production on Georges Bank compared with other shelf ecosystems. In: pp. 383-391. Georges Bank. R. H. Backus and D. W. Bourne (eds.). MIT Press, 593 pp.
- Ellertsen, B., P. Solemdal, S. Sundby, S. Tilseth, T. Westgard and V. Øestad. 1981. Feeding and vertical distribution of cod larvae in relation to availability of prey organisms. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 178: 317-319.
- Evans, C. and J. O'Reilly. 1983. A manual for the measurement of chlorophyll *a* in netplankton and nannoplankton. Biomass Handbook No. 9 SCAR/SCOR/IABO/ACMRR.
- Evans-Zetlin, C., C. Muchant, K. Ingham, P. Lyons, T. Finneran and D. McMillan. 1984. Biological, physical, and chemical dynamics along a New York Bight transect off Long Branch, New Jersey, May to October 1983. NMFS, NEFC, Sandy Hook Report No. 84-13.
- Harrison, W. 1980. Nutrient regeneration and primary production in the sea. In: Primary production in the sea. P. Falkowski, (ed.). Plenum Press, New York. 433-460.
- Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. Rapport Process-Verbaux Reunion Conseil Perm. Intern. Exploration Mer 20: 1-228.
- Hunter, J. R. 1981. Feeding Ecology and Predation of Marine Fish Larvae. In: Marine Fish Larvae Morphology, Ecology, and Relation to Fisheries. R. Lasker (ed.). University of Washington Press, Seattle. pp. 33-77.
- Huntley, M., K. W. Strong and A. T. Dengler. 1983. Dynamics and community structure of zooplankton in the Davis Strait and the Northern Labrador Sea. Arctic 36(2): 143-161.
- Koslow, J. A. 1983. Zooplankton community structure in the North Sea and Northeast Atlantic: Development and test of a biological model. Can. J. Fish. Aquat. Sci. 40: 1912-1924.
- Lasker, R. 1975. Field criteria for survival of anchovy larvae: The relation between inshore chlorophyll maximum layers and successful first feeding. Fishery Bulletin 73: 453-462.
- Lasker, R. 1978. The relationship between oceanographic conditions and larval anchovy food in the California current: identification of factors contributing to recruitment failure. Rapp. R.-v. Reun. Cons. int. Explor. Mer. 173: 212-230.

- Lasker, R. 1981. Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California current: Contrasting years 1975 through 1978. *Rapp. P.-v. Reun. Cons. int. Explor. Mer.* 178: 375-388.
- Malone, T. C. 1976. Phytoplankton productivity in the apex of the New York Bight: Environmental regulation of productivity/chlorophyll a. In: *Limnol. Oceanogr. Spec. Symp. Vol. 2, Middle Atlantic Continental Shelf and the New York Bight.*
- May, R. C. 1974. Larval mortality of marine fishes and the critical period concept. In: *The early life history of fish.* J.H.S. Blaxter (ed.), The Springer-Verlag, Berl. pp. 3-19.
- McGowan, J. and T. Hayward. 1978. Mixing and ocean productivity. *Deep Sea Research.* 25: 771-793.
- Moffatt, N. 1981. Survival and growth of northern anchovy larvae on low zooplankton densities as affected by the presence of a *Chlorella* bloom. *Rapp. P.-v. Reun. Cons. int. Explor. Mer.* 178: 475-480.
- O'Reilly, J., C. Evans-Zetlin and D. A. Busch. 1987. Primary production. pp. 220-233. In: *Georges Bank.* R. H. Backus and D. W. Bourne (eds.). MIT Press, 593 pp.
- Ryther, J. H. 1969. Photosynthesis and fish production. *Science* 166: 72-76.
- Shilling, W. C. 1981. Environmental report for the Philadelphia Sewage Sludge Disposal Site. Prepared for EPA, EPA 68-01-4610.
- Smayda, T. 1980. Phytoplankton species succession. In: *The Physiological Ecology of Phytoplankton.* I. Morris, ed. Univ. of California Press, Berkeley. pp. 493-570.
- Smith, S. K. 1973. Phytoplankton, pp. 47-54. In: *Environmental survey of an interim ocean dumpsite - Middle Atlantic Bight.* H. D. Palmer and D. W. Lear (eds.). EPA 903/9-73-001-A.
- Steele, J. H. and B. W. Frost. 1976. The structure of plankton communities. ICES, Plankton Committee C.M. 1976/L:22.
- Steven, D. M. 1975. Biological Production in the Gulf of St. Lawrence. In: *Energy flow--its biological dimensions, a summary of the IBP in Canada 1964-1974.* T. W. M. Cameron and L. W. Rillingsley (eds.). R. Soc. Can. Ottawa. 229-248.
- Sutcliffe, W. H., Jr., R. Loucks, K. Drinkwater and A. Coote. 1983. Nutrient flux onto the Labrador Shelf from Hudson Strait and its biological consequences. *Can. J. Fish. Aquat. Sci.* 40: 1692-1701.
- Sverdrup, H. 1955. The place of physical oceanography in oceanographic research. *Journal of Mar. Res.* 14(4): 287-294.

Walsby, A. and C. Reynolds. 1980. Sinking and Floating. In: The Physiological Ecology of Phytoplankton. I. Morris (ed.). Univ. of California Press, Berkeley. pp. 371-412.

Walsh, J. J. 1981. Shelf-sea ecosystems. In: Analysis of Marine Ecosystems. A. R. Longhurst (ed.). Academic Press. pp. 159-196.

Yentsch, C. S. 1977. Plankton production. MESA New York Bight Atlas Monograph 12. New York Sea Grant Institute, Albany, New York.

Zooplankton of the Northeast Shelf Ecosystem with  
a Focus on Waters of Southern New England and  
the Mid-Atlantic Bight<sup>1</sup>

by

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INTRODUCTION

Zooplankton in marine ecosystems function as links between primary producers (phytoplankton) and predatory populations of fish, marine birds, and mammals. Mesoscale changes in zooplankton abundance have been associated with disruption of predator-prey relationships resulting in economically disastrous declines in fish stocks (Glover, 1957; Glover et al., 1961; Williamson, 1961; Jacobsen, 1980). Although it has been demonstrated that large-scale (100-1000 km) seasonal and annual variability in abundance of zooplankton has been associated with advective processes in the Northeast Pacific and Northeast Atlantic (Wickett, 1967; Colebrook, 1977; Colebrook, 1978a,b), we have not observed any large-scale changes in abundance of zooplankton off the northeast coast of the United States. The region has been under investigation since the turn of the century, previous studies of zooplankton have been limited to restricted areas of the northeast shelf and covered relatively short periods of time (Fish, 1925, 1936a,b; Bigelow, 1926; Bigelow and Sears, 1939; Clarke and Zinn, 1937; Clarke, 1940; Clarke et al., 1943; Deevey, 1952, 1956, 1960; Grice and Hart, 1962; Sherman, 1968, 1970, 1976; Malone, 1977; Judkins et al., 1980). The results reported are provided as background information against which future perturbations within the northeast continental shelf ecosystem can be measured as part of the NEFC environmental assessment strategy. Most of the information in this report has been prepared for publication (Sherman et al., 1983).

METHODS

Our findings are based on 32 surveys of zooplankton conducted by the United States, Poland, Soviet Union, and German Democratic Republic between 1977 and 1981, as part of a joint MARMAP study of the ecosystem of the northeastern shelf (Sherman, 1980). Between 6 and 8 surveys were done per

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Southern New England, and Mid-Atlantic Bight, each characterized by distinct bathymetry and circulation (Butman et al., 1982; Emery and Uchupi, 1972) (Fig. 1). Zooplankton were collected at an average of 129 locations per survey situated 25-35 km apart, resulting in a total of 3,568 samples. At each sampling location, tows for zooplankton using a paired bongo-type sampler (Posgay and Marak, 1980) with 60-cm openings and nets of 0.333 and 0.505 mm-mesh covered the water column obliquely from 5 m above bottom to the surface. These nets were towed at ship speeds ranging from 1.5 to 3.5 knots, and were lowered at a wire speed of  $50 \text{ m min}^{-1}$  down to a maximum depth of 200 m and retrieved at  $20 \text{ m min}^{-1}$ . Water filtered through the net was measured with a flowmeter and a time-depth recorder was used to measure the towing profile of the sampler.

Zooplankton samples were sorted, identified and counted at the Plankton Sorting Center, Szczecin, Poland. The biomass of zooplankton is expressed as numbers of zooplankters per  $100 \text{ m}^3$  of water strained; numerical abundance is expressed as numbers of zooplankters per  $100 \text{ m}^3$  of water strained. Patterns of abundance of the dominant zooplankters are based on the analysis of the size-fraction retained in the 0.333 mm-net, which primarily captured late juvenile and adult copepods.

## RESULTS

### Coherent Patterns of Biomass

Displacement volumes expressed as  $\text{cc}/100 \text{ m}^3$  of water strained are used to represent standing stocks of zooplankton. The seasonal patterns of zooplankton biomass observed each year and compared with the 5-year means in MAB and the SNE subareas were coherent (Fig. 2a). The term coherent is used here to describe the recurring seasonal patterns of zooplankton biomass in which annual deviations from the 5-year mean are insignificant at the 0.05 level (Table 1). In Southern New England, zooplankton biomass is bimodal: an initial pulse occurs in May followed by a low in July, and a second peak occurs in August, followed by a decline in autumn and winter. In the Mid-Atlantic Bight biomass increases from an annual low in winter to an annual high in autumn.

### Coherence in Dominance

The Fager and McGowan (1963) index was used to identify the dominant zooplankters in each subarea by season. Of the 394 taxa in the samples, 50 were dominant in at least one location in one or more seasons. Summary statistics for all taxa, including rank, abundance, dominance, median abundance, and Delta-mean abundance (Pennington, 1983) are available from the authors. Twelve taxa, all copepods, comprised 85% of the dominance--Calanus finmarchicus, Pseudocalanus sp., Centropages typicus, Metridia lucens, Temora longicornis, Centropages hamatus, Acartia clausi, Acartia tonsa, Acartia spp. (A. clausi-A. longiremis), Oithona spp., Calanus spp., and Paracalanus parvus. Among these twelve taxa, C. finmarchicus, P. minutus, and C. typicus accounted for 75% of the total dominance.

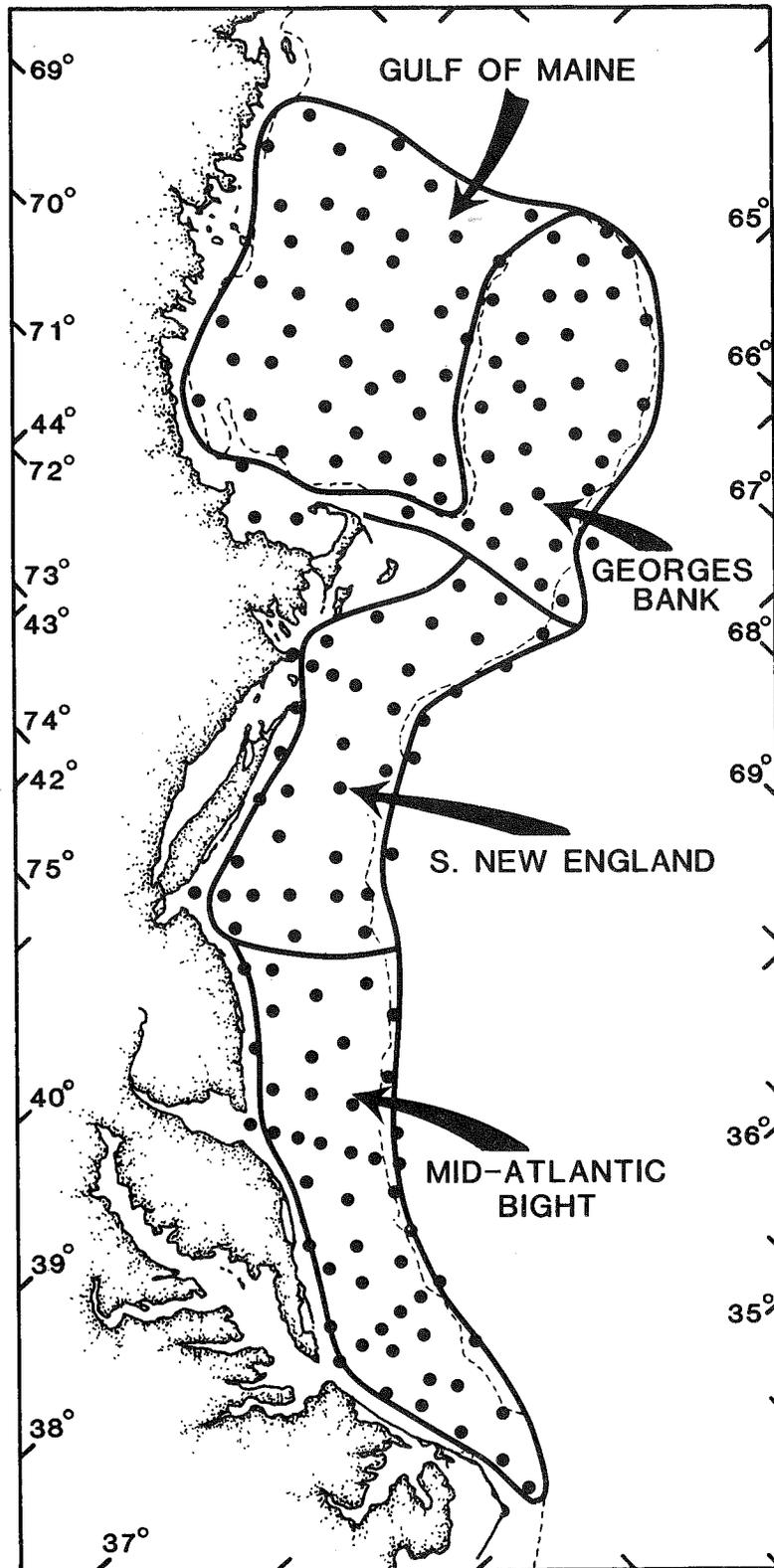


Figure 1. The four geographic areas of the Northwest Atlantic sampled for zooplankton during MARMAP operations from 1977 to 1981, with MARMAP station locations indicated by dots. The Middle Atlantic Shelf Water Management Unit essentially compares the Southern New England and Mid-Atlantic Bight areas.

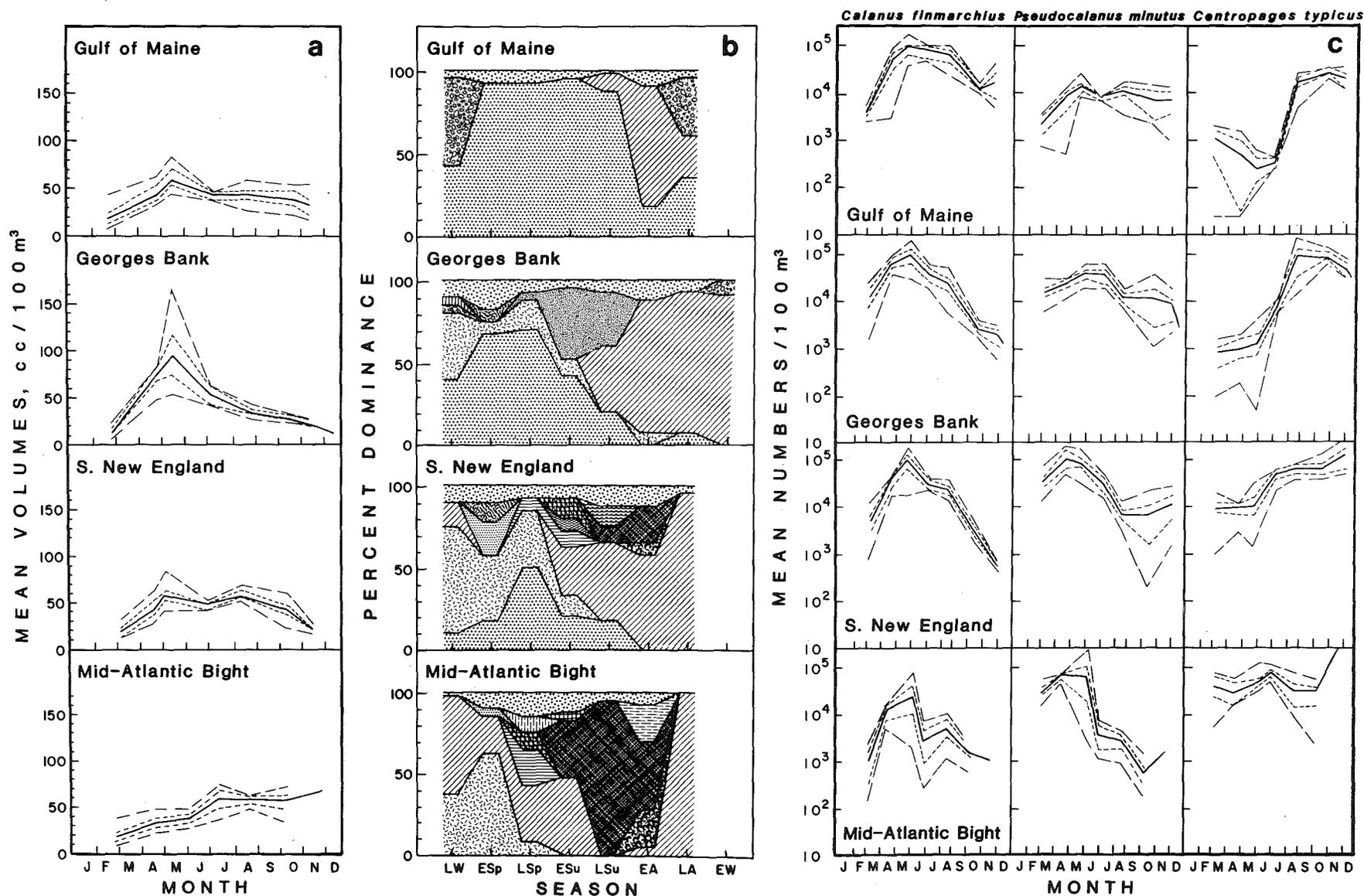
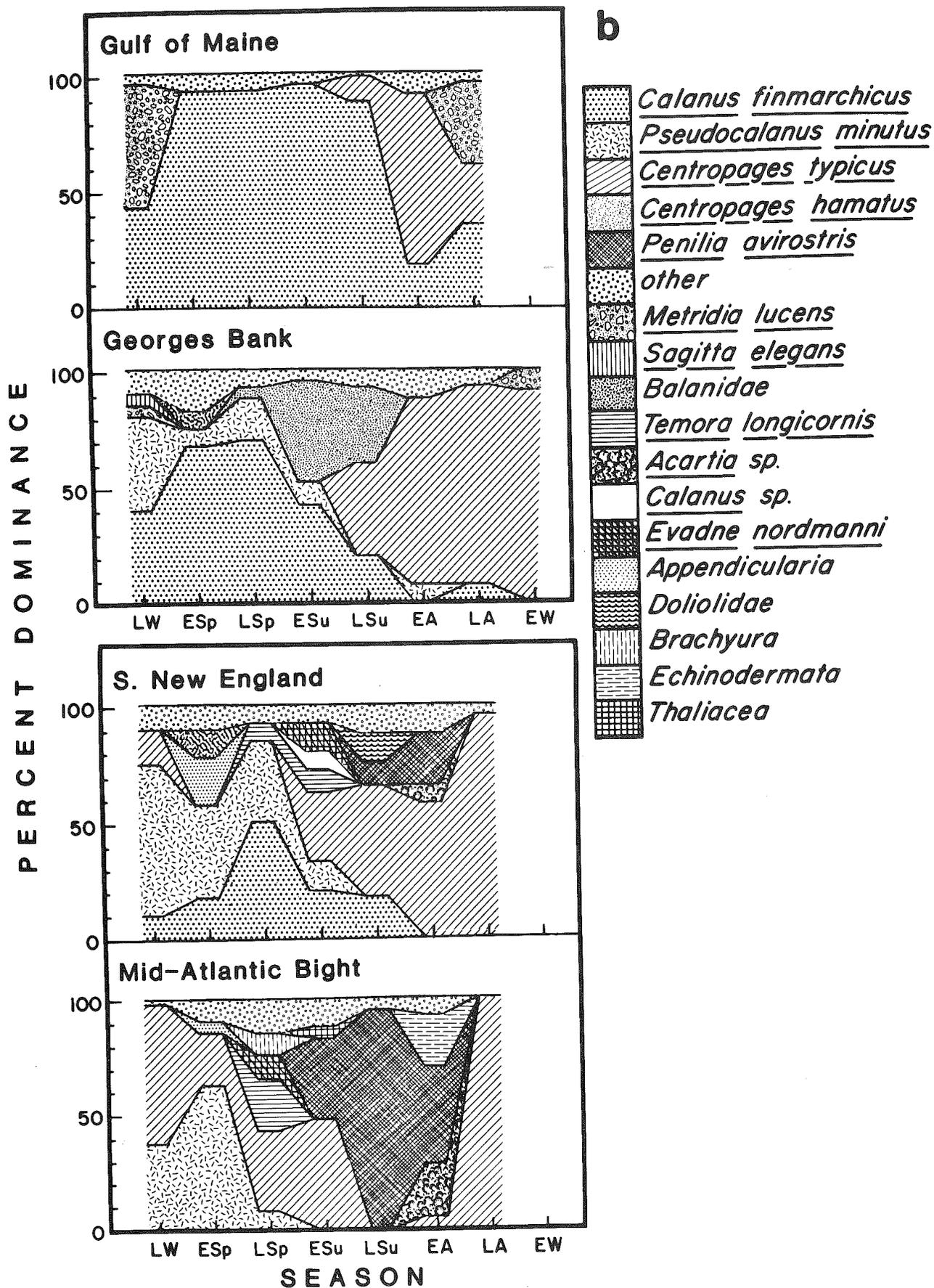


Figure 2. Patterns of zooplankton coherence in four northeastern U.S. continental shelf subareas--Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic Bight. (a)--Seasonal patterns in mean zooplankton standing stock (cc/100 m<sup>3</sup>) for the 5-yr. MARMAP time series; (b)--Seasonal patterns of dominance of zooplankters by subarea shown as a percentage of the samples with a dominant taxon in the 5-yr MARMAP time series (details of panel b shown separately). (c)--Seasonal pulses in abundance of the three dominant copepod species--*Calanus finmarchicus*, *Pseudocalanus minutus*, and *Centropages typicus* (no. /100 m<sup>3</sup>) in each of the subareas for the 5-yr time series.



Details of Figure 2, panel B. LW = late winter, ESu = early spring, LSp = late spring, ESu = early summer, LSu = late summer, EA = early autumn, EW = early winter.

### Species Shifts in Dominance

Although the three species co-occur on the shelf, their temporal and spatial patterns of dominance are different. These patterns are coherent among the 5 years. The proportion of the total zooplankton accounted for these three dominant species is shown for MAB and SNE subareas as a function of time in Figure 2b. In the southern portion of the MARMAP sampling area, C. finmarchicus is dominant in late spring and is replaced by P. minutus, C. typicus, and other less-abundant zooplankters, including other copepods, cladocerans, larval echinoderms, salps, and barnacle larvae in Southern New England and principally cladocerans in the Mid-Atlantic Bight. Annual deviations in the dominance patterns of C. finmarchicus, P. minutus, and C. typicus from the 5-year mean were insignificant at the 0.05 level in 95% of the comparisons made within the subareas (Table 1).

Table 1. Summary of probability statistics for the two-tailed Fisher-sign test for year-to-year coherence in the zooplankton volumes, dominance, and three dominant species--C. finmarchicus, P. minutus, and C. typicus. Annual departures from the MARMAP 5-year mean annual cycle were tested for each subarea. The ranges of the probability of the Fisher-sign statistic are tabulated. Of the 100 tests (5 yr x 4 areas x 5 variables) only four reject the null hypothesis at 0.05 significance.  $H_0$ : annual cycle - 5 yr mean cycle; \* = significant difference in the year indicated in parentheses.

Survey Variable	Southern New England	Mid-Atlantic Bight
MARMAP		
Volume	.227-.656	.109-.812
Dominance	.172-.637	.188-.500
<u>C. finmarchicus</u>	.500-.656	.188-.812
<u>P. minutus</u>	.344-.656 .992* (79)	.500-.812
<u>C. typicus</u> .891	.227-.891	.500-.891

While the numerical abundance of the three copepods were coherent within the envelope of one standard error of the mean and within the mean range in MAB and SNE subareas during the 5 years (Fig. 2c), the zooplankton standing stocks, dominance patterns, and abundance levels of the principal species in each of the subareas were different. In Southern New England (SNE) waters the bimodal peaks in zooplankton standing stock represent C. finmarchicus and P. minutus dominance in spring and early summer followed by large-scale C. typicus swarming in late summer and autumn (Fig. 2b and c). Further south in

the Mid-Atlantic Bight (MAB), *C. finmarchicus* abundance is diminished, and is replaced by *P. minutus* and *C. typicus* in late winter and early spring, followed by an increase in the standing stock of zooplankton from summer through autumn (Fig. 2a) related to the growing abundance of cladocerans and other zooplankters in summer and large-scale swarming of *C. typicus* in autumn (Fig. 2b and c). Deviations from the 5-year mean temporal patterns of abundance of the three dominant copepods were not significant at the 0.05 level in 95% of the comparisons (Table 1).

#### Comparison among Abundance Levels within Southern New England and Mid-Atlantic Bight (the Middle Atlantic Shelf WMU).

Within the Southern New England and Mid-Atlantic Bight subareas, abundance levels of zooplankton were examined between areas and among three depth zones--<40 m-100 m, and >100 m. In the Southern New England area *Calanus finmarchicus* abundance peaks in April and May. Although the seasonal pattern is similar in the three depth zones, absolute density varies by one order of magnitude. Peak values are 25,000/100 m<sup>3</sup> offshore; 80,000/100 m<sup>3</sup> midshelf; and 9,000/100 m<sup>3</sup> for the inshore zone (<40 m).

*C. finmarchicus* is less abundant in the Mid-Atlantic Bight, with typical abundance about half that for the respective depth zone in Southern New England waters. Again, greatest densities are reached on the midshelf (40 m-100 m), one order of magnitude greater than inshore densities. As in Southern New England the seasonal cycle reaches a peak in April/May, but there is sharp decline in the abundance of *C. finmarchicus* in July, a feature not present in the Southern New England area. This summer minimum is most pronounced in shallow waters but is discernible even in the offshore region.

*Pseudocalanus minutus* also has a spring peak in abundance in both areas. In Southern New England the onshore and midshelf seasonal patterns are similar with an April peak (100,000/100 m<sup>3</sup> and 60,000/100 m<sup>3</sup>, respectively), followed by a decrease to an October minimum one order of magnitude lower than the peak abundance. In Southern New England offshore waters this species reaches a peak of only 11,000/100 m<sup>3</sup> in April, followed by a precipitous decline to almost total absence in August, followed by a modest recovery in the fall.

In the Mid-Atlantic Bight inshore waters *P. minutus* density is approximately 50,000/100 m<sup>3</sup> through the cold water months of February, March, and April. Density of this calanoid copepod falls to about 2,000/100 m<sup>3</sup> in July and August and reaches a minimum of 300/100 m<sup>3</sup> in the fall. This pattern also holds for the midshelf where the density is higher. In contrast, in the offshore waters *P. minutus* shows a steady log normal decrease from its spring peak of 10,000/100 m<sup>3</sup> to a November minimum of about 500/100 m<sup>3</sup>.

Seasonal variation in abundance of *Centropages typicus* is less than in the two previously discussed species, with peak abundance typically less than one order of magnitude above the annual low. In Southern New England there is no well-defined seasonal pattern, although greatest density is found late in the year and productivity seems to peak in midsummer. Abundance in each depth region varies from about 3,000/100 m<sup>3</sup> to about 20,000/100 m<sup>3</sup>.

C. typicus in offshore waters of the Mid-Atlantic Bight follows this relatively constant seasonal pattern, and varies in the same abundance range as in Southern New England waters. However, in the two shallower regions of the Mid-Atlantic Bight abundance range from 8,000/100 m<sup>3</sup> to 200,000/100 m<sup>3</sup> in the November/December samples.

The copepod Centropages hamatus displays a markedly different pattern of abundance than its congener. In Southern New England inshore waters it rises from a winter minimum of 1,000/100 m<sup>3</sup> to a July maximum of 11,000/100 m<sup>3</sup>. This pattern is repeated in the midshelf waters; one order of magnitude lower in density. In the midshelf water there is a secondary fall peak not present in the shallow water. C. hamatus is never present in high numbers in the Southern New England offshore waters, and is totally absent in July and August.

In the Mid-Atlantic Bight, C. hamatus abundance also is greatest in the nearshore waters. Its density remains almost constant at 25,000/100 m<sup>3</sup> from February through July before falling to less than 100/100 m<sup>3</sup> in October. In midshelf waters C. hamatus is found from March to October and reaches a July peak of about 400/100 m<sup>3</sup>. As in Southern New England waters, this species is never abundant in offshore waters of the Mid-Atlantic Bight.

In contrast, Metridia lucens is most abundant in offshore waters. In Southern New England inshore water it reaches peak abundance (1,100/100 m<sup>3</sup>) in May, and again in November. It is present in greater numbers in the midshelf region, peaking in May at 12,000/100 m<sup>3</sup> before declining to a fall/winter plateau of 3,000/100 m<sup>3</sup>. In offshore waters of Southern New England M. lucens is present at a density of 100,000/100 m<sup>3</sup> throughout most of the year.

In the inshore waters of the Mid-Atlantic Bight the population of M. lucens is small and variable, reaching a peak of about 1,100/100 m<sup>3</sup> in June and November. It is more common in the deeper regions of this area, reaching peaks of about 10,000/100 m<sup>3</sup> and showing no marked seasonal pattern.

#### DISCUSSION

Observations on the zooplankton of the northeastern continental shelf made during the past half century (Bigelow, 1926; Bigelow and Sears, 1939; Grice and Hart, 1962; Judkins et al., 1980) can be divided into four periods: (i) the first measurement of volumes and species abundance made by Bigelow between 1912 and 1920, (ii) the volume measurements by Bigelow and Sears from 1929 to 1932, (iii) the volume and species measurements of Grice and Hart in 1960, and (iv) the more contemporary measurements of species abundance made by Judkins et al. in 1975. Data from these studies were converted where possible from volumes per standard haul and volumes per square meter to volumes per 100 m<sup>3</sup>; data from stations showing evidence of net clogging due to large amounts of gelatinous zooplankton, large numbers of organisms greater than 2.5 cm length or sampling gear and methods differing significantly from MARMAP methods were excluded. Throughout the sampling periods the mean seasonal zooplankton values of the earlier investigators were not significantly different from the mean values of the contemporary MARMAP data base (Table 2). In the earlier studies (Bigelow, 1926; Bigelow and Sears, 1939; Grice and Hart, 1962; Judkins et al., 1980) copepods were the predominant zooplankters: Calanus finmarchicus and Pseudocalanus minutus were

the most abundant species in the spring, with a shift to a Centropages typicus in late summer and autumn. These three species are important links in the energetics of the shelf ecosystem since

Table 2. Comparisons of zooplankton volumes (cc/100 m<sup>3</sup>) by subarea between MARMAP data and the earlier studies on the northeast continental shelf. No significant differences were found between MARMAP data and earlier studies in comparisons of displacement volumes (Kruskal Wallis  $P > 0.05$ ).

	Seasons							
	Late Winter	Early Spring	Late Spring	Early Summer	Late Summer	Early Autumn	Late Autumn	Early Winter
<u>Southern New England</u>								
MARMAP 1977-1981	13.2- 33.5	32.0- 66.5	46.7- 85.4	43.4- 54.4	57.4- 69.2	24.2- 60.9	21.4- 28.4	
Bigelow & Sears, 1929-1932	8.7- 19.5	59.6- 72.3	42.5- 93.0	40.3- 89.3		38.0- 40.6		
P	.180	.101	.631	.157		.770		
Grice & Hart, 1960	12			40	61	38	14	
P	.143			.180	.770	.380	.157	
<u>Mid-Atlantic Bight</u>								
MARMAP 1977-1981	11.8- 39.6	25.2- 51.5	29.5- 50.9	41.0- 73.2	50.4- 66.0	37.4- 76.0	70.1	
Bigelow & Sears, 1929-1932	33.6- 39.6	27.0- 48.7	24.7- 75.1	38.6- 52.4		44.8		
P	.180	.655	.715	.248		.380		

they provide food for larval, juvenile, and adult fish (Sherman and Honey, 1971; Sherman and Perkins, 1971; Marak, 1974; Sherman et al., 1981b; Cohen and Lough, 1982).

Our results provide evidence that the biomass and species composition of zooplankton have not changed substantially over the past 70 years. The persistent patterns of abundance and species dominance reflect coherence within the range of interannual variability observed since the early part of the century. These findings are in contrast with the 30-year decline in zooplankton, including the copepod component, reported for large areas of the

North Atlantic and North Sea (Colebrook, 1978b). It appears that the climatic changes influencing the zooplankton decreases in the Northeast Atlantic are more pronounced in the open ocean areas of the North Atlantic drift which in turn have greater impact on plankton in the North Sea (Colebrook, 1978a,b, 1982; Garrod and Colebrook, 1978). Based on MARMAP studies by the Northeast Fisheries Center, we have not detected large-scale influences of Gulf Stream eddies on populations of zooplankton or ichthyoplankton on the Northwest Atlantic shelf (Laurence and Burns, 1982; Cohen et al., 1982).

Within the Southern New England and Mid-Atlantic Bight subareas the distribution of zooplankton among three depth zones were different. Variation of zooplankton standing stocks and seasonal abundance patterns varied more among depth zones than between the Mid-Atlantic Bight and Southern New England areas. Other ecosystem measurements suggest that Southern New England is a transition zone between the oceanic Georges Bank area and the continental shelf west of the Hudson Canyon, in which the principal driving force appears to be the large estuarine outflow from the Delaware and Chesapeake Bays.

#### Mesoscale Sampling Strategies and Continental Shelf Perturbations

The fish stocks representing the mid-size predator component of the ecosystem of the northeast continental shelf have declined recently. During the period 1968 through 1975, the biomass of principal fish species declined approximately 50%. The decline was correlated with heavy fishing mortality (Clark and Brown, 1977). The relative stability observed in both zooplankton standing stock and species composition when considered in relation to the decline in finfish biomass and subsequent population explosion of fast-growing, short-lived zooplanktivorous sand eel (Sherman et al., 1981a) suggests that the reductions in fish abundance are not attributable to a lack of food at the lower end of the food chain. It appears that fishing mortality has imposed greater perturbations on fish populations of the northeast shelf than any changes in the abundance of zooplankton.

The mesoscale sampling strategies outlined in this report are designed to monitor large areas of the continental shelf ecosystem for significant changes due to chronic environmental perturbation. Possible short-term impacts of oil, gas, and mineral exploration and production and ocean dumping will need to be addressed with respect to the specific event. Specific zooplankton sampling strategies will be necessary to fully assess changes in the ecosystem and subsequent effects on fish stock recruitment from this type of environmental impact.

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#### LITERATURE CITED

- Bigelow, H. B. 1926. Plankton of the offshore waters of the Gulf of Maine. U.S. Bur. Fish. Bull. 40 (Part II): 1-509.
- Bigelow, H. B., and M. Sears. 1939. Studies of the waters on the continental shelf, Cape Cod to Chesapeake Bay. III. A volumetric study of the zooplankton. Mem. Mus. Comp. Zool., Har. Univ. 54: 179-378.
- Butman, B., R. C. Beardsley, B. Magnell, D. Frye, J. A. Vermersch, R. Schlitz, R. Limeburner, W. R. Wright, and M. A. Noble. 1982. Recent observations of the mean circulation on Georges Bank. J. Phys. Oceanogr. 12: 569-591.
- Clark, S. H., and B. E. Brown. 1977. Changes of biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-74, as determined from research vessel survey data. Fish. Bull., U.S. 75: 1-21.
- Clarke, G. L. 1940. Comparative richness of zooplankton in coastal and offshore areas of the Atlantic. Biol. Bull. (Woods Hole) 78: 226-255.
- Clarke, G. L., E. L. Pierce, and D. F. Bumpus. 1943. The distribution and reproduction of Sagitta elegans on Georges Bank in relation to hydrographical conditions. Biol. Bull. (Woods Hole) 85: 201-226.
- Clarke, G. L., and D. J. Zinn. 1937. Seasonal production of zooplankton off Woods Hole with special reference to Calanus finmarchicus. Biol. Bull. (Woods Hole) 76: 371-383.
- Cohen, E., D. Mountain, and W. Smith. 1982. Physical processes and year-class strength of commercial fish stocks on Georges Bank. EOS, Trans. Am. Geophys. Union 63(45): 956.
- Cohen, R. E., and R. G. Lough. 1982. Prey field of larval herring (Clupea harengus L.) on a continental shelf spawning area. Mar. Ecol. Prog. Ser. 10: 211-222.
- Colebrook, J. M. 1977. Annual fluctuations in biomass of taxonomic groups of zooplankton in the California Current, 1955-59. Fish. Bull., U.S. 75: 357-368.
- Colebrook, J. M. 1978a. Continuous plankton records. zooplankton and environment, northeast Atlantic and North Sea, 1948-1975. Oceanol. Acta 1: 9-23.
- Colebrook, J. M. 1978b. Changes in the zooplankton in the North Sea, 1948-1973. Rapp. P.-v. Réun. Cons. int. Explor. Mer 172: 390-396.

- Colebrook, J. M. 1982. Continuous plankton records. seasonal cycles of phytoplankton and copepods in the north Atlantic and the North Sea. *J. Plankton Res.* 4: 435-462.
- Dagg, M. J. 1978. Estimated, in situ, rates of eggs production for the copepod Centropages typicus (Kroyer) in the New York Bight. *J. Exp. Mar. Biol. Ecol.* 34: 183-196.
- Deevey, G. B. 1952. Quantity and composition of the zooplankton of Block Island Sound, 1949. *Bull. Bingham Oceanogr. Coll., Yale Univ.* 13: 120-164.
- Deevey, G. B. 1956. Oceanography of Long Island Sound, 1952-1954. V. Zooplankton. *Bull. Bingham Oceanogr. Coll., Yale Univ.* 15: 113-155.
- Deevey, G. B. 1960. Relative effects of temperature and food on seasonal variations in length of marine copepods in some eastern American and western European waters. *Bull. Bingham Oceanogr. Coll., Yale Univ.* 17: 54-86.
- Emery, K. O., and E. Uchupi. 1972. Western North Atlantic Ocean topography rocks, structure, water life and sediments. *Am. Assoc. Petrol. Geol. Mem.* 17: 1-532.
- Fager, E. W., and J. A. McGowan. 1963. Zooplankton species groups in the north Pacific. *Science* 140: 453-460.
- Fish, C. J. 1925. Seasonal distribution of the plankton of the Woods Hole region. *Bull. U. S. Bur. Fish.* 41: 91-179.
- Fish, C. J. 1936a. The biology of Calanus finmarchicus in the Gulf of Maine and Bay of Fundy. *Biol. Bull. (Woods Hole)* 70: 118-141.
- Fish, C. J. 1936b. The biology of Pseudocalanus minutus in the Gulf of Maine and Bay of Fundy. *Biol. Bull. (Woods Hole)* 70: 193-216.
- Garrod, D. J., and J. M. Colebrook. 1978. Biological effects of variability in the north Atlantic Ocean. *Rapp. P.-v. Réun. Cons. int. Explor. Mer* 173: 128-144.
- Glover, R. S. 1957. An ecological survey of the drift-net herring fishery off the northeast coast of Scotland. Part II: The planktonic environment of the herring. *Bull. Mar. Ecol.* 5(39): 1-43.
- Glover, R. S., G. A. Cooper, and D. C. T. Forsyth. 1961. An ecological survey of a Scottish herring fishery. Part III: Geographical and ecological groups in the plankton. *Bull. Mar. Ecol.* 5(47): 195-205.
- Grice, G. D., and A. D. Hart. 1962. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. *Ecol. Monogr.* 32(4): 287-308.

- Jacobson, J. 1980. The north Icelandic herring fishery and environmental conditions, 1960-1968. *Rapp. P.-v. Réun. Cons. int. Explor. Mer* 177: 460-465.
- Judkins, D. C., C. D. Wirick, and W. E. Esaias. 1980. Composition, abundance, and distribution of zooplankton in the New York Bight, September 1974-September 1975. *Fish. Bull., U.S.* 77: 669-683.
- Laurence, G. C., and B. R. Burns. 1982. Ichthyoplankton in shelf water entrained by warm-core rings. *EOS, Trans. Am. Geophys. Union* 63(45): 998.
- Laurence, G. C., J. R. Green, P. W. Fofonoff, and B. R. Burns. 1984. Small-scale spatial variability of plankton on Georges Bank with particular reference to prey organisms of larval cod and haddock. *MARMAP Contribution MED/NEFC 84-07. ICES 1984/L:9.*
- Malone, T. C. 1977. Plankton systematics and distribution. *MESA New York Bight Atlas Monograph No. 13, NY Sea Grant Institute, Albany, 45 p.*
- Marak, R. R. 1974. Food and feeding of larval redfish in the Gulf of Maine. In J. H. S. Blaxter (editor), *The Early Life History of Fish.* Springer-Verlag, Berlin, p. 267-275.
- Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys. *Biometrics* 39: 281-186.
- Posgay, J. A., and R. R. Marak. 1980. The MARMAP bongo zooplankton samplers. *J. Northw. Atl. Fish. Sci.* 1: 91-99.
- Sherman, K. 1968. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1965 and 1966. *U.S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish.* 562.
- Sherman, K. 1970. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1967 and 1968. *U.S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish.* 594.
- Sherman, K. 1976. Seasonal distributions of the copepod food of herring in coastal waters of the Gulf of Maine. *ICNAF Res. Doc.* 76-VI/82.
- Sherman, K. 1980. MARMAP, a fisheries ecosystem study in the NW Atlantic: Fluctuations in ichthyoplankton-zooplankton components and their potential for impact on the system. In F. P. Diemer, F. J. Vernberg, and D. Z. Mirkes (editors), *Advanced Concepts on Ocean Measurements for Marine Biology.* Belle W. Baruch Institute for Marine Biology and Coastal Research. Univ. S. C. Press, Columbia, p. 9-37.
- Sherman, K., J. R. Green, J. R. Goulet, and L. Ejsymont. 1983. Coherence in zooplankton of a large Northwest Atlantic ecosystem. *MARMAP Contribution MED/NEFC 82-68. Fish. Bull. U.S./ 81(4): (in press).*
- Sherman, K., and K. A. Honey. 1971. Seasonal variations in the food of larval herring in the coastal waters of central Maine. *Rapp. P.-v. Réun. Cons. int. Explor. Mer* 160: 121-124.

- Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981a. Congruent shifts in sand eel abundance in western and eastern north Atlantic ecosystems. *Nature* 291: 486-489.
- Sherman, K., R. Maurer, R. Byron, and J. Green. 1981b. Relationship between larval fish communities and zooplankton prey species in an offshore spawning ground. *Rapp. P.-v. R en. Cons. int. Explor. Mer* 178: 289-294.
- Sherman, K., and H. C. Perkins. 1971. Seasonal variations in the food of juvenile herring in coastal waters of Maine. *Trans. Am. Fish. Soc.* 100(1): 121-124.
- Wickett, W. P. 1967. Ekman transport and zooplankton concentration in the north Pacific Ocean. *J. Fish. Res. Board CXan.* 24: 581-594.
- Williamson, M. H. 1961. An ecological survey of a Scottish herring fishery. Part IV: changes in the plankton during the period 1949 to 1959. *Bull. Mar. Ecol.* 5(48): 207-229.

# Benthic Macrofauna of the Middle Atlantic Continental Shelf

by

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## INTRODUCTION

This chapter synthesizes data on the benthic macrofauna (here defined as those invertebrates which are collected in bottom samplers and retained on sieves of 0.5 mm or greater mesh size) of the Middle Atlantic Water Management Unit (WMU). Information on the benthic macrofauna can aid managers in several ways:

- 1) Benthic macrofauna are important as food for harvestable species. Changes in distribution, abundance and quality of forage can impair survival, growth and/or reproduction of fish and shellfish.
- 2) The benthos can also absorb and concentrate contaminants from sediments, bottom waters and sediment pore waters and pass these contaminants, via food webs, to resource or endangered species.
- 3) Their relative immobility and intimate association with sediments (the largest contaminant sink) make benthic invertebrates perhaps the best faunal group for monitoring many biological effects of environmental change. They can thus provide an "early warning" of environmental changes which can possibly later affect harvestable or endangered species.

Using benthic data to monitor environmental change usually requires detailed statistical analysis of large faunal data sets in conjunction with other data (e.g. sediment types and contaminant loads). It is not the purpose of this synthesis to present these data. Most of the data are discussed in published reports, and are also contained on computer files, where they can best be analyzed. Such analyses are ongoing or have recently been completed in several baseline/monitoring programs in the Middle Atlantic. Data available for detailed analyses, and their sources, are summarized in Section 2. Section 3 briefly presents information from several surveys on numerically dominant species in the WMU. The chapter then concentrates on those features of the benthic macrofauna that can be of more immediate use to managers in examining threats to living marine resources. These features include biomass (Section 4), production (Section 5) and forage value (Section 6) of major groups (e.g. crustaceans, polychaetes, molluscs, echinoderms). Contaminant

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uptake and transfer through food webs are only briefly discussed (Section 7), since they are covered in more detail in the chapter on Contaminant Input, Fate and Biological Effects. Some of these topics have previously been reviewed, but not specifically for the Middle Atlantic WMU, and/or not with the present emphasis on use of benthic information in managing living marine resources. Section 8 summarizes the chapter.

At present, links between the benthos (as forage, contaminant source and "early warning" biota) and harvestable or endangered species are generally qualitative at best. We cannot quantitatively extrapolate from observed or predicted changes in benthic standing crops or contaminant burdens to effects on fish and shellfish populations. As progress in quantifying these links continues, however, the material presented below will become more useful in understanding and possibly managing effects of environmental change on harvestable species.

#### PAST AND PRESENT BENTHIC STUDIES ON THE MIDDLE ATLANTIC SHELF

This section summarizes the major modern data sets available as of September 1984 for the Middle Atlantic WMU; it is not intended to be all-inclusive. Spatial coverage of each data set is shown in Figure 1 for studies which have not concentrated on the New York Bight. The numerous, often overlapping, studies within the New York Bight are indicated separately in Figure 2. Dates and methods are given in Table 1. The first survey to sample quantitatively the benthic macrofauna throughout the Middle Atlantic Bight was by the National Marine Fisheries Service (NMFS), with most sampling done between 1962 and 1965 (Wigley and Theroux 1981). That reference also lists earlier work in the area, most of which was non-quantitative and dealt only with bays, sounds and inner shelf waters. A review by Pratt (1973) of the Middle Atlantic benthos also notes a number of these studies. The earlier work is not included in Figures 1 or 2 or Table 1.

The only other sampling spanning the entire Middle Atlantic is that begun in 1978 by the NMFS Ocean Pulse (OP) Program, and continued when Ocean Pulse was integrated into NOAA's Northeast Monitoring Program (NEMP) in 1980. A third spatially extensive survey is the Virginia Institute of Marine Science's (VIMS) benchmark sampling for the then Bureau of Land Management in 1975-77, from off northern Virginia to central New Jersey (Boesch 1979).

The 1960s NMFS survey occupied many more stations (approximately 332 on the Middle Atlantic shelf) than either the NEMP-OP (25 stations) or VIMS (46 stations) surveys. However, the latter two surveys replicated sampling, repeated occupation of stations, and used smaller mesh sieves giving more complete information on the smaller macrofauna present; these were generally not features of the earlier survey. This chapter will therefore emphasize the VIMS data (which have already been synthesized by Boesch [1979]), augmented by NEMP data for portions of the WMU outside the coverage of the VIMS survey. The Wigley and Theroux (1981) data will be used to describe broad spatial patterns in benthic biomass.

#### SPATIAL PATTERNS IN MIDDLE ATLANTIC BENTHIC COMMUNITY STRUCTURE

Pratt (1973) reviewed most information available through 1972 and classified the benthos of the Middle Atlantic into three broad faunal zones

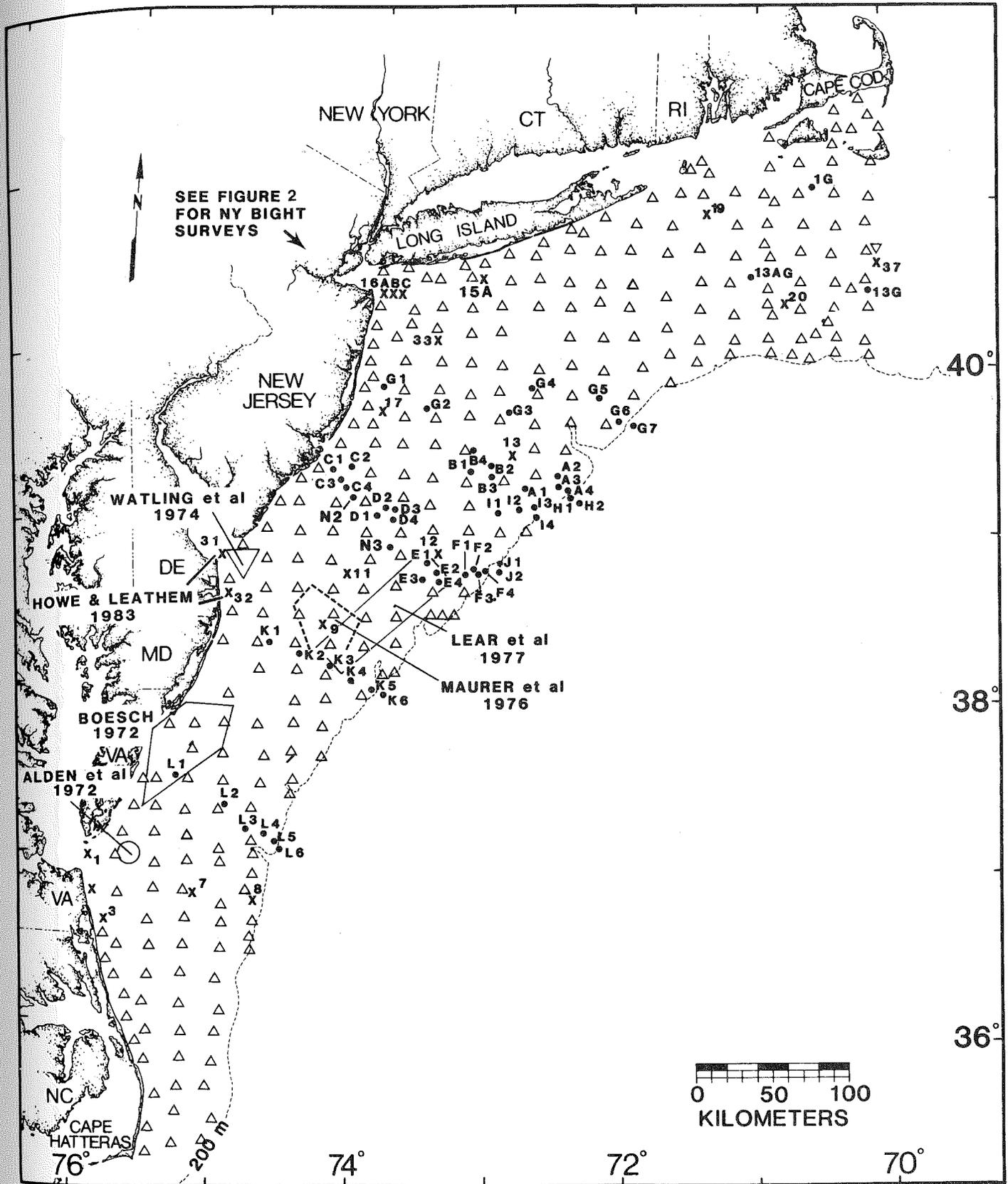


Figure 1. Approximate sampling locations for Middle Atlantic benthic surveys.  $\Delta$ =NMFS 1962-65 samplings; X=NEMP-OP 1978-present; other letter prefixes = VIMS 1975-79; station 1G is from 1977-78 Georges Bank monitoring. See Table 1 for details of each survey. Locations of New York Bight surveys are shown in Figure 2.

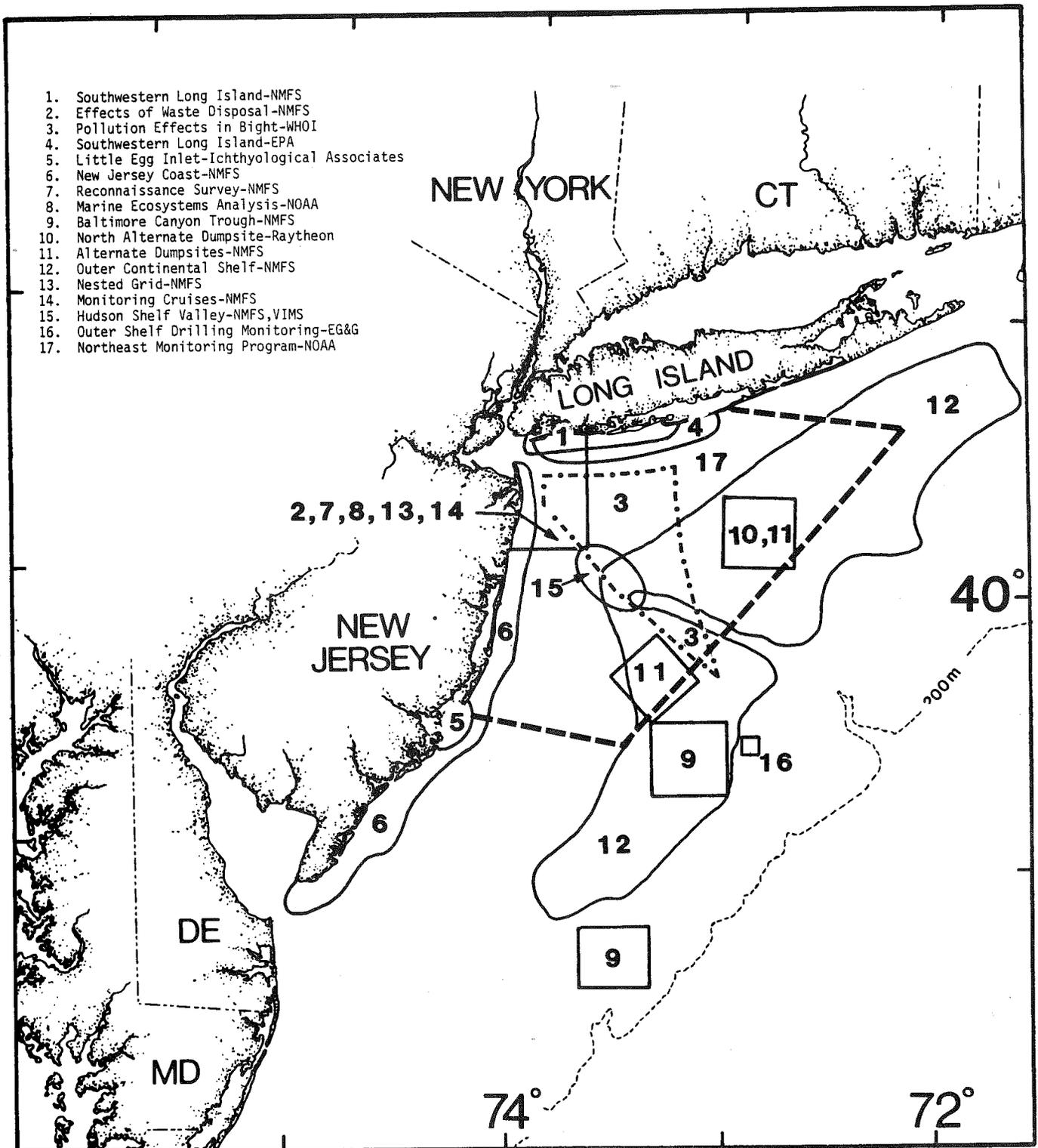


Figure 2. Existing surveys in the New York Bight portion of the Middle Atlantic Water Management Unit. Modified from Pearce et al. (1981). See Table 1 for details of each survey.

Table 1. Summary of benthic surveys in the Middle Atlantic Water Management Unit.

Survey and Reference(s)	Year(s)	Sampler(s) and Area of Samples	Sieve Size (mm)	Number of Stations	Replicates per Station	Station Sampling Frequency
<b>A. REGIONAL</b>						
1. National Marine Fisheries Service (Wigley and Theroux 1981)	1962-65	Van Veen (0.1 m <sup>2</sup> ) Smith McIntyre (0.1 m <sup>2</sup> ) Campbell (0.56 m <sup>2</sup> )	1.0	~332	1-2	Once
2. Virginia Institute of Marine Science (Boesch et al. 1977, 1979)	1975-77	Smith-McIntyre (0.1 m <sup>2</sup> )	0.5	46+	6	Eight quarterly samplings
3. National Marine Fisheries Service-Ocean Pulse and Northeast Monitoring Program (Reid et al. 1984)	1978-present	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0 until December 1979, then 0.5	25	5	Semiannual except quarterly in 1979
<b>B. NEW YORK BIGHT</b>						
1. Southwestern Long Island-NMFS (Steimle and Stone 1973)	1966-67	Petersen (0.06 m <sup>2</sup> )	1.0	39	1	Eleven monthly samplings
2. Effects of Waste Disposal (National Marine Fisheries Service 1972)	1968-72	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	240	1	Variable
3. Pollution Effects in Bight-Woods Hole Oceanographic Institution (Rowe 1971)	1968-71	Van Veen (0.2 and 0.04 m <sup>2</sup> ) Birge-Ekman (0.02 m <sup>2</sup> )	0.42-1.0	39	1	Once
4. Southwestern Long Island-EPA (Swartz et al. 1976)	1972-78	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	39	3-5	Quarterly 1972-75, then semiannual
5. Little Egg Inlet-Ichthyological Associates (Garlo et al. 1979)	1972-76	Ponar (0.05 m <sup>2</sup> )	1.0	53+	1-5	Once to monthly (1975)
6. New Jersey Coast-NMFS (Radosh unpublished) <sup>1</sup>	1973	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	246	1	Once
7. Reconnaissance Survey-NMFS (Pearce et al. 1978)	1973	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	29	5-20	Once
8. Marine Ecosystems Analysis Grid-NOAA (Pearce et al. 1977c)	1973-74	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	103	5	Five quarterly samplings

Table 1. (continued)

Survey and Reference(s)	Year(s)	Sampler(s) and Area of Samples	Sieve Size (mm)	Number of Stations	Replicates per Station	Station Sampling Frequency
9. Baltimore Canyon Trough-NMFS (Radosh et al. 1978)	1974	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	93	1-2	Once
10. North Alternate Dumpsite-(Raytheon 1977)	1974-75	Smith-McIntyre (0.1 m <sup>2</sup> )	0.5	15	5	Three times
11. Alternate Dumpsites-NMFS (Caracciolo-Ward and Steimle 1984)	1974-75, 1978	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	69	1-5	One to three times
12. Outer Continental Shelf-NMFS (Pearce et al. 1977b)	1975	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	60	5	Once
13. Nested Grid-NMFS (Pearce et al. 1977a)	1975	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	24	2	Once
14. Monitoring Cruises-NMFS (Caracciolo et al. 1978)	1975-76	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	13-15	2	Twice
15. Hudson Shelf Valley-VIMS (Boesch unpublished) <sup>2</sup>	1978	Smith-McIntyre (0.1 m <sup>2</sup> )	1.0	3	2	Once
16. Outer Shelf Drilling Monitoring-EG&G (1982)	1978-80	Smith-McIntyre (0.1 m <sup>2</sup> ) Ponar (0.1 m <sup>2</sup> )	0.5	40-48	6	Annual
17. Northeast Monitoring Program-NOAA (Reid et al. 1982)	1980-present	Smith-McIntyre (0.1 m <sup>2</sup> )	0.5	44-135	1-5	Annual
C. OTHER SURVEYS						
1. Northern Virginia Inner Shelf-VIMS (Boesch 1972)	1961-68	Van Veen (0.2 m <sup>2</sup> )	1.0	48	1	Once
2. Delaware Inshore Dumpsite-Univ. of Delaware (Watling et al. 1974)	1972	Van Veen (0.1 m <sup>2</sup> )	1.0	27	1	Once
3. Delmarva Peninsula-Univ. of Delaware (Maurer et al. 1976)	1973	Shipek (0.04 m <sup>2</sup> )	0.25	16	3-5	Once to twice
4. Philadelphia Dumpsites-EPA (Lear et al. 1977, pers. comm.) <sup>3</sup>	1973-81	Shipek (0.04 m <sup>2</sup> )	0.5	variable	3	30 cruises

Table 1. (continued)

Survey and Reference(s)	Year(s)	Sampler(s) and Area of Samples	Sieve size (mm)	Number of Stations	Replicates per Station	Sampling Frequency
5. Georges Bank Monitoring-ERCO (Maurer and Leathem 1980)	1977-78	Smith-McIntyre (0.1 m <sup>2</sup> )	0.5	42	6	Quarterly
6. Norfolk Dumpsite-Old Dominion Univ. (Alden et al. 1982)	1979-present	Shipek (0.04 m <sup>2</sup> )	0.5	5	5	Quarterly
7. Northeast Monitoring Program-NOAA/Univ. of Delaware Production Study (Howe and Leathem 1984)	1981-82	Smith-McIntyre (0.1 m <sup>2</sup> )	0.5	2	6	Bimonthly
8. Georges Bank Monitoring-Battelle-Woods Hole Oceanographic Institution (Maciolek-Blake et al. 1983)	1981-84	Van Veen (0.04 m <sup>2</sup> )	0.3	46	6	Quarterly

<sup>1</sup>D. Radosh, NOAA/NMFS, Sandy Hook Laboratory, Highlands, New Jersey 07732.

<sup>2</sup>D. Boesch, Louisiana Universities Marine Consortium, Chauvin, Louisiana 70344.

<sup>3</sup>D. Lear, 103 Spring Valley Drive, Annapolis, MD 21403.

related to water depth and sediment type (Figure 3). A "sand fauna" zone was defined for sandy sediments which are at least occasionally disturbed by waves; this occurs from depths of a few meters to 30-50 m, depending on exposure. Offshore of this was a zone termed "silty sand fauna" in stable sands containing at least a few percent silt, and more organic material than the sand zone (2% vs 1%). There are not distinct boundaries between the sand and silty sand zones. Silts and clays become predominant beyond a "mud line", which is usually found near the shelf edge but extends 40 miles (64 km) onto the shelf off southern New England. Fine sediments also floor much of the Hudson Shelf Valley, the drowned river valley extending from the apex of the New York Bight to the shelf edge. Pratt called the species characteristic of these sediments the "silt-clay fauna".

Based on extensive sampling in 1975-77, Boesch (1979) refined this scheme for the portion of the WMU from off northern Virginia through New Jersey. In most of this area, sediments are dominated out to the shelf edge by sand with little finer material, and no clear "mud line" is present. Since much overlap of species distributions was found on the shelf and upper slope, the faunal assemblages were considered to represent a continuum rather than occupying distinct zones. Still, changes were more evident in certain areas than in others, and five bathymetric subdivisions (Figure 3) were defined based on their species compositions. The inner shelf faunal subdivision extends from shore to 30 m depth, with portions characterized by coarse sands and other parts, especially off Maryland and Virginia, finer sands. The central shelf is from 30-50 m. (These two subdivisions together are similar to Pratt's "sand fauna" zone). There is an outer shelf region (50-100 m), roughly equivalent to Pratt's "silty sand" zone. The sharpest faunal changes are near the shelf break; this area (from 100-200 m) includes most of Pratt's "silt-clay fauna" zone. Beyond the shelf break is the continental slope zone.

Superimposed on the cross-shelf zonation is a smaller-scale pattern based on the ridge and swale (i.e., crest and valley of a large sand wave) topography found over much of the Middle Atlantic shelf (Boesch 1979; Stumpf and Biggs this volume). Distribution of major ridge fields in the VIMS study area is shown in Figure 3. Boesch (1979) presented a generalized picture (Figure 4) of the dimensions, sediment characteristics and associated faunal patterns of a typical ridge-swale system. Ridges, being on the order of 10 m higher than adjacent swales, are exposed to more energy from water currents. Ridges thus experience more sediment mobility than swales, and contain less fine sand, silt and clay. The relatively sheltered, depositional swales also accumulate more fine sediment-associated contaminants, such as trace metals and hydrocarbons. Benthic macrofaunal density, species richness and biomass are all greater in swales, due in part to the increased abundance of detrital food and the physically less rigorous conditions. Boesch points out that the greater biomass and potential to accumulate contaminants make swale fauna both more valuable and more vulnerable than fauna on ridges or other shelf areas.

Species composition differs between ridge and swale as it does over the major cross-shelf bathymetric subdivisions identified above. Boesch (1979) therefore divided the shelf in his study area into five habitats to present data on characteristic fauna: inner shelf, central shelf, central and inner shelf swales, outer shelf and outer shelf swales. Numerically dominant benthic species for each habitat are listed in Table 2. Table 2 also lists the living position (e.g., tube-dweller, burrower) and feeding category

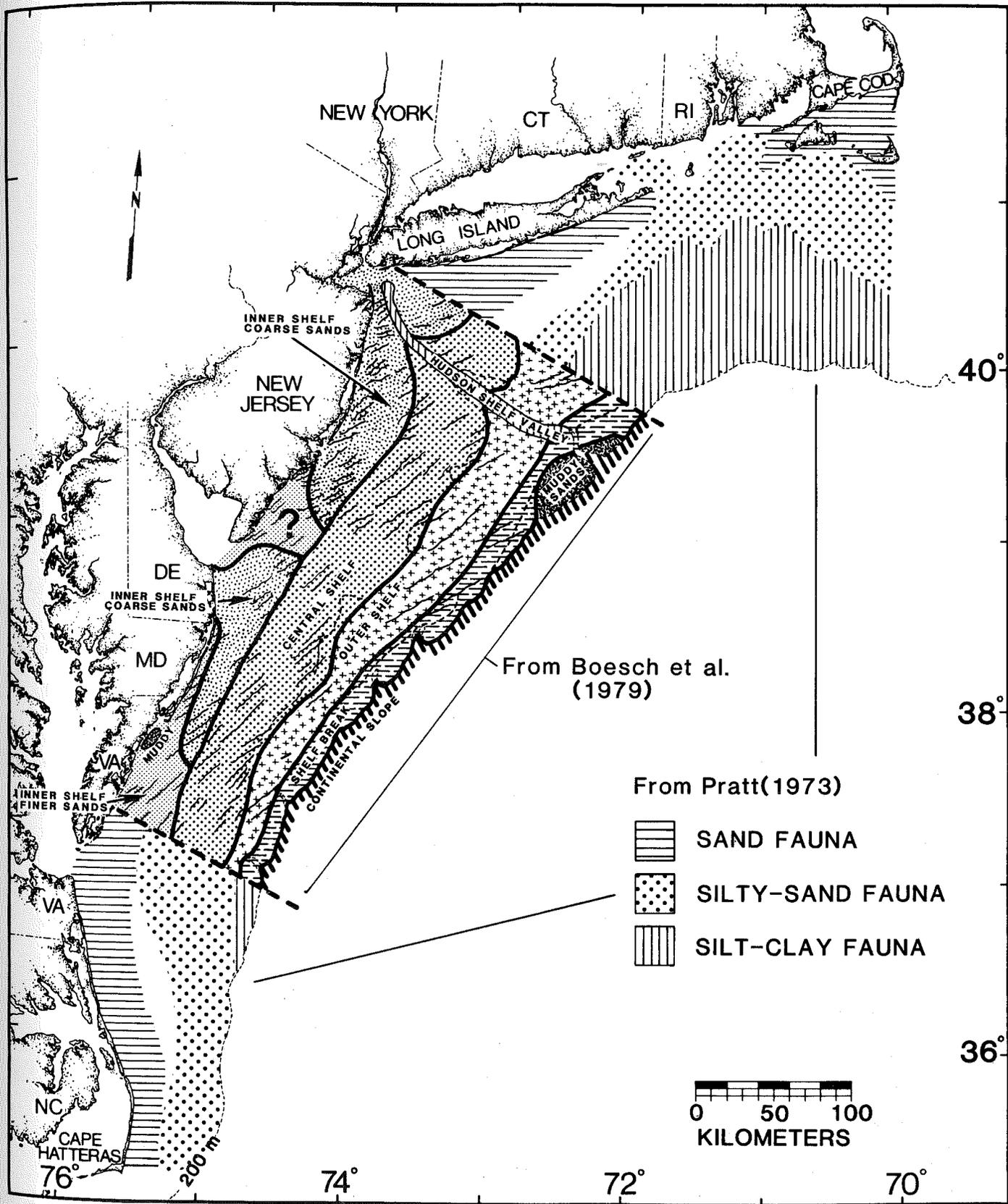


Figure 3. Schematic representation of major macrofaunal zones on the Middle Atlantic shelf. Approximate location of ridge fields indicated. From Boesch (1979) and Pratt (1973).

PATTERNS RELATED TO LOCAL TOPOGRAPHY-BENTHIC REALM  
N.J. OUTER SHELF

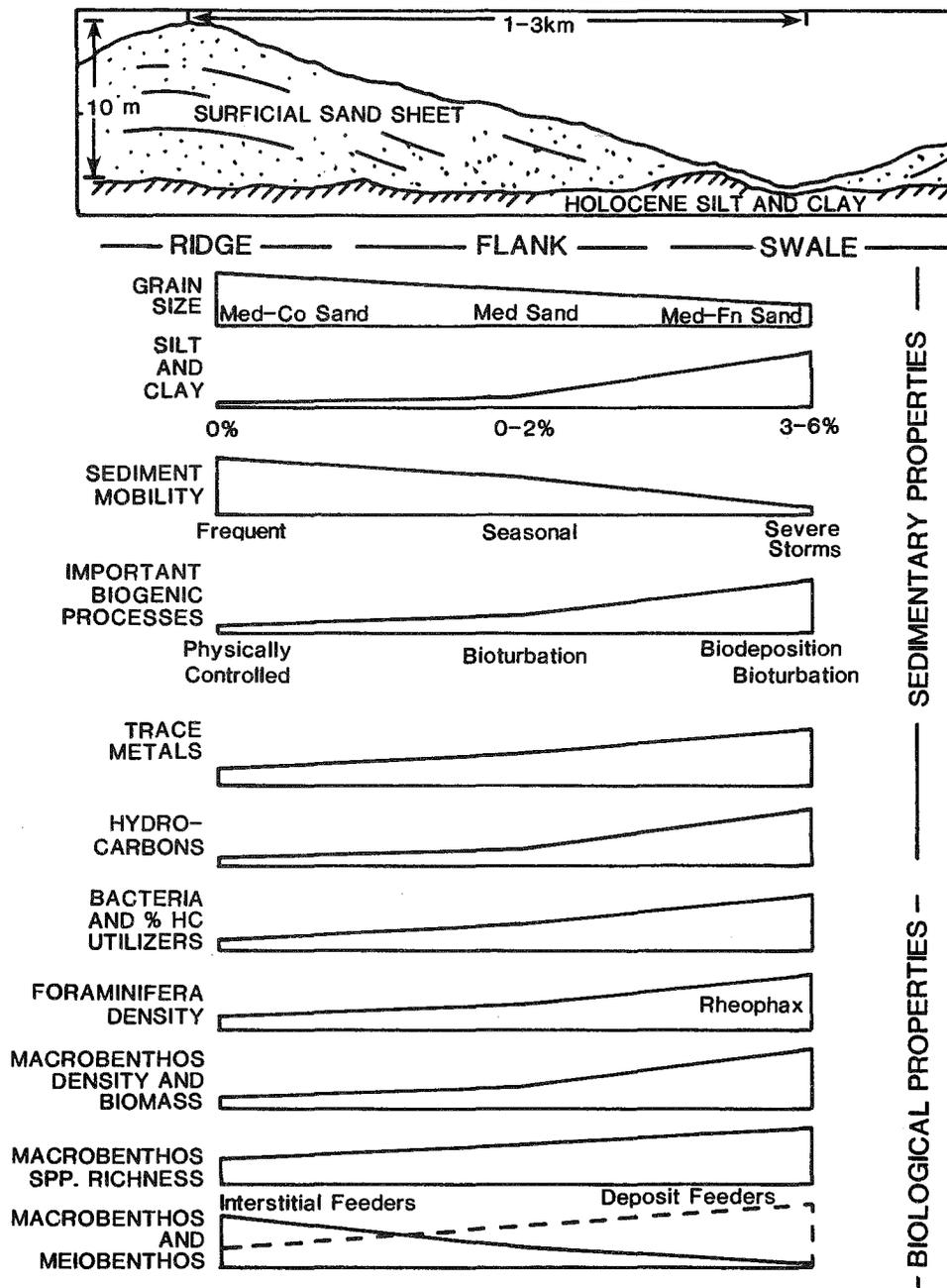


Figure 4. Benthic trends related to local topography observed during fall 1975-summer 1976, BLM-sponsored OCS studies in the Middle Atlantic. From Boesch (1979). Trends are generally similar to those found from the inner to outer shelf.

Table 2. Numerically dominant species in major bathymetric habitats (A = amphipod, B = bivalve, C = cumacean, E = echinoid, G = gastropod, Op = ophuroid, Os = ostracod, P = polychaete). Listed are geometric mean density and living position-feeding category (B = burrower, C = carnivore, D = subsurface deposit feeder, E = epifaunal, F = fossorial, I = interstitial feeder, P = suspension feeder, S = surface deposit feeder, T = tubicolous). Modified from Boesch (1979).

Species	Geometric mean density (m <sup>-2</sup> )	Living position/feeding category
<b>INNER SHELF</b>		
<i>Polygordius</i> sp. (P)	315.4	I
<i>Goniadella gracilis</i> (P)	307.6	I
<i>Spiophanes bombyx</i> (P)	276.3	T-S
<i>Tanaissus liljeborgi</i> (T)	227.5	I
<i>Tellina agilis</i> (B)	132.9	B-S
<i>Lumbrinerides acuta</i> (P)	83.8	I
<i>Spiula solidissima</i> (P)	56.7	B-P
<i>Pseudunciola obliquua</i> (A)	55.6	T-S
<i>Nephtys picta</i> (P)	39.1	B-D
<i>Echinarachnius parma</i> (E)	33.1	E-S
<b>CENTRAL SHELF</b>		
<i>Spiophanes bombyx</i> (P)	219.1	T-S
<i>Pseudunciola obliquua</i> (A)	200.0	T-S
<i>Goniadella gracilis</i> (P)	113.7	I
<i>Rhepoxynius epistomus</i> (A)	92.3	F
<i>Spiula solidissima</i> (B)	88.6	B-P
<i>Tanaissus liljeborgi</i> (T)	78.9	I
<i>Echinarachnius parma</i> (E)	63.3	E-S
<i>Byblis serrata</i> (A)	54.2	T-S
<i>Protohaustorius wigleyi</i> (A)	53.9	F
<i>Lumbrinerides acuta</i> (A)	25.3	I
<b>CENTRAL AND INNER SHELF SWALES</b>		
<i>Spiophanes bombyx</i> (P)	798.7	T-S
<i>Lumbrineris impatiens</i> (P)	292.5	B-D
<i>Polygordius</i> sp. (P)	276.0	I
<i>Nucula proxima</i> (B)	214.6	B-D
<i>Tellina agilis</i> (B)	195.8	B-S
<i>Nucula delphinodonta</i> (B)	168.4	B-D
<i>Cytheretta edwardsi</i> (Os)	153.1	E-S
<i>Clymenella torquata</i> (P)	126.1	T-D
<i>Rhepoxynius epistomus</i> (A)	111.0	F
<i>Unciola irrorata</i> (A)	93.0	T-S

Table 2. (continued)

Species	Geometric mean density (m <sup>-2</sup> )	Living-position feeding category
OUTER SHELF		
<i>Ampelisca vadorum</i> (A)	460.4	T-S
<i>Spiophanes bombyx</i> (P)	329.0	T-S
<i>Erichthonius rubricornis</i> (A)	302.2	T-S
<i>Unciola irrorata</i> (A)	260.0	T-S
<i>Clymenella zonalis</i> <sup>1</sup> (P)	233.0	T-D
<i>Ampelisca agassizi</i> (A)	215.2	T-S
<i>Goniadella gracilis</i> (P)	188.0	I
<i>Byblis serrata</i> (A)	148.9	T-S
<i>Exogone naidina</i> <sup>1</sup> (P)	132.0	B-C, S
<i>Euchone</i> sp. A (P)	111.1	T-P
<i>Lumbrinerides acuta</i> (P)	91.0	I
<i>Unciola inermis</i> <sup>1</sup> (A)	72.4	T-S
<i>Aricidea cerruti</i> <sup>1</sup> (P)	66.8	B-S
<i>Rhepoxynius epistomus</i> (A)	63.7	F
OUTER SHELF SWALES		
<i>Ampelisca agassizi</i> (A)	7054.2	T-S
<i>Unciola irrorata</i> (A)	552.7	T-S
<i>Erichthonius rubricornis</i> (A)	464.0	T-S
<i>Diastylis bispinosa</i> (C)	332.0	F
<i>Photis dentata</i> (A)	238.4	T-S
<i>Lumbrineris impatiens</i> (P)	217.5	B-D
<i>Notomastus latericeus</i> (P)	189.0	B-D
<i>Euchone</i> sp. A (P)	172.5	T-P
<i>Eudorella pusilla</i> (C)	149.5	F
<i>Echinarachnius parma</i> <sup>1</sup> (E)	130.5	E-S, P
<i>Mitrella dissimilis</i> <sup>1</sup> (G)	86.8	E-C
<i>Spiophanes bombyx</i> (P)	85.1	T-S
<i>Polydora socialis</i> <sup>1</sup> (P)	79.0	T-S
<i>Cerastoderma pinnulatum</i> <sup>1</sup> (B)	60.7	B-P
<i>Scalibregma inflatum</i> (P)	60.3	B-D
OTHER ABUNDANT MIDDLE ATLANTIC SPECIES; HABITATS AND DENSITIES NOT REPORTED		
<i>Magelona</i> spp. <sup>2,3</sup> (P)		B-S
<i>Aglaophamus cinginata</i> <sup>4</sup> (P)		B-O
<i>Nephtys picta</i> <sup>2,3</sup> (P)		B-O
<i>Nephtys bucera</i> <sup>3</sup> (P)		B-O
<i>Sphaerosyllis erinaceus</i> <sup>4</sup> (P)		I-S
<i>Asychis elongata</i> <sup>3</sup> (P)		T-D
<i>Parapionosyllis longicingrata</i> <sup>4</sup> (P)		I-C
<i>Nereis arenaceodentata</i> <sup>3</sup> (P)		I-C

Table 2. (continued)

Species	Geometric mean density (m <sup>-2</sup> )	Living-position feeding category
<i>Axiothella</i> sp. <sup>4</sup> (P)		T-D
<i>Ophelia</i> sp. <sup>3</sup> (P)		B-D
<i>Schistomeringos caeca</i> <sup>4</sup> (P)		C-S
<i>Chaetozone setosa</i> <sup>4</sup> (P)		B-S
<i>Scoloplos fragilis</i> <sup>3</sup> (P)		B-D
<i>Sthenelais limicola</i> <sup>3</sup> (P)		B-C
<i>Arctica islandica</i> <sup>2</sup> (B)		B-P
<i>Cyclocardia borealis</i> <sup>2</sup> (B)		B-P
<i>Spisula solidissima</i> <sup>2,3</sup> (B)		B-P
<i>Ensis directus</i> <sup>3</sup> (B)		B-P
<i>Tellina agilis</i> <sup>3</sup> (B)		B-S
<i>Colus pygmaeus</i> <sup>2</sup> (G)		B-C
<i>Lunatia heros</i> <sup>2,3</sup> (G)		B-C
<i>Polinices duplicatus</i> <sup>2,3</sup> (G)		B-C
<i>Margarites groenlandicus</i> <sup>2</sup> (G)		B-S
<i>Nassarius trivittatus</i> <sup>2</sup> (G)		E-C
<i>Protohaustorius deichmannae</i> <sup>2</sup> (A)		B-P
<i>Protohaustorius wigleyi</i> <sup>2</sup> (A)		B-P
<i>Cirolana concharum</i> <sup>2</sup> (I)		B-O
<i>Cirolana polita</i> <sup>2</sup> (I)		B-O
<i>Chiridotea arenicola</i> <sup>2</sup>		B-O
<i>Leptocuma minor</i> <sup>2</sup> (C)		B-P
<i>Tanaissus liljeborgi</i> <sup>4</sup> (T)		I-C
<i>Crangon septemspinosus</i> <sup>3</sup> (D)		E-O
<i>Cancer borealis</i> <sup>2</sup> (D)		E-C
<i>Cancer irroratus</i> <sup>2,3</sup> (D)		E-C
<i>Asterias forbesi</i> <sup>2</sup> (As)		E-C
<i>Asterias vulgaris</i> <sup>2</sup> (As)		E-C

<sup>1</sup>NMFS data (Radosh et al. 1978) for dominant species

<sup>2</sup>Maurer et al. (1976)

<sup>3</sup>Pratt (1973)

<sup>4</sup>Lear (pers. comm.)

Table 3. Selected mean wet weight benthic macrofauna biomass values for the western North Atlantic continental shelf (from Steimle 1985).

Area	Biomass (g m <sup>-2</sup> )	Screen size (mm)	Reference
Labrador	22	1.0	Nesis (1970)
Nain Bay, Labrador	458	?	Mills (1975)
Newfoundland	65	1.0	Nesis (1970)
Grand Banks	461	1.0	Nesis (1970)
Flemish Cap	25	1.0	Nesis (1970)
N. Nova Scotia	175	1.0	Nesis (1970)
Scotian Shelf	23	?	Mills and Fournier (1979)
Georges Bank	234/314	1.0/0.5	Steimle (in press)
Southern New England <sup>1</sup>	246	1.0	Maurer and Wigley (1981)
Block Island Sound <sup>1</sup>	158	1.0	Steimle (1982)
New York Bight Shelf <sup>1</sup>	282	1.0	Wigley and Theroux (1981)
New York Bight <sup>1</sup>	238	0.5	Steimle (1985)
Christiaensen Basin and Valley <sup>1</sup>	191	0.42	Rowe (1971)
Chrstiaensen Basin and Valley <sup>1</sup>	127/344	1.0/0.5	Steimle (1985)
NJ-VA Continental Shelf <sup>1</sup>	~280	0.5	Boesch (1979)
Chesapeake Bight <sup>1</sup>	101	1.0	Wigley and Theroux (1981)

<sup>1</sup>Middle Atlantic Bight values

(subsurface deposit feeder, carnivore, etc.) for these species. Such information can be useful in assessing ecological roles and effects of man's activities.

#### SPATIAL AND TEMPORAL TRENDS IN BENTHIC BIOMASS

Numerical densities are one index of benthic species abundance. However, the species with highest densities are often very small and less important in food webs than larger, less abundant organisms. Biomass, or standing crop, gives a better indication of the potential availability of food for resource species.

The most spatially comprehensive survey of benthic biomass levels and distribution in the Middle Atlantic Bight was the NMFS 1962-1965 study (Wigley and Theroux 1981). This survey was conducted only during the summer, and for the most part only single samples were taken at each station. Although a single sample is usually inadequate to assess biomass at a station with confidence, the accumulated data from all stations probably suffice to estimate broad or mesoscale patterns (Figure 5). The benthic biomass data, based on replicate sampling at each station, of Boesch (1979) and Steimle (1985) are in general agreement with the basic mesoscale patterns suggested by Wigley and Theroux (1981). There are however, differences at smaller scales and in areas not sufficiently covered by the Wigley and Theroux survey, e.g. around the New York Bight apex dumpsites. In general, mean levels of macrofaunal biomass found by various surveys in the Middle Atlantic Bight are comparable to levels found in other important fishery areas, e.g. Georges Bank, and greater than values for most other shelf areas of the North Atlantic (Table 3).

Wigley and Theroux (1981) found the benthic biomass (Figure 6) of the Middle Atlantic Bight to be generally dominated by molluscs, which contributed an average of 71% of the overall biomass in that region. In the New York Bight, the ocean quahog (*Arctica islandica*) is the mollusc species comprising most of the biomass in deeper silty-sand areas (Caracciolo-Ward and Steimle 1984; Steimle 1985), although surf clams (*Spisula solidissima*) are dominant in shallower, sandy inshore areas (see also the chapter on commercial shellfish). There were areas where other taxa were dominant, especially sand dollars (Echinodermata:Echinoidea). Echinoderms made up 12% of the benthic biomass, with annelids 7%, arthropods 5%, and all other taxa 5%. The distributions of polychaete annelids and crustacean arthropods, primarily amphipods and decapods, are of particular interest because of their relative importance in the diets of resource species (discussed in detail later). Although their biomass levels are low compared to those of molluscs and echinoderms, their generally greater food energy value (twice that of shelled molluscs and echinoderms), productivity (triple), and the general tolerance of polychaetes and intolerance of crustaceans to anthropogenic disturbance, make them potentially more important to resource managers. Figure 7 shows that crustacean biomass is rather evenly distributed, with slightly higher concentrations off southern New England. Polychaete biomass is similarly uniform except for higher levels in the "Mud Patch," a depositional area on the southern New England shelf. Boesch (1979) has shown that, at smaller scales, these taxa and many molluscs are found at higher concentrations in the silty depressions and swales of the shelf than in coarse sand environments.

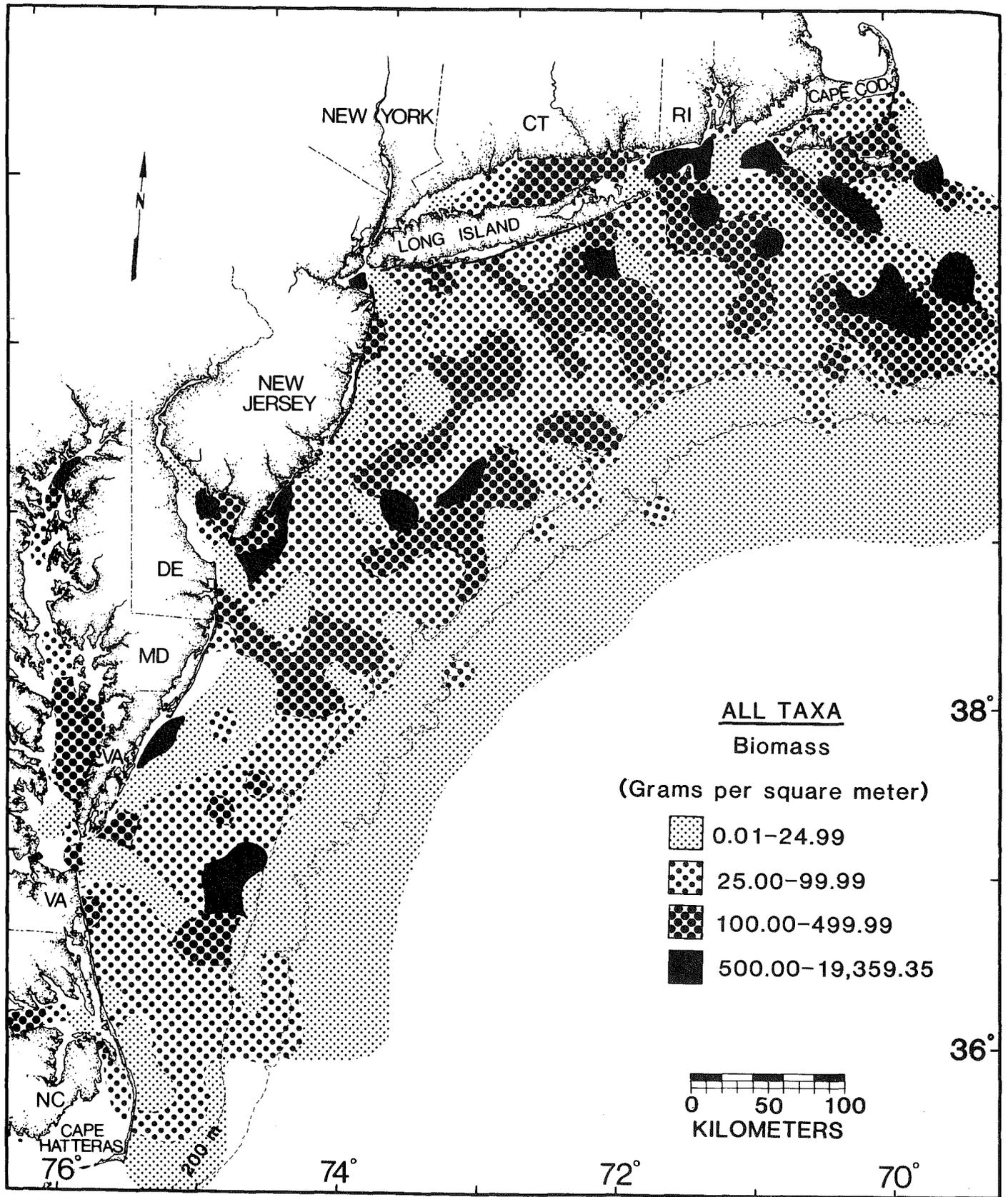


Figure 5. Geographic distribution of the biomass of all taxonomic groups combined and expressed as damp weight per square meter of bottom area. From Wigley and Theroux (1981).

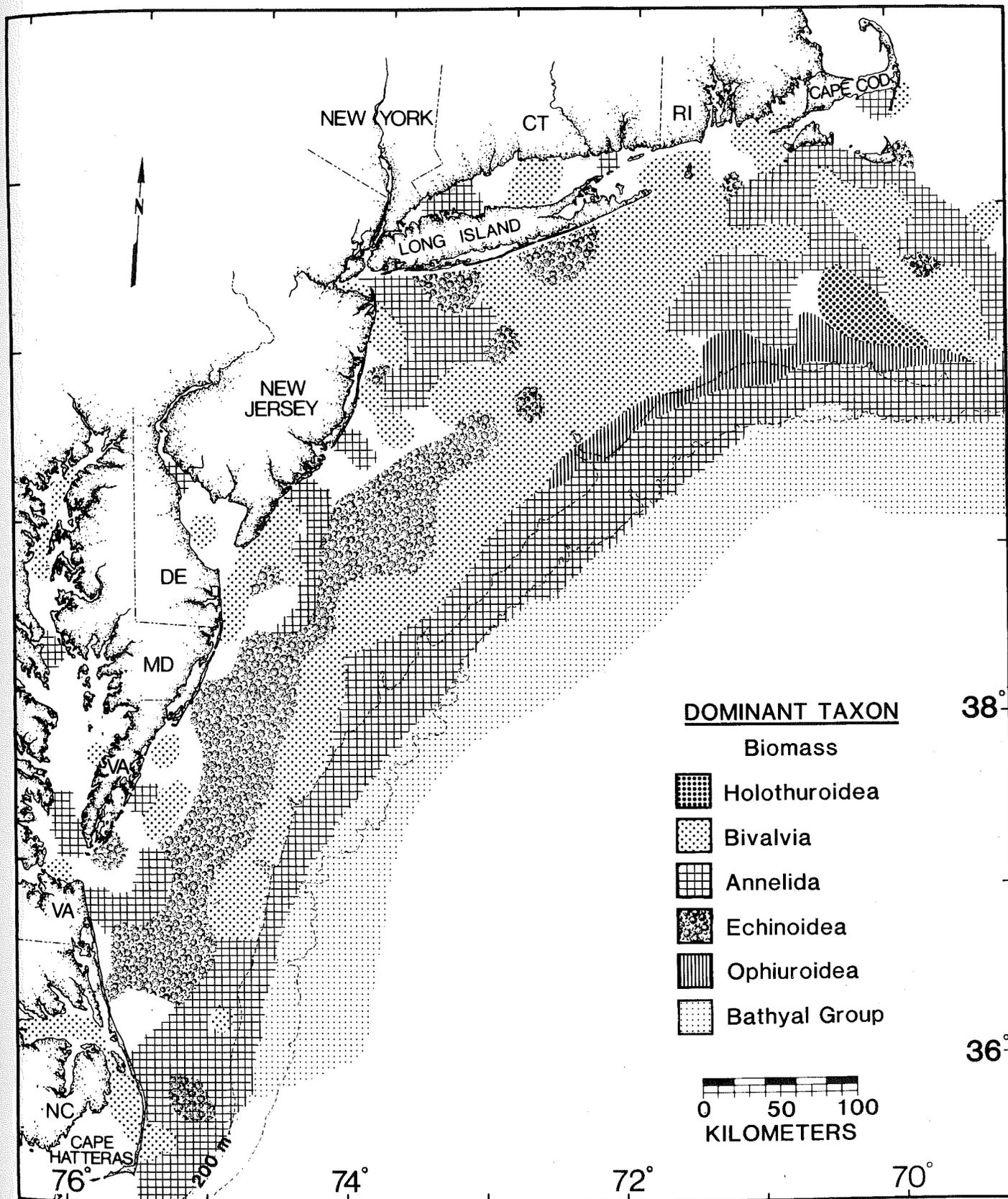


Figure 6. Geographic distribution of the biomass for each dominant taxon in the entire Middle Atlantic Bight region. From Wigley and Theroux (1981).

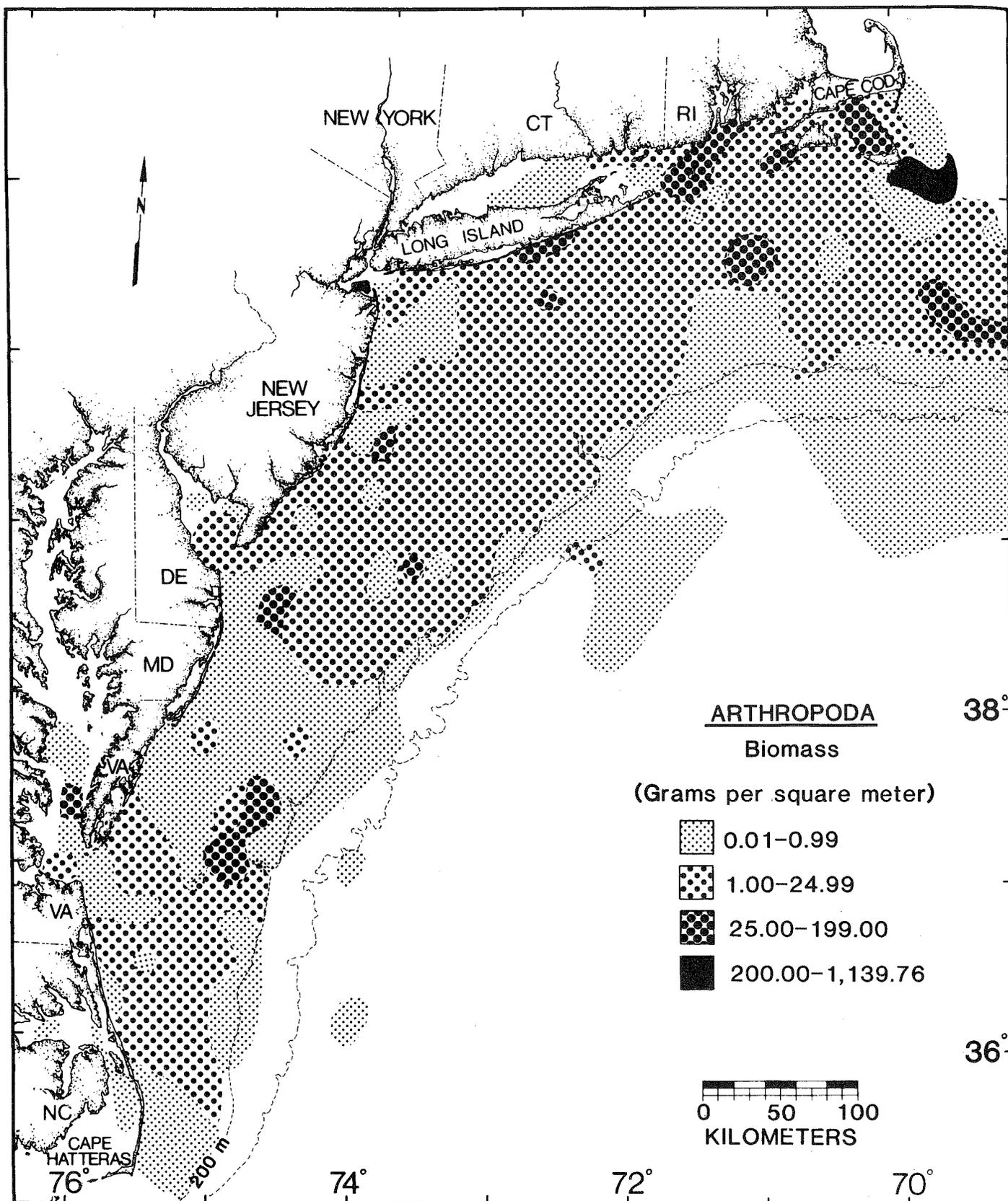


Figure 7. Geographic distribution of the biomass of Arthropoda, expressed as damp weight per square meter of bottom area. The high levels south of Cape Cod are barnacles, of limited values to fish; the remaining levels and distributions are mainly amphipods and decapods. From Wigley and Theroux (1981).

Wigley and Theroux (1981) defined broad trends that they attribute to water depth in the Middle Atlantic Bight (Table 4). Finer-scale patterns were reported by Boesch (1979) and Steimle (1985). Boesch found the greatest total biomass in swales at 34-94 m depths; Steimle (op cit) found greatest biomass levels generally at approximately these same depths in the silty Hudson Shelf Valley. Inshore and/or sandy areas typically contained lesser biomass in both studies. Boesch's results, however, agree closely with those of Wigley and Theroux at depths greater than 100 m.

Sediment type, which is related to water depth, appears to be a principal influence on benthic biomass levels. Boesch (1979) and Steimle (1985) demonstrated that greater biomass is generally associated with silty sands. The summary data of Wigley and Theroux (1981) for the New York Bight (Table 5) support this conclusion, although not for the two other subregions. Epibenthic tunicates, barnacles and bivalves (*Modiolus* sp.?) are partially responsible for the high biomass levels associated with gravel and sand in southern New England, and a variety of molluscs are responsible for the high biomass levels in the Chesapeake Bight shell-fragment sediments.

Benthic biomass levels are known to vary seasonally. Boesch (1979) found increases in overall biomass of crustaceans, polychaetes and, to some degree, molluscs (but not echinoderms) in the spring in swale environments (Figure 8). Molluscs and echinoderms, having longer life spans than polychaetes and small crustaceans, are less influenced by seasonality, and the influx of juvenile recruits to their populations is less important to biomass levels than the sample-to-sample variability of the older populations. Preliminary analysis of summer and late fall samples of the OP-NEMP program has indicated consistent summer increases in total biomass levels over a four year period at most of the ~20 stations in the Middle Atlantic Bight. Such increases undoubtedly reflect recruitment and growth in the warmer months, with mean summer levels generally being 50-500% above late fall levels.

Over longer time periods, there is a certain degree of constancy (within an order of magnitude) in overall biomass levels for many areas. Preliminary analysis covering several years of OP benthic monitoring data showed most stations had relatively level mean biomass, except for the above-mentioned seasonal influences. Kruskal-Wallis analysis of variance of the raw, unpublished 1962-1965 data from Wigley and Theroux (1981) for stations closest to or congruent with OP-NEMP stations showed no significant difference in biomass, at the .05 level of confidence, at about half of the 20 stations. However, since the distance between the Wigley-Theroux sites and the OP-NEMP sites can be as much as six miles, and Boesch (1979) has demonstrated the importance of small-scale ridge and swale variability, this suggestion of long term constancy should be considered tentative until a thorough site-by-site comparison can be made. Also, it is possible that the Wigley and Theroux and OP-NEMP samplings are at similar positions in a longer-term cycle that could contain significant fluctuations within the 15-20 year interval between these two studies. Gray and Christie (1983) discuss evidence for cycles in long-term hydrographic, plankton and benthic data in the eastern and central North Atlantic. These cycles can be as short as three years or as long as thousands, and must be considered for accurate long-term trend analysis. These cycles may be reflected more in community composition than in overall levels of biomass, especially ash-free or energy-converted biomass, which is a relatively conservative parameter (Buchanan et al. 1974). Sherman (pers.

Table 4. Mean biomass (wet wt) of the macrobenthic invertebrate fauna in relation to water depth for each subarea and for the entire Middle Atlantic Bight region (Wigley and Theroux 1981).

Water Depth (meters)	Mean Biomass in Grams Per Square Meter			
	Southern New England	New York Bight	Chesapeake Bight	Entire Area
0-24	404	804	114	368
25-49	343	123	102	163
50-99	237	166	80	189
100-199	89	36	109	79
200-499	34	17	28	28
500-999	17	7	11	12
1,000-1,999	5	5	11	7
2,000-3,080	8	7	10	8

Table 5. Mean biomass ( $\text{g}/\text{m}^2$ ) of the macrobenthic invertebrate fauna in relation to bottom sediments for each subarea and for the entire Middle Atlantic Bight region.

Sediment Type	Mean Biomass			
	Southern New England	New York Bight	Chesapeake Bight	Entire Area
Gravel	286	-	-	286
Sand-gravel	379	94	12	256
Shell	117	-	706	559
Sand-shell	3	82	72	74
Sand	321	146	85	179
Silty sand	105	1,725	100	414
Silt	76	72	35	59
Clay	5	6	102	52

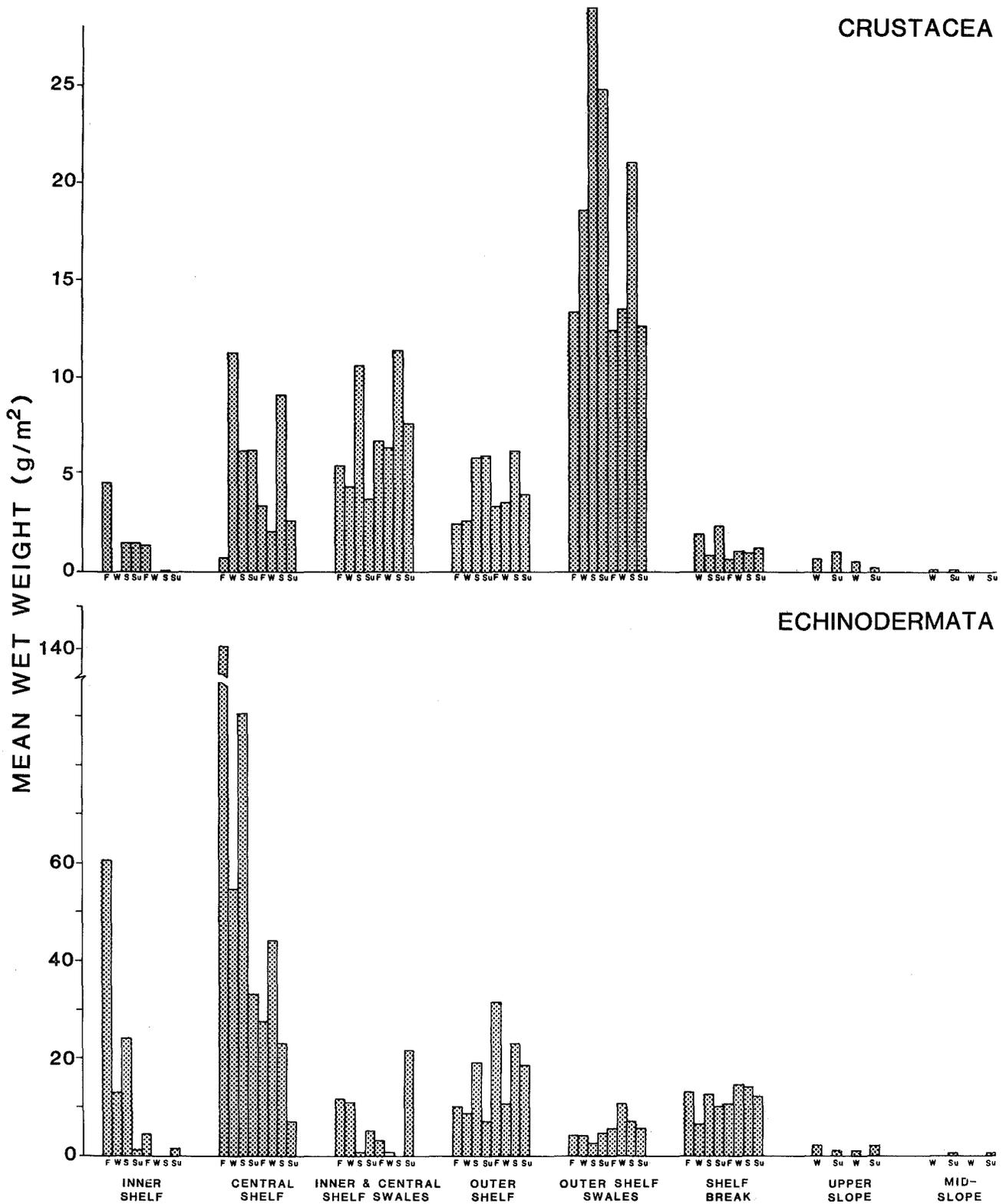


Figure 8. Geometric mean wet weight biomass of macrobenthic taxa by major habitat and season. Redrawn from Boesch (1979).

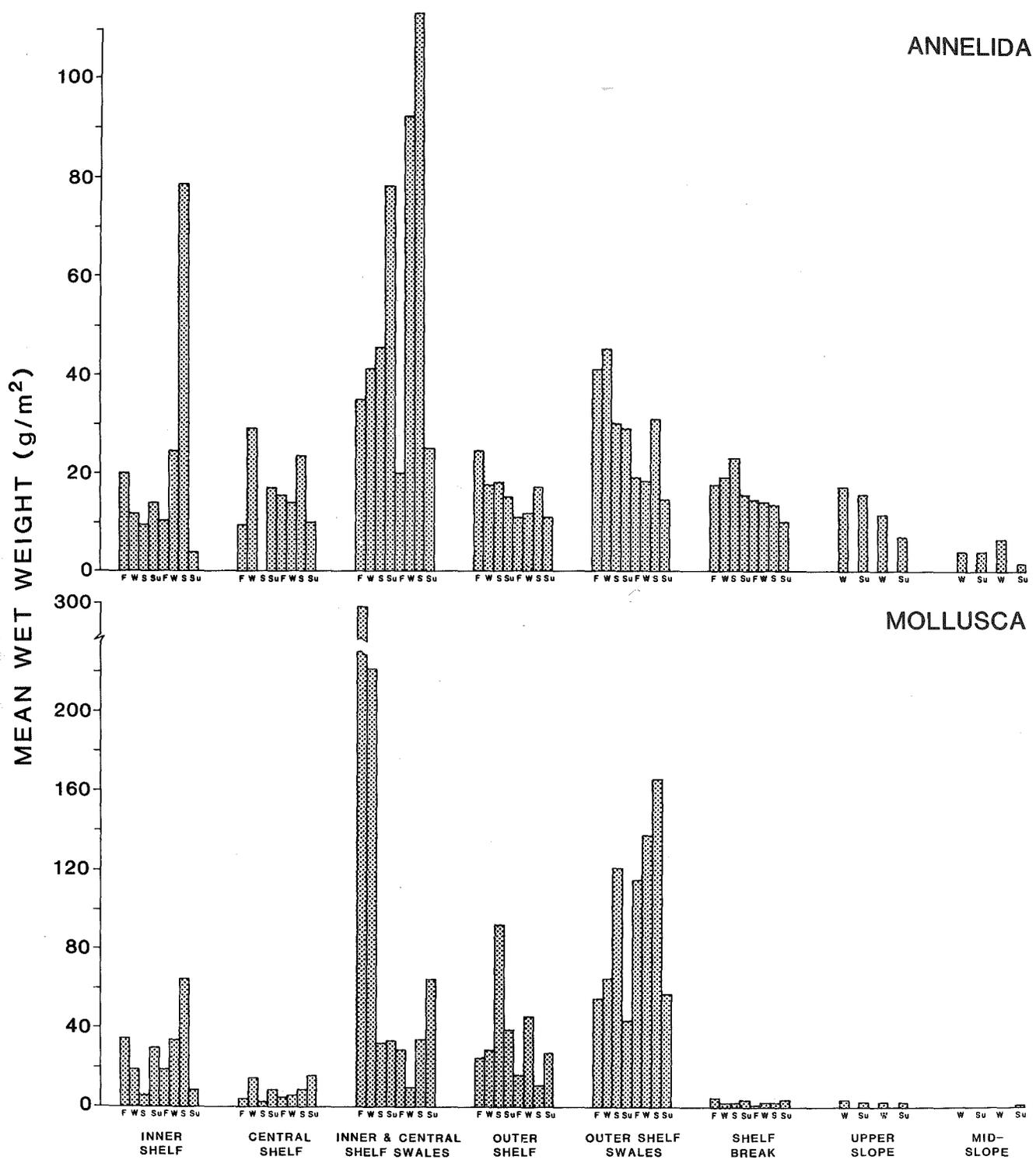


Figure 8. Continued.

comm.\*), however, believes there has been little change in the plankton community in the western North Atlantic since at least 1912, indicating the whole concept of long-term cycles needs more elucidation.

#### BIOENERGETICS AND PRODUCTION

The inclusion of shells and tests in the non-ash-free biomass of some taxa influences the value of a given overall biomass as a forage index for resource species. Other factors are also involved, i.e. relating biomass to energy or nutritional equivalence (Steimle and Terranova 1985). Biomass alone often bears no direct relationship to food value; a high biomass for a taxon can indicate that it is somehow unavailable or undesirable as prey, and a low biomass could reflect heavy cropping of a preferred food item. Thus, to be of optimal use to managers, biomass data must be evaluated in terms of caloric content, production or turnover rates, and the food habits of demersal resources species. We are just beginning to accurately convert raw biomass values of dominant benthic species on the continental shelf to their energy equivalents (Steimle and Terranova 1985). A summary of mean energy content values for major taxa from this study is presented in Table 6, which demonstrates the variability among different taxa.

There have been only two estimates of benthic macrofauna productivity in the Middle Atlantic Bight (Howe and Leathem 1984; Steimle 1985); data are also available (Sanders 1956) for Long Island Sound, just inshore of this WMU. Howe and Leathem (1984) estimated the secondary productivity of the benthos at three OP-NEMP stations in and outside of Delaware Bay over a two year period. This study used direct measurements of population growth and survival of selected species to estimate production. A production gradient was found with highest levels in the Bay and lowest at the station furthest from the Bay mouth. Values for the least productive station were approximately 25% of those for the most productive (see Table 7). This study also demonstrated the variability that small opportunistic species can induce in productivity estimates.

Steimle (1985) estimated the production of macrofauna in the New York Bight using mean production to biomass (P:B) ratios, summarized from an intensive review of the scientific literature (see Table 6); this may be less accurate than the direct method used by Howe and Leathem. These ratios were applied to OP-NEMP Bight benthic biomass data for 1980-1982 and to Bight apex data for 1973 and 1980-1982. Results indicated the average estimated productivity of both the New York Bight and its apex to be relatively high compared to what we know of the benthic production of other North Atlantic areas (Table 7). The distribution of these production estimates shows a strong relationship to biomass levels (but not in consistent proportions) and indicates a band of elevated production relatively congruent with the silty-sand depression of the upper Hudson Shelf Valley, and mid-depth continental shelf areas. Shallow (<25 m) sandy areas were estimated to be less

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Table 6. Mean energy equivalence and turnover ratios (P:B) for major taxa, from Steimle (1985).

Taxa	Energy equivalency <sup>1</sup> (Kcal/g)	P:B
Coelenterates	0.4	2.0
Rhynchocoels	1.1	1.0
Polychaetes	1.0	3.0
Crustaceans	1.3	3.0
Molluscs <sup>2</sup>	0.6	1.0
Echinoderms	0.7	1.2
Phoronids	0.6	2.0
Tunicates	0.5	1.0

<sup>1</sup> Based, for the most part, on Steimle and Terranova (1985).

<sup>2</sup> Estimate is based on preliminary data that indicate the shell weight of molluscs is approximately 50% of total wet weight (Tyler 1973 and original unpublished data). Also, this equivalency value does not consider the organic content of the shell itself, that may contribute as much as 20% to the total whole body organic content of molluscs (Paterson 1982).

Table 7. Secondary productivity estimates for North Atlantic shelf benthic macrofauna (from Steimle 1985).

Area	P(Kcal m <sup>-2</sup> y <sup>-1</sup> )	Source and method used (if known)
Nova Scotia, Canada	27-31.5 <sup>1</sup>	Mills and Fournier (1979); P:B = 2.0-2.5
North Sea	60	Gerlach (1978); various
North Sea	50	Steele (1974); P:B = 2-5
North Sea	9 <sup>1</sup>	Buchanan and Warwick (1974); cohort analysis
Loch Ewe, Scotland	30 <sup>1</sup>	McIntyre and Eleftheriou (1968); P:B = 2
Kiel Bight, W. Germany	108 <sup>1</sup>	Arntz (1971); ?
Bristol Channel, England	103	Warwick et al.(1978); cohort analysis
English Channel	44	Harvey (1950); ?
Delaware coast, USA	43-171 <sup>1</sup>	Howe and Leathen (1984); cohort analysis
Nova Scotia, Canada	84	Miller et al. (1971); P:R
Georges Bank, USA	93-102	Steimle (in press); variable P:B per taxa
Bay of Fundy	58	Wildish and Peer (1983); variable P:B per taxa
New York Bight	347	Steimle (1985)

<sup>1</sup> Kcal estimates are based on the following conversion factors for original published data: g dry weight (x4) and ash free dry weight (x5) based on Crisp (1971); gC (x11) based on Salonen et al. (1976).

productive, consistent with Howe and Leathem's (1984) results. (The areas sampled did not include any dense beds of surf clams, which can be very productive.)

Because of the difference in energy content equivalencies and P:B ratios for each taxon (Table 6), the contribution of heavily calcified molluscs and echinoderms to the total estimated organic production is less, relative to that of polychaetes and crustaceans, than is their contribution to overall biomass. Thus in 1973, the polychaetes, Nephtys incisa, Ninoe nigripes and Pherusa affinis, dominated production in the Christiaensen Basin, while the bivalve, Nucula proxima, predominated further down the upper Hudson Shelf Valley. The polychaete, Spiophanes bombyx, dominated production in most shallow areas, except where there were large aggregations of the sand dollar, Echinarachnius parma, and at the single station where the polychaete, Capitella capitata, was dominant. In 1980-1982, Arctica islandica dominated estimated production in the apex, wherever it occurred, because of its usually large biomass. Elsewhere, in the Christiaensen Basin and upper Hudson Shelf Valley, N. proxima and N. incisa dominated production. Outside the Bight apex, E. parma, and to a lesser degree A. islandica, generally dominated estimated production as they did biomass.

#### THE BENTHOS IN FOOD WEBS

Benthic macrofauna is a significant source of food for a wide variety of adult (Table 8) and juvenile (Table 9) finfish and larger harvestable crustacea. Most benthic macrofauna species feed on the residual organic material in the sediment, detritus and microorganisms at the sediment surface, and suspended plankton and detritus just above the bottom. These feeding modes or trophic linkages are important in keeping the organic matter produced by primary production active in fishery-related food webs. Although zooplankton is usually thought to be the key linkage between primary production and fish production, during the massive bloom of phytoplankton that occurs in spring as much as half of the N.Y. Bight primary production may go ungrazed by zooplankton and reach the bottom (Dagg and Turner 1982). If not utilized by the macrofaunal benthos, this would mostly be lost to the food web leading to harvestable species, since benthic meiofauna and microorganisms appear to be of little direct value to fish food webs.

No detailed energy budgets exist for Middle Atlantic food webs. Figure 9 shows such a budget for Georges Bank; the qualitative relationships are the same in the Middle Atlantic, though the actual values will differ. Note that in the Georges Bank model, production of demersal fish exceeds that of pelagics, and demersal production is mostly based on the macrobenthos (plus a small meiobenthic component).

Marine mammals may also rely on benthic prey. Oliver et al. (1984) reported that dense patches of ampeliscid amphipods were the primary food of gray whales off British Columbia. In the Middle Atlantic WMU, however, use of benthos by mammals is not well documented.

Reduced availability of benthic populations important as forage, whether due to natural or anthropogenic causes, can be expected to reduce productivity of the species that depend on this forage. Amounts of benthic forage needed to sustain a given resource population or individual have generally not been

Table 8. Contribution of benthic prey to the diets of adults of common demersal species in the Middle Atlantic area. Values are mean percent of total stomach contents by weight, except Crustacea which are percent frequency of occurrence (based on Weiss 1970; Scarrett and Lowe 1972; Maurer and Bowman 1975; Bowman et al. 1976; Langton and Bowman 1980, 1981; Bowman and Michaels 1983; Sedberry 1983). The "+" indicates trace amounts, but less than 0.5%.

Demersal species	Benthic Prey Taxa							1
	Cnidaria	Polychaeta	Crustacea	Mollusca	Echinodermata	Pisces	Miscellaneous	
American lobster	25	59	90	75	4	49	-	
Rock crab	2	19	5	18	15	-	-	
Spiny dogfish	1	+	2			63	34	
Little skate		16	61	5		5	13	
Conger eel			6		94			
Goosefish		+	1		+	96	4	
Atlantic cod	+	3	16	1	+	75	5	
Haddock	+	9	42	1	1	+	47	
Silver hake		1	21			58	20	
Red hake	+	2	51	2	+	33	12	
Ocean pout		4	17	1	75	+	3	
Black sea bass		54	36	+		1	9	
Scup		37	14	4	1	+	44	
Northern searobin		42	6	3			49	
Longhorn sculpin		3	89	1		4	3	
Summer flounder			1	+		48	51	
Fourspot flounder	+	+	46	+		24	30	
Windowpane	+	+	31	1		2	66	
Witch flounder	+	67	7	+		+	26	
Winter flounder	32	41	8	6	4	+	9	
Yellowtail flounder	+	39	38	3	3	2	15	

<sup>1</sup> Miscellaneous can include sand and gravel and other non-living material, as well as unidentifiable animal remains, algae and minor benthic taxa.

Table 9. Summary of the stomach contents of juvenile groundfish from the northwestern Atlantic, expressed as percentage of total food weight, for fish collected between the years 1953-1976. Subtotals are underlined and a "+" indicates present in the diet but <0.1% (from: Bowman 1981).

Stomach contents	Atlantic cod	Haddock	Silver hake	Pollock	Red hake	White hake	Spotted hake	Fourbeard rockling	American plaice	Yellowtail flounder
Polychaeta	<u>0.4</u>	<u>13.6</u>	<u>0.3</u>	<u>0.7</u>	<u>2.4</u>	<u>2.9</u>	-	-	<u>72.1</u>	<u>3.0</u>
Crustacea	<u>81.6</u>	<u>62.3</u>	<u>89.0</u>	<u>68.2</u>	<u>90.1</u>	<u>94.9</u>	<u>85.9</u>	<u>33.3</u>	<u>21.1</u>	<u>94.4</u>
Amphipoda	<u>22.5</u>	<u>27.6</u>	<u>6.6</u>	<u>1.5</u>	<u>19.4</u>	<u>15.4</u>	<u>77.1</u>	<u>33.3</u>	<u>17.3</u>	<u>38.8</u>
Decapoda	11.2	11.5	30.4	0.3	41.6	58.2	+	-	+	3.7
Isopoda	-	0.7	+	1.2	0.1	-	-	-	-	1.0
Cumacea	0.2	0.7	0.1	-	0.5	-	-	-	+	10.2
Euphausiacea	18.0	13.0	44.4	55.8	6.4	-	-	-	-	-
Mysidacea	12.9	1.5	2.6	-	3.6	-	-	-	3.8	33.4
Copepoda	4.8	0.6	0.1	0.2	1.3	-	7.0	-	+	+
Other Crustacea	12.0	6.7	4.8	9.2	17.2	21.3	1.8	+	+	7.3
Mollusca	<u>0.1</u>	<u>0.1</u>	+	-	<u>0.2</u>	-	-	-	+	-
Chaetognatha	+	<u>0.2</u>	<u>0.8</u>	-	<u>0.3</u>	-	+	-	-	-
Echinodermata	-	1.2	-	-	+	-	-	-	-	-
Echinoidea	-	<u>0.1</u>	-	-	-	-	-	-	-	-
Ophiuroidea	-	1.1	-	-	+	-	-	-	-	-
Pisces	<u>16.0</u>	<u>5.0</u>	<u>8.5</u>	+	<u>1.9</u>	-	-	-	-	-
<i>Ammodytes americanus</i>	-	-	<u>3.0</u>	-	-	-	-	-	-	-
<i>Merluccius bilinearis</i>	-	2.2	-	-	-	-	-	-	-	-
Gadidae	-	-	2.1	-	-	-	-	-	-	-
Cottidae	-	-	2.3	-	-	-	-	-	-	-
Other Pisces	16.0	2.8	1.1	+	1.9	-	-	-	-	-
Miscellaneous	<u>0.1</u>	<u>0.6</u>	<u>0.7</u>	<u>5.8</u>	<u>0.2</u>	<u>0.1</u>	+	-	+	<u>0.2</u>
Unidentified	<u>1.6</u>	<u>15.5</u>	<u>0.7</u>	<u>24.9</u>	<u>4.9</u>	<u>1.3</u>	14.1	66.7	<u>3.9</u>	<u>2.0</u>
Sand	<u>0.2</u>	<u>1.5</u>	+	<u>0.4</u>	+	<u>0.8</u>	-	-	<u>2.9</u>	<u>0.4</u>
Number examined	107	2,159	440	22	229	23	16	3	10	56
Number empty	21	144	74	1	6	1	6	2	5	3
Mean weight per stomach (g)	0.064	0.107	0.086	0.271	0.061	0.085	0.038	0.020	0.010	0.043
Mean fish length (cm)	7 FL	13 FL	9 FL	17 FL	7 TL	9 TL	6 TL	8 TL	5 TL	7 TL
Length range (cm)	3-19 FL	2-20 FL	3-20 FL	4-20 FL	2-20 TL	5-20 TL	4-10 TL	6-9 TL	4-7 TL	4-9 TL

quantified. It is likely that resource population sizes are largely determined by conditions encountered during the egg, larval and early juvenile stages; after this, food may not be limiting. Poxton et al. (1983) have shown that the year-class strength of plaice in a Scottish estuary depended mostly on amounts of food available to juveniles, more so than on numbers of plaice reaching the bottom after the larval phase.

Another potential problem occurs when benthic forage is available but contains elevated levels of organic and/or inorganic contaminants. This is discussed in the next section.

#### CONTAMINANT BURDENS AND FLOWS

Contamination of resource and endangered species is a major environmental concern facing ocean managers. Contaminated benthic organisms can contribute to the body burdens of those species (Tables 8 and 9) which feed on benthos. To understand and eventually control contaminant uptake in those species, we need information on contaminant levels in the benthos, and on processes controlling transfer up food webs.

A data base on contaminant concentrations in Middle Atlantic benthos is accumulating only slowly. This is due in part to the difficulty of collecting enough material for analysis. As of late 1985, there was not enough information on contamination in benthic macrofauna, appropriately screened for quality assurance, for inclusion in this report. More data are available for larger benthic invertebrates such as lobsters, crabs, surf clams, sea scallops, ocean quahogs and mussels (e.g. Steimle et al. 1986), especially for adults of these species, but they are not as frequently preyed on. Collection and contaminant analyses of benthic forage species is continuing, and the information can be provided, as accrued, in an update to this report.

Transfer of contaminants up food webs is not the only means by which contaminants enter resource species. Direct uptake from water and sediments have also been reported as major avenues. Several studies, however, have documented food as the most important source of contaminants to higher trophic levels, including fish (e.g. Rubinstein et al. 1984; Pizza and O'Connor 1983; Willis and Sunda 1984).

It appears that biomagnification (continued increases in concentration moving up a food web) is greater for synthetic organic compounds than for metals, petroleum hydrocarbons, or radionuclides (Olsen 1984). Because fish are unable to detoxify chlorinated hydrocarbons, such as PCBs, even a low rate of input from food can result in gradual accumulation. Fish can detoxify metals and petroleum hydrocarbons to some degree, keeping these contaminants from accumulating at high levels in edible tissues.

Contamination of resource species may affect both their health and marketability. These subjects, along with effects on benthic populations themselves, are discussed further in the chapter on contaminant inputs, fates and effects.

## SUMMARY

A. Bottom living invertebrates of the Middle Atlantic WMU are important as food and contaminant sources for resource species. The benthos is also useful as an indicator of biological effects of environmental change.

B. The benthos of the area, especially the New York Bight, has been relatively well sampled. Sources, dates, locations, and methods of the major surveys are summarized. These data sets permit some description of trends in benthic communities over space and time, and also provide baselines against which effects of future environmental change can be measured.

C. Within the WMU latitudinal changes in benthic assemblages are fairly small. More distinct are changes with depth and sediment type (the two are highly correlated) from the inner to the outer shelf. Similar though smaller-scale faunal differences are associated with the shelf's ridge and swale topography. One classification scheme divides the shelf into five broad benthic habitats: inner shelf (coarse sands, out to 30 m depths), central shelf (30-50 m, sandy), central and inner shelf swales, outer shelf (50-100 m, mostly silty sand) and outer shelf swales. Densities, living and feeding habits of numerically dominant species in each habitat are noted. General trends include greater numbers of benthic species and individuals, and greater proportions of deposit feeders, from inner to outer shelf and from ridges to swales.

D. Benthic biomass is more useful than numerical density as an indicator of food potentially available to resource species. Biomasses for much of the mid-Atlantic shelf compare to those of productive Georges Bank, and are greater than values reported for most other North Atlantic shelf areas. Biomass is usually dominated by molluscs and echinoderms. As a rule, levels are higher in silty sands, especially in swales and other depressions, than in inshore and/or sandy areas. There is some seasonality in biomass, with higher values generally found in the warmer months, reflecting increased recruitment and growth. Biomasses are relatively consistent between years. The chapter figures depict spatial biomass patterns within the WMU, and also seasonal variations for each major taxon in each of the above-mentioned habitats.

E. Energy contents and annual production rates of benthic species are yet more indicative of available forage, but have not been as well documented. Crustaceans have the highest energy content per unit biomass, followed by polychaetes and rhynchocoel worms. Production:biomass ratios are also highest for crustaceans and polychaetes. Estimated benthic productivity of the contaminated inner New York Bight is high compared to most other North Atlantic areas for which data are available.

F. Benthic macrofauna is an important food for many species of resource fish and crustaceans. Data on diets of both adults and juveniles of these species are presented. Crustaceans and polychaetes have greatest overall importance in the diets, despite their relatively small contribution to benthic biomass. This reflects their high production and energy content noted above, and also such factors as size and availability to predators. No detailed energy budget exists for the Middle Atlantic; a model for Georges Bank demonstrates the qualitative relationships between benthos, resource species, and other ecosystem components.

G. Contaminants from benthos contribute to, and sometimes dominate, the body burdens of their predators. More information is needed on levels of contaminants in benthos and on processes controlling transfer up food webs. Biomagnification of contaminants appears to be greater for synthetic organics than for metals, petroleum hydrocarbons, or radionuclides.

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#### LITERATURE CITED

- Alden, R. W., III, D. M. Dauer and J. H. Rule. 1982. Environmental studies at a proposed Mid-Atlantic dredged material disposal site. pp. 1034-1041. In: Oceans 82 Conference Proceedings, Washington, DC.
- Arntz, W. E. 1971. Biomasse und produktion des makrobenthos in den tieferen Tielen der Kieler Bucht im Jahre 1968. *Kieler Meersforschungen* 27: 36-72. (Cited in Buchanan and Warwick 1984).
- Boesch, D. F. 1972. Species diversity of marine macrobenthos in the Virginia area. *Ches. Sci.* 13: 206-211.
- Boesch, D. F. 1979. Benthic ecological studies: macrobenthos. Chapter 6 In: Middle Atlantic Outer Continental Shelf Environmental Studies. Conducted by Virginia Institute of Marine Science under Contract AA550-CT6-62 with the Bureau of Land Management. 301 p.
- Bowman, R. E. 1981. Food of 10 species of northwest Atlantic juvenile groundfish. *Fish. Bull.*, U.S. 79(1): 200-206.
- Bowman, R. E. and W. L. Michaels. 1984. Food of seventeen species of Northwest Atlantic fish. NOAA Tech. Mem. NMFS-F/NEC-28. 183 p.
- Bowman, R. E., R. O. Maurer and J. A. Murphy. 1976. Stomach contents of twenty nine fish species from five regions in the Northwest Atlantic - Data Report. NEFC, Woods Hole Lab. Ref. No. 76-10. 37 p.
- Buchanan, J. B. and R. M. Warwick. 1974. An estimate of the benthic macrofaunal production in the offshore mud of the Northumberland coast. *J. Mar. biol. Assoc. U.K.* 54: 197-222.
- Buchanan, J. B., P. F. Kingston and M. Sheader. 1974. Long-term population trends of the benthic macrofauna in the offshore mud of the Northumberland coast. *J. Mar. biol. Ass. U.K.* 54: 785-795.
- Caracciolo-Ward, J. and F. W. Steimle, Jr. 1984. A review of the benthic fauna at the proposed 60-mile northern alternate site for waste disposal and risks if used. NOAA, NMFS, NEFC, Sandy Hook Laboratory Report SHL 84-03. 22 p.

- Caracciolo, J. V., J. B. Pearce, M. Halsey and L. Rogers. 1978. Distribution and abundance of benthic organisms in the New York Bight, first and second monitoring cruises, November 1975 and March 1976. NOAA Data Report, ERL-MESA No. 40. 48 p.
- Cohen, E. B., M. D. Grosslein, M. P. Sissenwine, F. Steimle and W. R. Wright. 1982. Energy budget of Georges Bank. pp. 95-107. In: M. C. Mercer (ed.). Multispecies approaches to fisheries management advice. Can. Spec. Publ. Fish. Aquat. Sci. 59.
- Crisp, D. J. 1971. Energy flow measurements. pp. 197-279. In: A. Holme and A. D. McIntyre (eds.). Methods for the Study of Marine Benthos. Blackwell, Oxford.
- Dagg, M. J. and J. T. Turner. 1982. The impact of copepod grazing on the phytoplankton of Georges Bank and the New York Bight. Can. J. Fish. Aquatic. Sci. 39: 979-990.
- EG&G. 1982. A study of environmental effects of exploratory drilling on the Middle Atlantic outer continental shelf. Final Report of the Block 684 Monitoring Program. EG&G Environmental Consultants, 300 Bear Hill Road, Waltham, MA 02154. XIX + 138 p. + appendices.
- Garlo, E. V., C. B. Milstein and A. E. Jahn. 1979. Impact of hypoxic conditions in the vicinity of Little Egg Inlet, New Jersey, in summer 1976. Estuar. Coastal Mar. Sci. 8: 421-432.
- Gerlach, S. A. 1978. Food-chain relationships in subtidal silty sand marine sediments and the role of meiofauna in stimulating bacterial productivity. Oecologia (Berlin) 33: 55-69.
- Harvey, H. W. 1950. On the production of living matter in the sea. J. Mar. biol. Assoc. U.K. 29: 97-136.
- Howe, S. and W. A. Leathem. 1984. Secondary production of select benthic species in coastal Delaware. NOAA Tech. Memo. NMFS-F/NEC-32. 62 p.
- Langton, R. W. and R. E. Bowman. 1980. Food of fifteen Northwest Atlantic gadiform fishes. NOAA Tech. Rept. NMFS-SSRF-740. 23 p.
- Lear, D. W., M. L. O'Malley and S. K. Smith. 1977. Effects of ocean dumping activity, Mid-Atlantic Bight-1976. US EPA Interim Rept. No. 903/9-77-029. 168 p.
- Maciolek-Blake, N., J. A. Blake, J. F. Grassle and J. M. Neff. 1983. Georges Bank benthic infauna monitoring program - year 1. pp. 978-982. In: Oceans 83 Conference Proceedings.
- Maurer, R. O. and R. E. Bowman. 1975. Food habits of marine fishes of the Northwest Atlantic - Data Report. NEFC, Woods Hole Lab. Ref. No. 75-3. 90 p.

- Maurer, D. and W. Leathem. 1980. Ecological distribution of polychaetous annelids of Georges Bank. College of Marine Studies, Univ. of Delaware, Lewes, DL. Rept. CMS-1-80. 181 p.
- Maurer, D. and R. L. Wigley. 1981. Distribution of biomass and density of macrobenthic invertebrates on the U.S. continental shelf off Martha's Vineyard, Massachusetts. NOAA, NMFS, NEFC, Woods Hole Laboratory Ref. Doc. No. 81-15: 1-97.
- Maurer, D., P. Kinner, W. Leathem and L. Watling. 1976. Benthic faunal assemblages of the Delmarva Peninsula. *Estuar. Coastal Mar. Sci.* 4: 163-177.
- McIntyre, A. D. and A. Eleftheriou. 1968. The bottom fauna of a flatfish nursery ground. *J. Mar. Biol. Assoc. U.K.* 48: 113-142.
- Miller, R. J., K. H. Mann and D. J. Scarrett. 1971. Production potential of a seaweed-lobster community in eastern Canada. *J. Fish. Res. Bd. Can.* 28: 1733-1738.
- Mills, E. L. and R. O. Fournier. 1979. Fish production and the marine ecosystem of the Scotian Shelf, eastern Canada. *Mar. Biol.* 54: 101-108.
- National Marine Fisheries Service. 1972. The effects of waste disposal in the New York Bight. Final Report. Submitted to U.S. Army Corps of Engineers, Coastal Engineering Research Center, Washington, DC. NOAA, NMFS, MACFC, Sandy Hook Laboratory. 9 sections.
- Oliver, J. S., P. N. Slattery, M. A. Silberstein and E. F. O'Connor. 1984. Gray whale feeding on dense ampeliscid amphipod communities near Bamfield, British Columbia. *Can. J. Zool.* 62: 41-49.
- Olsen, L. A. 1984. Effects of contaminated sediment on fish and wildlife: review and annotated bibliography. U.S. Fish and Wildlife Service/OBS-82/66.
- Pearce, J. B., J. V. Caracciolo, M. Halsey and L. Rogers. 1977a. Distribution and abundance of benthic macrofauna at nested stations in the sewage sludge disposal area, New York Bight apex, February 1975. NOAA Data Report, ERL-MESA No. 36. 38 p.
- Pearce, J., J. Caracciolo, M. Halsey and L. Rogers. 1977b. Distribution and abundance of benthic macrofauna in the New York-New Jersey outer continental shelf. NOAA Data Report ERL-MESA No. 30. 80 p.
- Pearce, J., L. Rogers, J. Caracciolo and M. Halsey. 1977c. Distribution and abundance of benthic organisms in the New York Bight apex. Five seasonal cruises, August 1973-September 1974. NOAA Data Report, ERL-MESA No. 32. 803 p.
- Pearce, J., C. MacKenzie, J. Caracciolo and L. Rogers. 1978. Reconnaissance survey of the distribution and abundance of benthic organisms in the New York Bight apex, 5-14 June 1973. NOAA Data Report, ERL-MESA No. 41. 203 p.

- Pearce, J. B., D. Radosh, J. Caracciolo and F. Steimle. 1981. Benthic fauna. MESA, New York Bight Atlas, Monograph 14. 79 p.
- Pizza, J. C. and J. M. O'Connor. 1983. PCB dynamics in Hudson River striped bass. II. Accumulation from dietary sources. *Aquatc. Toxicol.* 3: 313-327.
- Poxton, M. G., A. Eleftheriou and A. D. McIntyre. 1983. The food and growth of 0-group flatfish on nursery grounds in the Clyde Sea area. *Estuar. Coastal Shelf Sci.* 17: 319-337.
- Pratt, S. 1973. Benthic fauna. Chapter 5. In: Coastal and offshore environmental inventory, Cape Hatteras to Nantucket Shoals. Univ. of Rhode Island, Marine Publication Series No. 2. 70 p.
- Radosh, D. J., A. B. Frame, T. E. Wilhelm and R. N. Reid. 1978. Benthic survey of the Baltimore Canyon Trough, May 1974. Prepared under Interagency Agreement AA-550-1A7-35 between Bureau of Land Management and National Marine Fisheries Service. NOAA, NMFS, NEFC, Sandy Hook Laboratory Report SHL 78-18. Unpubl. 133 p.
- Raytheon Company. 1977. Environmental survey of a proposed alternate dumpsite in the outer New York Bight. Report to U.S. Environmental Protection Agency. Raytheon Co., Portsmouth, RI.
- Reid, R., J. O'Reilly and V. Zdanowicz (Eds.). 1982. Contaminants in New York Bight and Long Island Sound sediments and demersal species, and contaminants effects on benthos, summer 1980. NOAA Tech. Memo. NMFS-F/NEC-16. 96 p.
- Reid, R. N., F. W. Steimle, Jr., C. MacKenzie, D. Radosh, A. Frame, S. Fromm, J. Caracciolo-Ward, D. Jeffress and R. Terranova. 1984. Northeast Monitoring Program Annual Report, October 1982-September 1983. Benthic Ecology. NOAA, NMFS, NEFC, Sandy Hook Laboratory, Highlands, NJ. Unpubl. report.
- Rowe, G. T. 1971. The effects of pollution on the dynamics of the benthos of New York Bight. *Thalassia Jugoslavica* 7(1): 353-359.
- Rubinstein, N. I., W. T. Gilliam and N. R. Gregory. 1984. Dietary accumulation of PCBs from a contaminated sediment source by a demersal fish (*Leiostomus xanthurus*). *Aquatic Toxicology* 5: 331-342.
- Sanders, H. L. 1956. Oceanography of Long Island Sound, 1952-1954. X. Biology of marine bottom communities. *Bull. Bingham. Oceanogr. Coll.* 15: 345-414.
- Salonen, K., S. Jouks, I. Hakala and M. Viljanen. 1976. The relation of energy and organic carbon in aquatic invertebrates. *Limnol. Oceanogr.* 21: 724-730.
- Scarrett, D. J. and R. Lowe. 1972. Biology of rock crab (*Cancer irroratus*) in Northumberland Strait. *J. Fish. Res. Board Can.* 29: 161-166.

- Sedberry, G. R. 1983. Food habits and trophic relationships of a community of fishes on the outer continental shelf. NOAA Tech. Rept. NMFS-SSRF 773. 56 p.
- Steele, J. H. 1974. The Structure of Marine Ecosystems. Blackwell, Oxford. 128 p.
- Steimle, F. W. 1986. Production by the Benthic Fauna. pp. 310-314. In: Georges Bank. MIT Press, 593 pp. R. H. Backus and D. W. Bourne, eds.
- Steimle, F. W. 1985. Biomass and estimated productivity of the benthic macrofauna in the New York Bight: a stressed coastal area. Estuar. Coastal Shelf Science. 21: 539-554.
- Steimle, F. W., Jr. and R. B. Stone. 1973. Abundance and distribution of inshore benthic fauna off southwestern Long Island, NY. NOAA Tech. Rept. NMFS SSRF-673. 50 p.
- Steimle, F. W. and R. J. Terranova. 1985. Energy equivalents of marine organisms from the continental shelf of the temperate northwest Atlantic. J. Northwest. Atl. Fish. Sci. 6(2): 117-124.
- Steimle, F. W., P. D. Boehm, V. S. Zdanowicz and R. A. Bruno. 1986. Organic and trace metal levels in ocean quahog, *Arctica islandica* Linne, from the northwest Atlantic. Fish. Bull. (U.S.) 84(1): 133-140.
- Swartz, R. C. 1976. Research needs concerning pollution of the marine benthos. Proc. Intl. Symp. on Marine Pollution Research, Jan. 27-29, 1976. Louisiana State Univ., Baton Rouge, LA.
- Warwick, R. M., C. L. George and J. R. Davis. 1978. Annual macrofauna production in a Venus community. Est. Coast. Mar. Sci. 7: 215-241.
- Watling, L., W. Leathem, P. Kinner, C. Wethe and D. Maurer. 1974. Evaluation of sludge dumping off Delaware Bay. Mar. Poll. Bull. 5(3): 39-42.
- Weiss, H. M. 1970. The diet and feeding behavior of the lobster Homarus americanus in Long Island Sound. Ph.D. Thesis, Univ. CT. 80 p.
- Wigley, R. L. and R. B. Theroux. 1981. Atlantic continental shelf and slope of the United States - macrobenthic invertebrate fauna of the Middle Atlantic Bight region - faunal composition and quantitative distribution. U.S. Geol. Survey Prof. Pap. 529-N. 198 p.
- Wildish, D. J. and D. Peer. 1983. Tidal current speed and production of benthic macrofauna in the lower Bay of Fundy. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 309-321.
- Willis, J. N. and W. G. Sunda. 1984. Relative contributions of food and water in the accumulation of zinc by two species of marine fish. Mar. Biol. 80: 273-279.

## Shellfish

by

Clyde L. MacKenzie<sup>1</sup>

### INTRODUCTION

Three bivalve mollusc species harvested commercially from 3 to 200 miles offshore are significant in their contribution to the Middle Atlantic fishing economy. During the period from 1980-87, ocean quahog, surf clam, and sea scallops meats comprised ca. 88 percent of the total shellfish yield and 47 percent of the landed weights of commercial fishery products from New York and New Jersey offshore waters. During the same period their joint landed value has averaged approximately 50 percent of the fishery products total landed in the area.

#### SURF CLAM (Spisula solidissima)

The surf clam occurs on the continental shelf from the Gulf of St. Lawrence to Cape Hatteras (Merrill and Ropes, 1969). It is most abundant on the middle Atlantic shelf where it occurs in highest abundance in sandy bottoms in water shallower than 43 m; it is most abundant in 18 to 37 m (Figure 1). The commercial fishery for the clam has grown from a small bait fishery during the years before World War II (Ropes et al., 1969) to one comprising about 72 percent of all clam meats produced in the United States. In 1982 surf clam production was 48.7 million pounds of meat and its value was \$29.5 million in the Middle Atlantic Bight.

#### Reproduction

Surf clams are heterosexual, although hermaphroditism occurs as a rare anomaly (Ropes, 1968a); the sex ratio is 1:1 (Ropes, 1968b). Some male and female clams can spawn when one year old; they are all mature when they are two years old (Ropes, 1979). The fecundity of the clam is not known, but probably individual females produce millions of eggs each season.

The setting season of surf clam larvae begins in April at the southern end of its range off North Carolina (Williams and Porter, 1971), and probably begins in May in more northern waters. Fertilized clam eggs reach the veliger stage in 24 h at 22°C; metamorphosis of larvae from the veliger to the setting stage takes 19 days at 22°C (Loosanoff and Davis, 1963).

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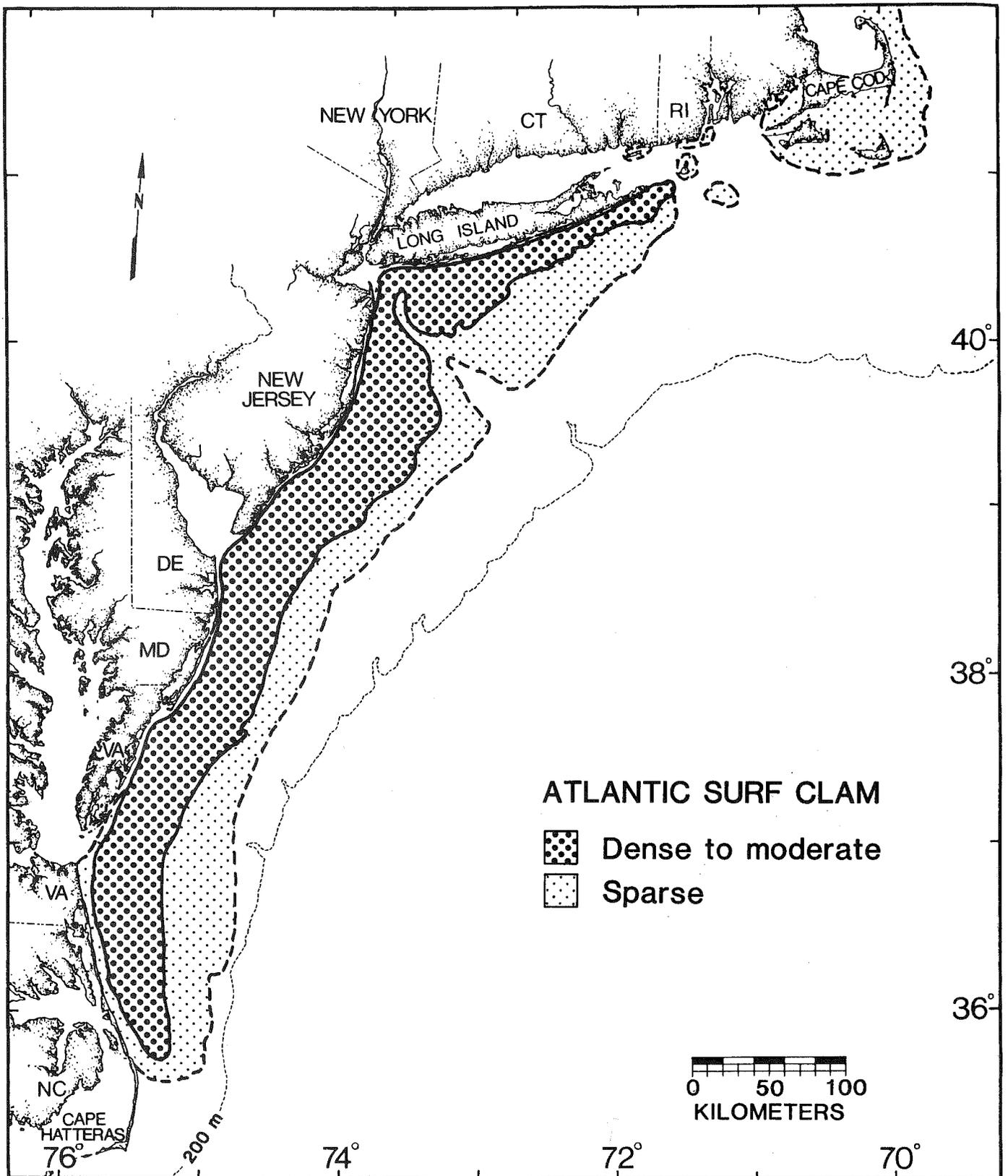


Figure 1. Distribution of surf clam in the Middle Atlantic Bight.

### Sedentary Stage

Off the coasts of western Long Island and eastern New Jersey and within about 2.5 km of shore, juvenile surf clams have densities as high as at least 8,000 m<sup>-2</sup> (MacKenzie et al., in press).

Adult surf clams do not vacate their burrowed position in the bottom, and nearly all remain where they settle as larvae (Ropes and Merrill, 1973). However, storms may temporarily wash clams out of the bottom where they occur close to shore (Yancey and Welch, 1968), but most reburrow where they are left by a storm; the remainder may be washed onto a beach (Ropes and Merrill, 1973).

Surf clams grow to a length of about 50 mm by the time they are two years old; growth continues at a rapid rate to about 150 mm at age seven, which is the average commercial size (Ropes, 1979a). Thereafter, growth diminishes, but clams grow to about 226 mm.

The longevity of surf clams is uncertain. Three records of known clams are 17 (Westman and Bidwell, 1946), 20 (Loesch and Ropes, 1977) and 30 (Jones et al., 1978) years old.

Similar to many bivalves, surf clams feed on plankton. Feeding, respiration and excretion of clams are intimately associated in the process of passing water through their siphons. Loosanoff and Davis (1950, 1963) grew larval clams on cultures of mixed algal species.

### Predators

Little is known about the predators of the larvae of surf clams. Off the coasts of western Long Island and eastern New Jersey and within about 2.5 km of shore, juvenile surf clams have nearly 100 percent mortalities from predation within 10 months after setting. The principal predators are the lady crab (Ovalipes ocellatus) and rock crab (Cancer irroratus) (Garlo, 1982; MacKenzie et al., in press). An important predator of older clams is the moon snail (Lunatia heros); however, it does not bore surf clams longer than 80 mm (Franz, 1977).

## Environmental Requirements

### Temperature

Surf clam larvae do not tolerate a water temperature as high as 30°C; the optimum temperature for larval development is around 22°C (Loosanoff and Davis, 1963). Juvenile clams survive higher temperatures than adults; they become inactive at and below 4°C (Saila and Pratt, 1973). Adult clams are unable to burrow at temperatures below 2°C or above 29°C; the burrowing rate of clams increases as the water temperature rises to 20°C, and decreases as it rises above that temperature (Savage, 1976).

## Salinity

The minimum salinities for larval and adult clams is 16 and 12 ppt, respectively (Castagna and Chanley, 1973). Adult clams tolerate salinities to 52 ppt (concentrated seawater) (Theede, 1965). The distribution of the clams into estuaries is probably limited by salinity (Ropes, 1980).

## Dissolved Oxygen

Several instances of severe depletion of dissolved oxygen in the bottom waters of the ocean have produced mortalities of surf clams. A major hypoxic event occurred in 1976. An area of about 9,722 km<sup>2</sup> contained 1 ppm or less of dissolved oxygen. Nearly the entire area from along the New Jersey coast to a depth of 75m had 2.0 ppm or less oxygen (Steimle and Sindermann, 1978). Surf clams were killed in an area covering 6,758 km<sup>2</sup> in size. About 62 percent of the surf clam resource off the New Jersey coast was killed (Steimle and Sindermann, 1978).

## Population Size and Fisheries

The modern food fishery for the surf clam began off Long Island in the mid-1940s; commercial landings increased from 546 to 2,148 MT of meats between 1944 and 1945. Annual average landings were about 6,400 MT of meats during the 1950s. Extensive beds of surf clams were discovered off the Delmarva Peninsula and Virginia during the late 1960s and 1970s, which further increased landings. Landings reached as high as 43,580 MT in 1974. The Virginia beds were depleted rapidly, however, and catches declined; annual landings were only about 23,000 MT in 1976 and 1977 (Ropes et al., 1982).

In recent years, NMFS surveys have shown that the abundance of surf clams is much lower than it was in the 1960s (Serchuk et al., 1979). The abundance of the surf clams off the Delmarva Peninsula has been more stable than those of other regions (Ropes et al., 1982).

A Fishery Management Plan was implemented in November 1977 to increase the abundance of surf clams (National Marine Fisheries Service, 1977). The plan restricts annual offshore surf clam landings to 13,000 MT, and regulates quarterly landings and clamming efforts (fishing time per vessel per week). The plan also established a limited entry system for the surf clam fishery (Ropes et al., 1982).

## OCEAN QUAHOG (Arctica islandica)

The ocean quahog is distributed on the continental shelf from Newfoundland to Cape Hatteras. Commercial concentrations in the Middle Atlantic Bight are mostly in bottoms consisting of soft sandy mud and silty-sand (Parker and McRae, 1970) at depths from 25 to 60m (Figure 2). In 1982 ocean quahog production was 35.9 million pounds and its value was \$11.0 million in the Middle Atlantic Bight.

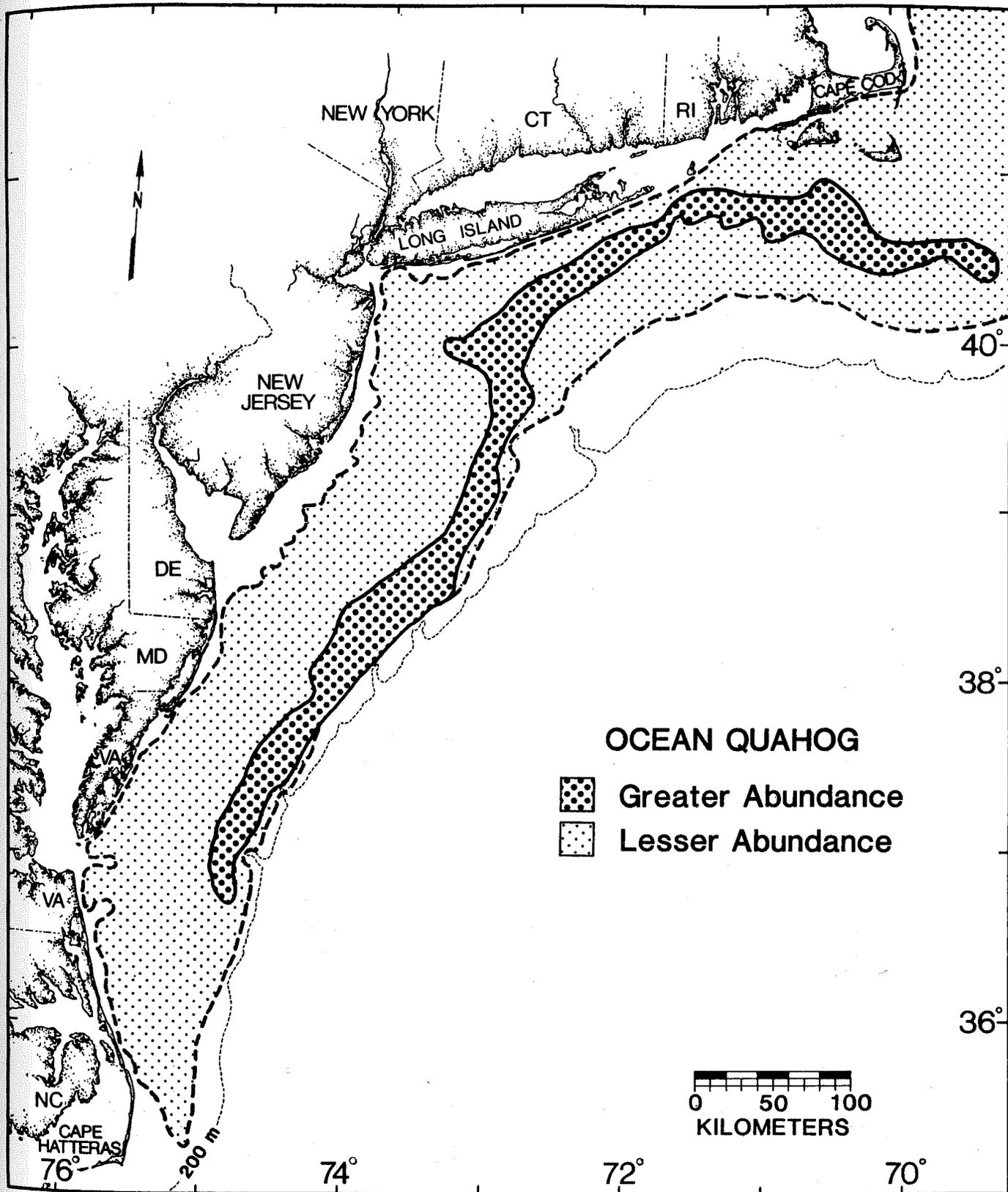


Figure 2. Distribution of ocean quahog in the Middle Atlantic Bight.

## Reproduction

Ocean quahogs are heterosexual (Serchuk et al., 1982). The spawning season of quahogs begins in early summer when water temperatures reach about 13.5°C and ceases in early October (Loosanoff, 1953). Sexual maturity appears to be first attained when quahogs are about 26 mm long, but it maybe delayed until they are 47mm long (Serchuk et al., 1982). The eggs and larvae are planktonic and undergo typical molluscan development to metamorphosis (Landers, 1976). It took larvae 60 days to reach metamorphosis at 10° and 12°C in laboratory culture (Landers, 1972).

## Sedentary Stage

Little is known about the juvenile life of ocean quahogs, but predation is probably high (Ropes, 1979a). Quahogs live a relatively long time. Examinations of the annual lines on the cut edge of sectioned shells of four exceptionally large quahogs showed that their ages were 53, 93, 157 and 221 years old (Ropes and Murawski, 1982).

Annual increases in shell length were 6.3% at age 10, 0.5% at age 50, and 0.2% at an estimated age of 100 years (Murawski et al., 1982).

Ocean quahogs feed on plankton. Examinations of stomach contents showed mixed species of diatoms (unpublished data). Quahogs have been maintained on unicellular algae in the laboratory (Winter, 1970; Landers, 1976).

## Predators

Boring snails (Merrill et al., 1969), bottom feeding fish, particularly cod, which often have large numbers of small ocean quahog shells in their stomachs (Gould and Binney, 1970; Arntz, 1978), and probably crabs, such as rock crabs (Cancer irroratus) and Jonah crabs (Cancer borealis), are major predators of quahogs.

## Environmental Requirements

### Temperature

Little is known about the temperature limits of the ocean quahog except that they are restricted to areas where bottom temperatures rarely exceed 20°C (Golikov and Scarlato, 1973). In the Middle Atlantic Bight, quahogs are restricted to offshore areas of the shelf, but in cooler waters of the Gulf of Maine and Gulf of St. Lawrence they are found in more inshore areas, suggesting that temperature limits their inshore distribution.

### Salinity

Little is known about the salinity tolerances of ocean quahogs. It is believed that they do not tolerate estuarine salinities.

## Dissolved Oxygen

A major hypoxic event occurred on the middle Atlantic shelf in 1976. About 25 percent of the ocean quahogs which occurred in a 9,105 km<sup>2</sup> area affected by hypoxia water were killed. Most quahogs occurred outside the affected area, however, and were not harmed. Quahogs can respire anaerobically for periods as long as seven days (Taylor, 1976), a capability believed to be the reason that most quahogs survived the hypoxic water.

## Population Size and Fisheries

Commercial exploitation of the ocean quahog began during World War II in response to the U.S. War Food Production Program (Arcisz and Neville, 1945). Landings increased from 301 MT (meats) in 1944 to 685 MT in 1946, but sharply declined afterward; annual landings averaged only 107 MT from 1947 through 1969 (Ropes, 1979). During the 1970s expansion of harvesting and marketing increased (Rathjen, 1977) with annual landings averaging 658 MT 1970-75. The development of the NJ fishery in 1976 and the Delmarva Peninsula fishery in 1977 resulted in marked increases in annual catches. Landings in 1977 were 8,074 MT (Serchuk et al., 1982).

Fishing effort was transferred from the mid-Atlantic surf clam fishery to ocean quahogs in 1976 and 1977 because surf clams had become much scarcer, and technological advances in the utilization of ocean quahog meats were made. To prevent overfishing of the ocean quahogs, a Fishery Management Plan which regulated ocean quahog harvests was implemented in November 1977 for a two-year period. The plan restricted the annual ocean quahog catch to 13,600 MT (Serchuk et al., 1982).

## SEA SCALLOP (Placopecten magellanicus)

The sea scallop occurs only in the northwest Atlantic on the continental shelf from the Straits of Belle Isle to the Virginia capes (Posgay, 1957). It is restricted to relatively deep water in the Middle Atlantic Bight (Figure 3). Beds having enough scallops to support commercial fishing are found on hard bottoms at depths between 40 and 100 m; scattered scallops occur to 200 m. Scallops can 'swim', but concentrations occur in the vicinity of Hudson, Baltimore and Norfolk canyons (Posgay, 1982). In 1982, sea scallop production was 3.5 million pounds and its value was \$13.5 million in the Middle Atlantic Bight.

## Production

Sea scallops are heterosexual, although hermaphroditism does occur very rarely (Merrill and Burch, 1960; Naidu, 1970). The sex ratio is about 1:1 (MacKenzie et al., 1978). Most scallops become sexually mature when they are three years old at about 75 mm long (Posgay, 1982). Once, however, a scallop 50 mm long was observed spawning on Georges Bank (Posgay and Norman, 1958). The fecundity of scallops has never been studied, but probably individual females produce millions of eggs each season. The spawning season begins during July off North Carolina and Virginia, but in the mid and northern parts of its range scallop spawn later, i.e., late September and October (Posgay and Norman, 1958). Spawning probably ends on Georges Bank in late October (MacKenzie et al., 1978). In the New York Bight scallops spawn at

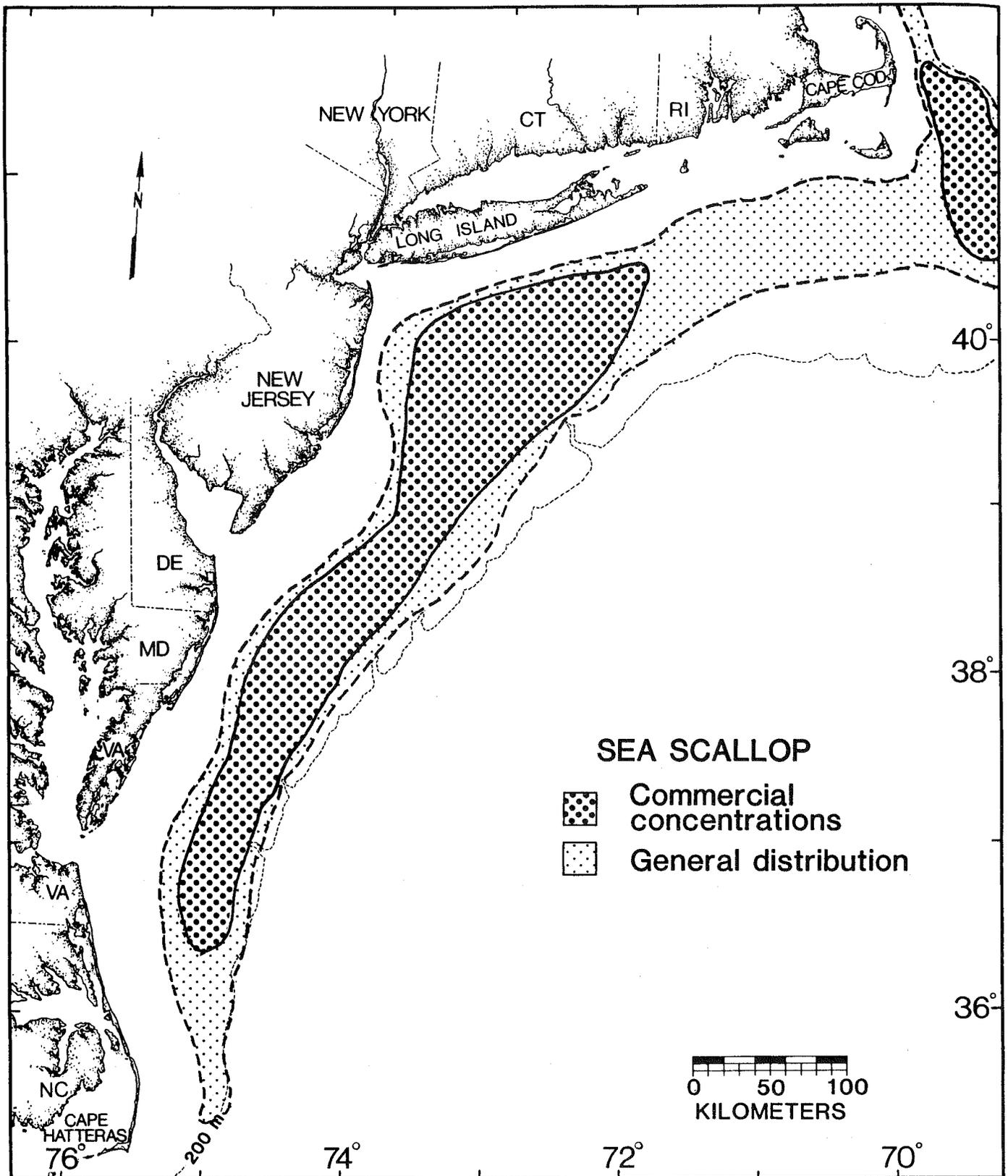


Figure 3. Distribution of sea scallops in the Middle Atlantic Bight.

temperatures from about 6.5 to 11°C (Posgay and Norman, 1958; MacKenzie et al., 1978). Fertilized scallop eggs develop into ready-to-set larvae at 12° to 18°C in about 35 days (Culliney, 1974).

### Adult Stage

Sea scallop larvae set by attaching a byssus to a substrate, which can include the shells of live sea scallops (Maidu, 1970), small shell fragments (Caddy, 1968), bryozoa (Baird, 1953; Caddy, 1972a) and red algae (Naidu, 1970). After setting, the spat often cut their byssus and crawl over the bottom, and then reattach on another site. When about 10 mm long in the year following spatfall, scallops cut the byssus and migrate to the bottom. The juveniles spend about 75 percent of their time attached to shells and stones on the bottom. A combination of attachment and swimming makes for considerable versatility in habitat and behavior. The proportion attached decreases progressively from 75 percent for scallops that are 2-5 mm long to almost zero for those larger than 120 mm long (Caddy, 1972a).

The sea scallop is capable of 'swimming' by opening and closing its valves. The mean height reached above bottom during a swim is usually about 0.4 m; over bottom speeds is around 67 cm/sec; and point-to point swimming distances range up to 4 m. Scallops larger than 100 mm rarely attempt to 'swim' (Caddy, 1968). More extensive swims sometimes occur. Small scallops have been observed on the water surface where the depth exceeded 46 m (Posgay, 1953). The longevity of scallops has not been studied but some individuals probably live at least 15-20 years.

The scallop grows rapidly during its first few years of life and then growth slows. The shell length and meat weight of scallops at ages 3 to 9 are as follows (Posgay, personal communication).

#### Middle Atlantic Shelf

Age (years)	3	4	5	6	7	8	9
Length (cm)	6.6	8.8	10.4	11.7	12.6	13.3	13.8
Weight (gm)	5.2	12.6	21.3	29.9	37.6	44.1	49.3

$$L_t(\text{mm}) = 151.84 [1 - e^{-2.997(t-1.1256)}]$$

$$\ln W(\text{gm}) = 3.0431 (\ln L(\text{mm})) - 11.0851$$

Scallop spat that had set on navigation buoys grew to lengths of about 5, 12 and 20 mm in 6, 12 and 18 months, respectively (Merrill and Posgay, 1967).

Sea scallops feed on plankton, collecting it from water passing through their mantle cavities. In laboratory culture, larvae have been grown on the phytoflagellate, Isochrysis galbana (Culliney, 1974). In the laboratory, scallop spat have been reared on mixtures of Isochrysis galbana and Chrosomonas salina (Culliney, 1974), and adults have been kept alive on the diatom, Phaeodactylum tricornutum (Bourne, 1964).

## Predators

The entire assemblage of predators that consume the sea scallop, as larvae, juveniles and adults has scarcely been examined. Presumably, 1) predators of larvae exist in the water column and on the bottom, and 2) predators consume a great many juvenile scallops, which can be easily bored, cracked open and swallowed whole. Predators cannot take many adults which are too large and have extremely hard shells. The percentages of scallops beginning with the egg, larval and juvenile stages that attain a commercial length have not been determined anywhere.

Identified predators of juvenile sea scallops include the cod (Gadus morhua), American plaice (Hippoglossoides platessoides) and wolffish (Anarhichas lupus) (Medcof and Bourne 1964) and the starfish (Asterias vulgaris) (Welch 1950; Dow 1962, 1969; Medcof and Bourne 1964). The juvenile scallop, about 15 mm long, is also preyed upon by, as yet, unidentified gastropods (MacKenzie unpublished observations). The burrowing anemone (Ceriantheopsis americanus) is suspected as a predator of scallop larvae (MacKenzie, personal observation). The anemone is widespread and abundant.

## Environmental Requirements

### Temperature

The sea scallop dies at temperatures above 20-24°C (Posgay 1953; Johannes 1957; Dickie 1958); once, in laboratory culture, scallop larvae died at a temperature of 19°C (Culliney 1974).

Temperature limits the north-south distribution of the sea scallop, and probably the inshore distribution on the middle Atlantic shelf. At the southern end of the scallop range off Cape Hatteras, North Carolina, the average 20°C isotherm is near shore and extends northward until it is parallel to the 100-fm (183 m) curve. The scallop does not range south of the Cape because the temperature is too high (Posgay 1957). The scallop ranges much closer to shore off Long Island than farther south off the Delmarva Peninsula (MacKenzie et al. 1978) because summer temperatures near shore off the peninsula are probably too high for the scallop.

### Salinity

The sea scallop occurs in areas where salinities are oceanic. In laboratory culture, scallop larvae remained viable in a salinity of 10.5 o/oo and swam about normally at salinities from 16.9 to 30.0 o/oo within a 42-h period (Culliney 1974).

### Dissolved Oxygen

The sea scallop dies in water which is depleted of oxygen. During the summer of 1976 anoxic and hypoxic bottom water covered a large area of the inner continental shelf off New Jersey. In July and thereafter for a few months, commercial fishery and personnel on National Marine Fisheries Service survey cruises, found that all scallops and most other biota were dead in the

inner side of the distribution zone of the scallop. Approximately 10 percent of all scallops were killed on the shelf off New Jersey (Ropes et al. 1979).

### Turbidity

Increased turbidity causes some stress, depresses feeding and causes weight loss in sea scallops (Stone 1975).

### Population Size and Fishery

The sea scallop fishery in the Middle Atlantic Bight has exhibited considerable variability. From 1952 to 1964 annual landings averaged about 10,400 MT. Landings rose sharply to a record high of 75,000 MT in 1966; the increase was based on an unusually large 1961 year class. Production declined gradually thereafter to about 9,000 MT in 1970-74. The years 1975-78 showed another large increase, based on an unusually large 1972 year class; landings for 1978 were about 72,000 MT. Landings have since declined (Posgay 1982).

### LITERATURE CITED

- Arcisz, W. and W. C. Neville. 1945. Description of the fishery. In: The ocean quahog fishery of Rhode Island (W. C. Neville, Coordinator). RI Dep. Agric. Conserv., Div. Fish Game. pp. 7-14.
- Arntz, W. E. 1978. The food of adult cod (Gadus morhua L.) in the Western Baltic. Ber. It. Wiss. Komm. Meeresforsch. 26: 60-69.
- Baird, F. T., Jr. 1953. Observations on the early life history of the giant sea scallop (Pecten magellanicus). Maine Dep. Sea and Shore Fish. Res. Bull. No. 14, 7 p.
- Bourne, N. 1964. Scallops and the offshore fishery of the Maritimes. Fish. Res. Board Can. Bull. No. 145, 60 p.
- Caddy, J. F. 1968. Underwater observations on scallop (Placopecten magellanicus) behavior and drag efficiency. J. Fish. Res. Board Can. 25: 2123-2141.
- Caddy, J. F. 1972a. Progressive loss of byssus attachment with size in the sea scallop, Placopecten magellanicus (Gmelin)]. J. Exp. Mar. Biol. Ecol. 9: 179-190.
- Castagna, M. and P. Chanley. 1973. Salinity tolerance of some marine bivalves from inshore and estuarine environments in Virginia waters on the western Mid-Atlantic coast. Malacologia 12: 47-96.
- Culliney, J. L. 1974. Larval development of the giant scallop, Placopecten magellanicus (Gmelin). Biol. Bull. (Woods Hole, Mass.) 147: 321-332.
- Dickie, L. M. 1958. Effects of high temperature on survival of the giant scallop. J. Fish. Res. Board Can. 15: 1189-1211.
- Dow, R. L. 1962. A method of predicting fluctuations in the sea scallop populations of Maine. Comm. Fish. Rev. 24(10): 1-4.

- Dow, R. L. 1969. Sea scallop fishery. In: The Encyclopedia of Marine Resources, Frank E. Firth, ed. Van Nostrand Reinhold Co., New York. 616-623 pp.
- Franz, D. R. 1977. Size and age-specific predation by Lunatia heros (Say, 1822) on the surf clam Spisula solidissima (Dillwyn, 1817) off Western Long Island, New York. Veliger 20: 144-150.
- Garlo, E. V. E. 1982. Increase in a surf clam population after hypoxic water conditions off Little Egg Inlet, New Jersey. J. Shelf. Res. 1: 59-64.
- Golikov, A. W. and O. A. Scarlato. 1973. Method for indirectly defining optimum temperatures for inhabitancy for marine cold-blooded animals. Mar. Biol. 20: 1-5.
- Gould, A. A. and M. G. Binney. 1870. Report on the invertebrata of Massachusetts. University Press, Cambridge, MA.
- Haskin, H. H., R. R. Schneider, and N. Tarnowski. 1979. Recent studies on the surf clam populations in southern New Jersey. Proc. Natl. Shellf. Assoc. 69: 195 (Abstract).
- Johannes, R. E. 1957. High temperature as a factor in scallop mass mortalities. MS Rept. Fish. Res. Board Can. Biol. Ser. No. 638. 18 p.
- Jones, D. S., I. Thompson, and W. Ambrose. 1978. Age and growth rate determinations for the Atlantic surf clam Spisula solidissima (Bivalvia: Mactracea), based on internal growth lines in shell cross-sections. Mar. Biol. (Berl.) 47: 63-70.
- Landers, W. S. 1972. Early development in the ocean quahog, Arctica islandica (L.). Proc. Nat. Shellfish. Assoc. 63: 3.
- Landers, W. S. 1976. Reproduction and early development of the ocean quahog, Arctica islandica, in the laboratory. The Nautilus 90: 88-92.
- Loesch, J. G. and J. W. Ropes. 1977. Assessment of surf clam stocks in nearshore waters along the Delmarva Peninsula and in the fishery south of Cape Henry. Proc. Natl. Shellfish. Assoc. 67: 29-34.
- Loosanoff, V. L. 1953. Reproductive cycle in Myrtilina islandica. Biol. Bull. 104: 146-155.
- Loosanoff, V. L. and H. C. Davis. 1950. Conditioning V. mercenaria for spawning and breeding in winter and rearing its larvae in the laboratory. Biol. Bull. (Woods Hole) 98: 60-65.
- Loosanoff, V. L. and H. C. Davis. 1963. Rearing of bivalve mollusks. In: F. S. Russell (ed.). Advances in Marine Biology. Vol. 1, Academic Press, NY. 410 pp.
- MacKenzie, C. L., Jr., A. S. Merrill, and F. M. Serchuk. 1978. Sea scallop resources off the northeastern U.S. coast, 1975. Mar. Fish. Rev. 40(2): 19-23.

- MacKenzie, C. L., Jr. D. J. Radosh, and R. N. Reid. 1985. Densities, growth and mortalities of juvenile surf clams (Spisula solidissima) in the New York Bight. *J. Shellf. Res.* 5(2): 81-84.
- Medcof, J. C. and N. Bourne. 1964. Causes of mortality of the sea scallop, Placopecten magellanicus. *Proc. Natl. Shellf. Assoc.* 53: 33-50.
- Merrill, A. S. and J. B. Burch. 1960. Hermaphroditism in the sea scallop, Placopecten magellanicus (Gmelin]. *Biol. Bull.* (Woods Hole, MA) 119: 197-201.
- Merrill, A. S. and J. A. Posgay. 1967. Juvenile growth of the sea scallop, Placopecten magellanicus. *Amer. Malacol. Union Inc. Annu. Rep.* 1967. 51-52 pp. (Abstract).
- Merrill, A. S., J. L. Chamberlin, and J. W. Ropes. 1969. Ocean quahog fishery. In: *The Encyclopedia of Marine Resources* (F. E. Firth, ed.). Van Nostrand Reinhold Publ. Co., New York, NY, pp. 125-29.
- Merrill, A. S. and J. W. Ropes. 1969. The general distribution of the surf clam and ocean quahog. *Proc. Natl. Shellfish. Assoc.* 59: 40-45.
- Murawski, S. A. and F. M. Serchuk. 1979. Dynamics of the ocean quahog, Arctica islandica, population off the Middle Atlantic coast of the United States. U.S. Dep. Comm., Nat. Marine Fish. Serv., Northeast Fisheries Center, Woods Hole, MA. Lab. Ref. No. 79-16.
- Murawski, S. A., J. W. Ropes, and F. M. Serchuk. 1982. Growth of the ocean quahog, Arctica islandica, in Middle Atlantic Bight. *Fish. Bull.* 80(1): 21-34.
- Naidu, K. S. 1970. Reproduction and breeding cycle of the giant scallop Placopecten magellanicus (Gmelin) in Port-au-Port Bay, Newfoundland. *Can. J. Zool.* 48: 1003-1012.
- Parker, P. S. and E. D. McRae, Jr. 1970. The ocean quahog, Arctica islandica, resource of the northwestern Atlantic. *Fish. Jud. Res.* 6: 185-195.
- Posgay, J. A. 1953. Sea scallop investigations. Sixth report in investigations of the shellfisheries of Massachusetts. *Div. Mar. Fish., Dept. of Conserv., Commonwealth of Massachusetts, Boston.* 9-24 pp.
- Posgay, J. A. 1957. The range of the sea scallop. *The Nautilus* 71: 55-57.
- Posgay, J. A. 1963. Tagging as a technique in population studies of the sea scallop. *Spec. Publ. Int. Comm. Northwest Atl. Fish.* 4: 268-271.
- Posgay, J. A. and K. D. Norman. 1958. An observation o the spawning of the sea scallop, Placopecten magellanicus (Gmelin), on Georges Bank. *Limnol. Oceanogr.* 3: 478.

- Posgay, J. A. 1982. Sea scallop, Placopecten magellanicus. In: Fish Distribution (M. D. Grosslein and T. R. Azarovitz, eds.). MESA New York Bight Atlas Monograph 15. New York Sea Grant Institute, Albany, NY. pp. 130-133.
- Rathjen, W. F. 1977. Fisheries development in New England -- a perspective. Mar. Fish. Rev. 39(2): 1-6.
- Ropes, J. W. 1968a. Hermaphroditism in the surf clam, Spisula solidissima. Proc. Natl. Shellfish. Assoc. 58: 63-65.
- Ropes, J. W. 1968b. Reproductive cycle of the surf clam, Spisula solidissima, in offshore New Jersey. Biol. Bull. (Woods Hole) 135: 349--365.
- Ropes, J. W., J. L. Chamberlin, and A. S. Merrill. 1969. Surf Clam Fishery. In: F. E. Firth (ed.), the Encyclopedia of the Marine Resources. Van Nostrand Reinhold, Co., NY. 740 p.
- Ropes, J. W. and A. S. Merrill. 1973. To what extent do surf clams move? Nautilus 87: 19-21.
- Ropes, J. W. 1979a. Biology and distribution of surf clams (Spisula solidissima) and ocean quahogs (Arctica islandica) off the Northeast coast of the United States. In: Proceedings of Northeast Clam Industries: Management for the Future. Exten. Sea Grant Prog., Univ. Mass. and Mass. Inst. Tech. SP-112: 47-66.
- Ropes, J. W. 1979b. Shell length at sexual maturity of surf clams, Spisula solidissima, from an inshore habitat. Proc. Natl. Shellfish. Assoc. 69: 85-91.
- Ropes, J. W., A. S. Merrill, S. A. Murawski, S. Chang, and C. L. MacKenzie, Jr. 1979. Chapter 11. Impact on clams and scallops. Part 1. Field Survey Assessments. In Oxygen depletion and associated benthic mortalities in New York Bight, 1976 (R. L. Swanson and C. J. Sindermann, eds.). NOAA Professional Paper 11. pp. 263-275.
- Ropes, J. W. 1980. Biological and fisheries data on the Atlantic surf clam, Spisula solidissima (Dillwyn). Technical Series Report No. 24. Northeast Fisheries Center. Sandy Hook Laboratory, Highlands, NJ, 88 p.
- Ropes, J. W., S. A. Murawski, and F. M. Serchuk. 1982. Atlantic surf clam Spisula solidissima. In: Fish Distribution (M. D. Grosslein and T. R. Azarovitz, eds.). MESA New York Bight Atlas Monograph 15. New York Sea Grant Institute, Albany, NY. pp. 141-144.
- Ropes, J. W. and S. A. Murawski. 1983. Maximum shell length and longevity in ocean quahogs, Arctica islandica Linn. International Council for the Exploration of the Sea. C.M. 1983/K:32. Shellfish Committee. 8 p.

- Saila, S. B. and S. D. Pratt. 1973. Mid-Atlantic Bight Fisheries. In: Saila, S. B. (Coordinator). Coastal and Offshore Environmental Inventory, Cape Hatteras to Nantucket Shoals. Mar. Exp. Sta., Grad. School Oceanogr., Univ. Rhode Island, Kingston, RI, Mar. Publ. Ser. No. 2, p. 6-1 to 6-125.
- Savage, N. B. 1976. Burrowing activity in Mercenaria mercenaria (L.) and Spisula solidissima (Dillwyn) as a function of temperature and dissolved oxygen. Mar. Behav. Physiol. 3: 221-234.
- Serchuk, F. M., S. A. Murawski, and J. W. Ropes. 1982. Ocean quahog, Arctica islandica. In: Fish Distribution (M. D. Grosslein and t. R. Azarovitz, eds.). MESA New York Bight Atlas Monograph 15. New York Sea Grant Institute, Albany, NY. pp. 144-46.
- Steimle, F. W. and C. J. Sindermann. 1978. Review of oxygen depletion and associated mass mortalities of shellfish in the Middle Atlantic Bight in 1976. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 40(12): 17-25.
- Stone, R. L. 1975. Sublethal effects of experimental turbidity concentrations on selected marine organisms. Contract DACW-33-74-C-0101 rep. to New England Aquarium and U.S. Army Corps of Engineers.
- Taylor, A. C. 1976. Burrowing behavior and anaerobiosis in the bivalve, Arctica islandica (L). J. Mar. Biol. Assoc. UK 56: 95-109.
- Theede, H. 1965. Vergleichende experimentelle Untersuchungen über die zellulare Gefrierrestenz mariner Muscheln. (Comparative experimental investigations of the cellular freezing resistance of marine bivalves). Kiel. Meeresforsch. 2: 153-166.
- Welch, W. R. 1950. Growth and spawning characteristics of the sea scallop, Placopecten magellanicus (Gmelin), in Maine waters. M.A. Thesis. U. of Maine, Orono. 95 p.
- Westman, J. R. and M. H. Bidwell. 1946. The surf clam. Economics and biology of New York marine resources. Typewritten ms. on file at U.S. Dept. Comm., NOAA, NMFS, Northeast Fisheries Laboratory, Oxford, MD.
- Williams, A. B. and H. J. Porter. 1971. A ten-year study of meroplankton in North Carolina estuaries: occurrence of postmetamorphol bivalves. Chesapeake Sci. 12: 26-32.
- Winter, J. E. 1970. Filter feeding and food utilization in Arctica islandica L. and Modiolus modiolos L. at different food concentrations. In: Marine Food Chains (J. H. Steele, ed.). Edinburgh: Oliver and Boyd. pp. 196-206.
- Yancey, R. M. and W. R. Welch. 1968. The Atlantic coast surf clam - with a partial bibliography. U.S. Dept. Interior, Fish and Wildl. Serv., Circular 288, 13 p.

# Seasonal Distribution, Abundance and Diversity Patterns of Fish Eggs and Larvae in the Middle Atlantic Bight

by

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## INTRODUCTION

The Middle Atlantic Bight is an ecological transition area where annual environmental conditions shift from tropical-like in summer to boreal-like in winter. Water temperatures fluctuate by more than 25°C between winter and summer (Grosslein and Azarovitz, 1982). During vertically stratified summer conditions, surface and bottom temperatures can differ by as much as 16°C and cross-shelf salinity values routinely differ by as much as 5 o/oo (Ingham, 1982). Furthermore, being adjacent to one of the world's great metropolitan centers, parts of the bight and adjacent estuaries rank among the most heavily degraded coastal regions on earth (Pearce, 1983; Mayer, 1982). Despite the harsh environmental realities and man-induced perturbations, the bight remains among the biologically richest and heavily fished areas in the western hemisphere. In 1980 commercial landings in ports from Rhode Island to North Carolina exceeded 600 thousand metric tons (mt) valued at \$360 million, and recreational fishermen caught more than 133 million fish in coastal waters off the middle Atlantic states (Thompson, 1984). Most of the species that contribute to commercial and recreational fisheries, as well as many important forage species, spawn in the bight. Their eggs and larvae represent two most vulnerable life stages, for during these early phases of development mortality is highest and year class population levels are essentially established.

For nearly a decade biologists at NOAA's Northeast Fisheries Center have investigated the interacting ecological events that influence the success of recruiting year classes through a comprehensive fishery ecosystem study known as MARMAP<sup>2</sup> (Sherman, 1980). MARMAP is a broad-based program that integrates information from ocean surveys, fine-scale field studies and laboratory research to investigate recruitment processes. In addition to providing a description, abundance and production of fish eggs and larvae, the surveys provide an effective, fishery-independent means for assessing the adult spawning biomass of important fishery resources (Berrien, 1981, 1983; Berrien et al., 1981; Morse, 1982).

In this report we describe temporal and areal distribution, abundance and diversity patterns of ichthyoplankton in the Middle Atlantic Bight from MARMAP surveys conducted during the 4-year period between 1977 and 1980. Emphasis is

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on the early stages of economically and/or ecologically important taxa. Our objective is to demonstrate the significance of the bight as a spawning and nursery ground for a wide range of coastal fishes and, thereby, provide information useful to those with the awesome task of balancing the conflicting demands of society with the well-being of coastal fishery resources and their supporting food chain organisms. Other studies dealing with the broadscale occurrence of fish eggs and larvae in the Middle Atlantic Bight include: Sette (1943), Fahay (1974), Kendall and Reintjes (1975), Smith et al. (1975), Grosslein (1976), Berrien et al. (1978), Berrien et al. (1978), Kendall and Walford (1979) and Smith et al. (1975, 1979, 1983).

## METHODS

The MARMAP survey area includes shelf waters from Cape Hatteras, North Carolina to Cape Sable, Nova Scotia, an area of some 260,000 km<sup>2</sup>. This report deals with the southern part of the survey area, or the 118,232 km<sup>2</sup> between Cape Hatteras and Great South Channel, which lies just east of Nantucket Shoals. For analytical purposes we separate the Middle Atlantic Bight into two subareas: a northern, henceforth referred to as the southern New England subarea, which extends from Great South Channel westward to the vicinity of the Hudson Canyon; and a southern, known as the middle Atlantic subarea, which includes shelf waters from the canyon southward to Cape Hatteras. The subareas are further divided into three depth strata to depict cross-shelf changes in species composition and abundance. The strata are: inshore (<40 m); mid-shelf (40 to 100 m) and outer shelf (>100 m). Within the reporting area stations are spaced at 8- to 18-km intervals along five transects. All other sampling sites are scattered at 25- to 35-km intervals to provide uniform coverage of the shelf (Figure 1).

Surveys are conducted 6 to 7 times a year. During the 1977-80 period we completed 27 surveys. Plankton samples are collected on each survey by double-oblique tows with a 61-cm bongo fitted with 0.333 and 0.505-mm mesh nets. The bongo is lowered to within a few meters of bottom or to a maximum depth of 200 m at 50 m min<sup>-1</sup> and retrieved at 20 m min<sup>-1</sup>. Ship speed varies between 1 and 2 kts to maintain a 45° wire angle during a tow. A flow meter in the mouth of each net provides information for computing the amount of water filtered, and a bathykymograph records a trace of the vertical tow profile and the maximum sampling depth. The 0.505-mm mesh samples are used for ichthyoplankton analysis; the 0.333-mm mesh samples for invertebrate zooplankton studies. All larval catches are standardized to represent the number of larvae under 10 m<sup>2</sup> surface area, an estimate of abundance.

An index of larval diversity (D) by season, subarea and depth stratum demonstrates within-year changes in the number of taxa (larvae) and the relative contribution in numbers of each taxa. D was computed as:

$$D = 3.3219 \left( \log_{10} \frac{N-1}{N} n_i \log_{10} n_i \right)$$

where N = the total number of larvae in the depth stratum, and n<sub>i</sub> is the conversion from log<sub>10</sub> to log<sub>2</sub> (Peet, 1974). A seasonal mean diversity is presented for the four years to indicate temporal and spatial trends in distribution and abundance within the study area.

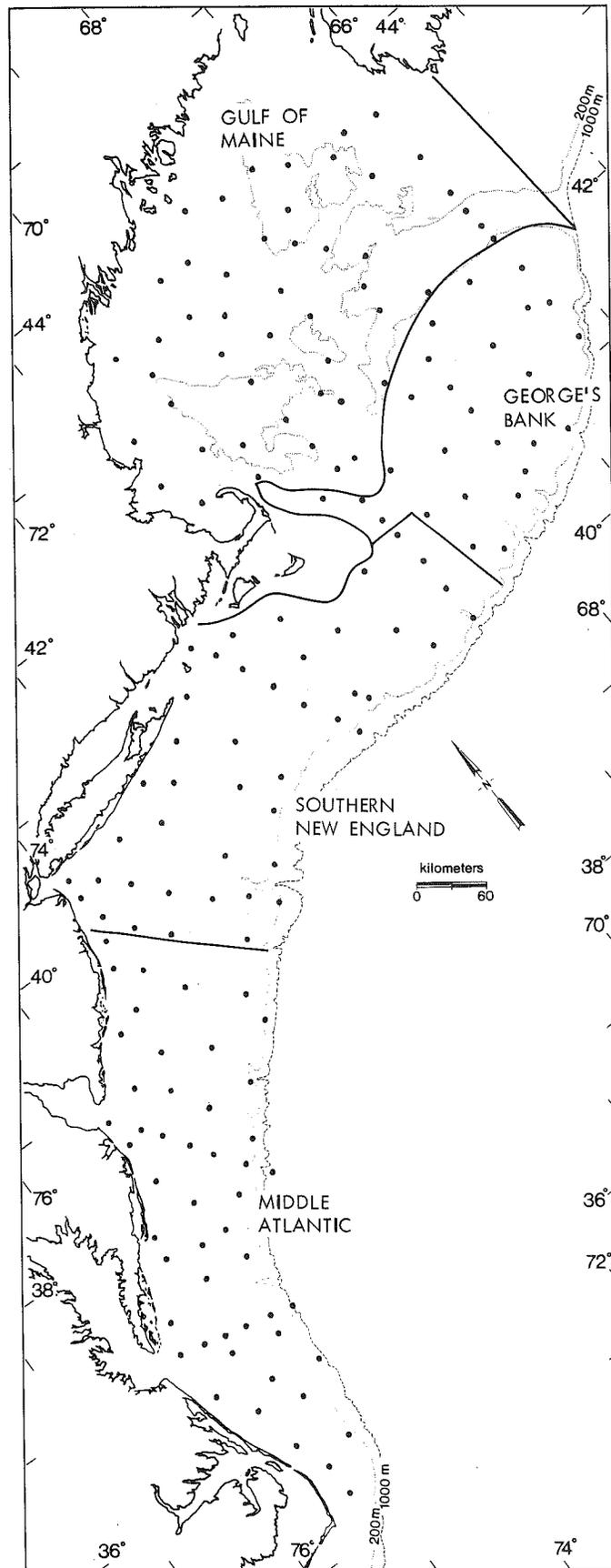


Figure 1. Station plan and four subareas for MARMAP ichthyoplankton surveys.

## RESULTS

Fish eggs and/or larvae representing more than 200 taxa are collected annually on MARMAP surveys in the Middle Atlantic Bight. Although spawning continues year-round in the bight, spawning cycles of most coastal species are seasonal, i.e., climatic changes are followed closely by changes in species composition of the ichthyoplankton (Figure 2). The number of taxa represented in the larval community increases from a winter low of 25 in the southern New England subarea to a late spring high of 107 in the middle Atlantic subarea. Eggs and larvae of some species are areally limited; for others broadly distributed. The overlapping concentrations of spawning products form ever-changing mosaic patterns that continually blanket the entire continental shelf (Figure 3).

Survey results for the 1977-80 time period show a repeated cycle in the seasonal abundance of both eggs and larvae. Eggs occur at relatively low levels of abundance during the late winter period but by mid-April the spring spawning cycle is in full swing throughout the Middle Atlantic Bight. Atlantic mackerel, Scomber scombrus, and yellowtail flounder, Limanda ferruginea, eggs account for most of the increase in the southern New England subarea while weakfish, Cynoscion regalis, butterfish, Peptrilus triacanthus, and anchovies (Engraulidae) are the principal contributors to the dense concentrations of eggs found off Virginia and North Carolina. The abundance of eggs continues to increase through late spring as spawning cycles of the above taxa reach peak levels. Summer catches are comprised largely of Gulf Stream flounder, Citharichthys arctifrons, windowpane flounder, Scophthalmus aquosus, silver hake, Merluccius bilinearis, and hake, Urophycis spp. eggs off southern New England while tautog, Tautoga onitis, smallmouth flounder, Etropus microstomus, Gulf Stream flounder, sea robins, Poronotus spp., and bluefish, Pomatomus saltatrix, begin to numerically dominate catches from New Jersey southward. Spawning activity is sharply reduced throughout the bight by autumn. Eggs of summer flounder, Paralichthys dentatus, are abundant off southern New England while summer flounder, Atlantic menhaden, Brevoortia tyrannus, and sea robin egg concentrations occur in the middle Atlantic subarea (Figure 4).

As with eggs, larvae also exhibit cycles in abundance which follow seasonal trends from year to year. However, annual abundance curves for larvae differ from those for eggs because of a population explosion in the mid-1970s of sand lance, Ammodytes spp., a taxon that spawns demersal eggs in late autumn and winter throughout the bight. This phenomenal increase in sand lance results in a bimodal curve with a winter peak that is >95% sand lance. The second peak occurs in summer and is comprised largely of larvae of the above listed summer spawners but, as previously noted, species composition of the larval fish community at the southern end of the survey area is at an annual high in late spring and summer and a plankton sample from a given sampling site may contain more than 30 taxa (Figure 4).

Larval diversity indices for inshore, mid-shelf and outer shelf depth strata differ between seasons but, with a few exceptions, within-season indices are similar between strata and follow a cyclic pattern (Figure 5). Because of the ubiquitous distribution and numerical dominance of sand lance larvae, winter diversity indices are low in all strata throughout the bight. The index in the outer shelf strata of the middle Atlantic subarea in winter

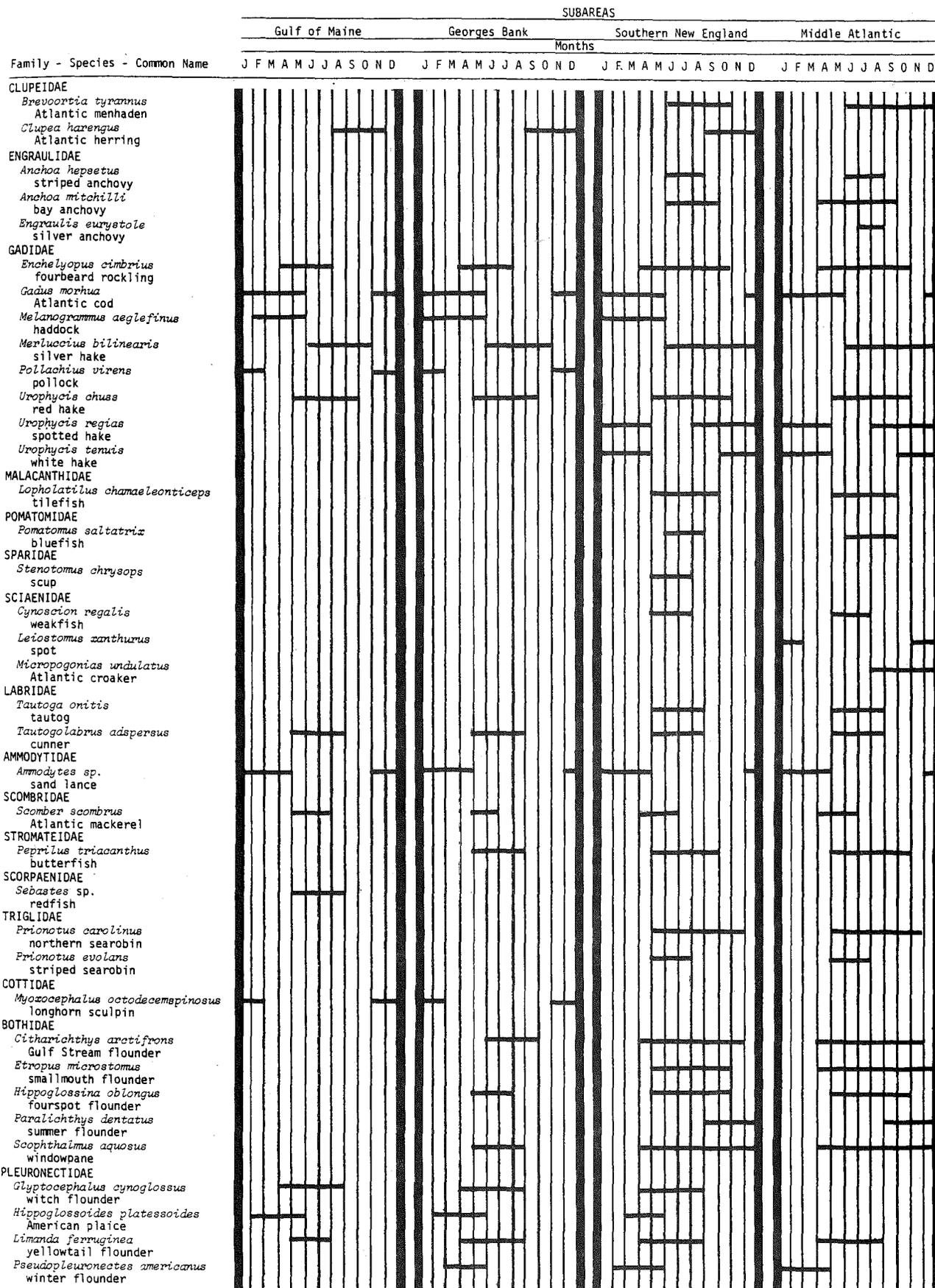


Figure 2. Spawning seasons of principal species, based on larval occurrences, in four analytical subareas of northeastern United States (after Colton et al. 1979).

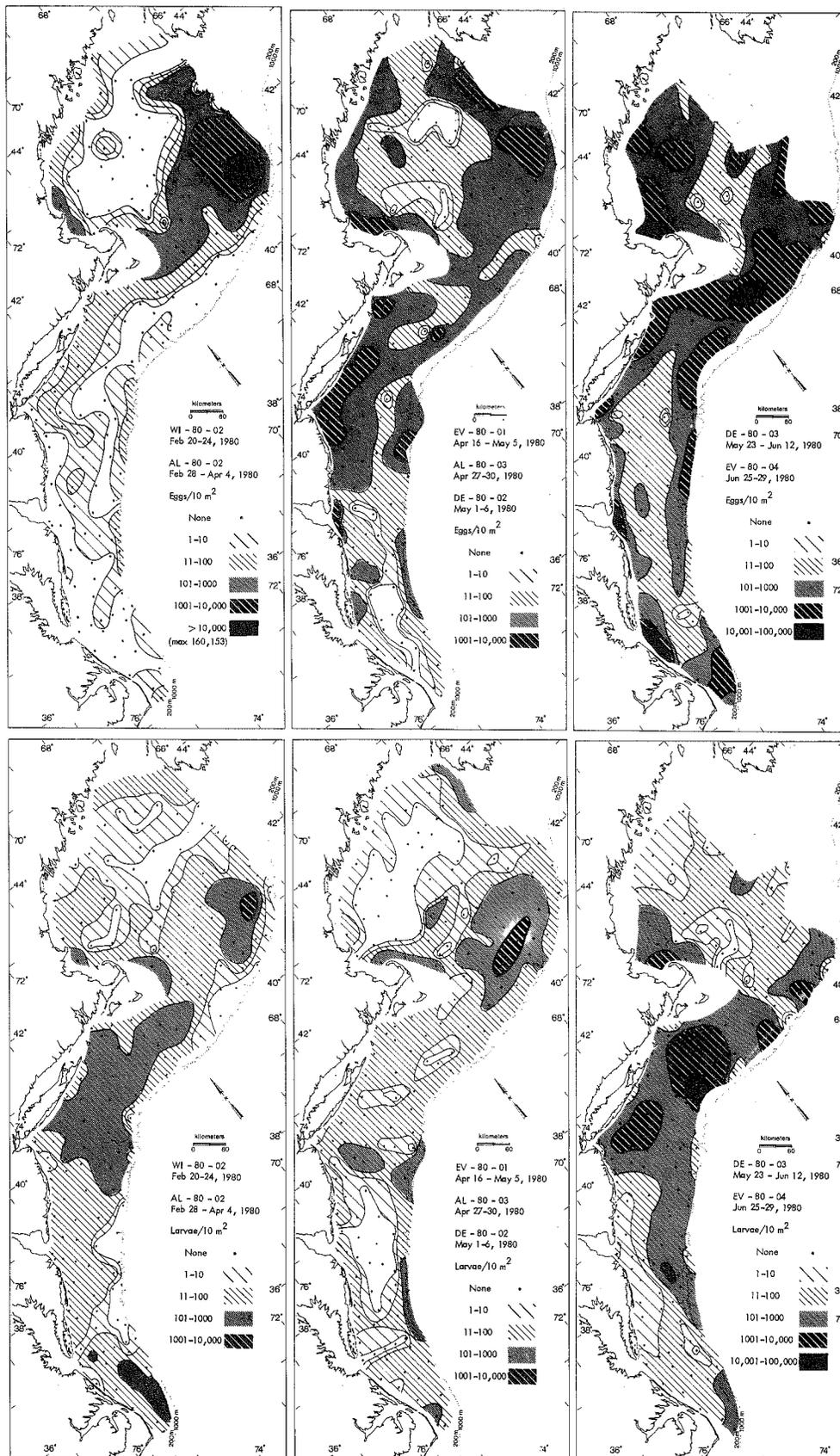


Figure 3. Distribution and abundance of fish eggs (top) and larvae (bottom) during MARMAP plankton surveys off northeastern United States in 1980, showing seasonal shifts in patchiness and widespread occurrence of spawning products.

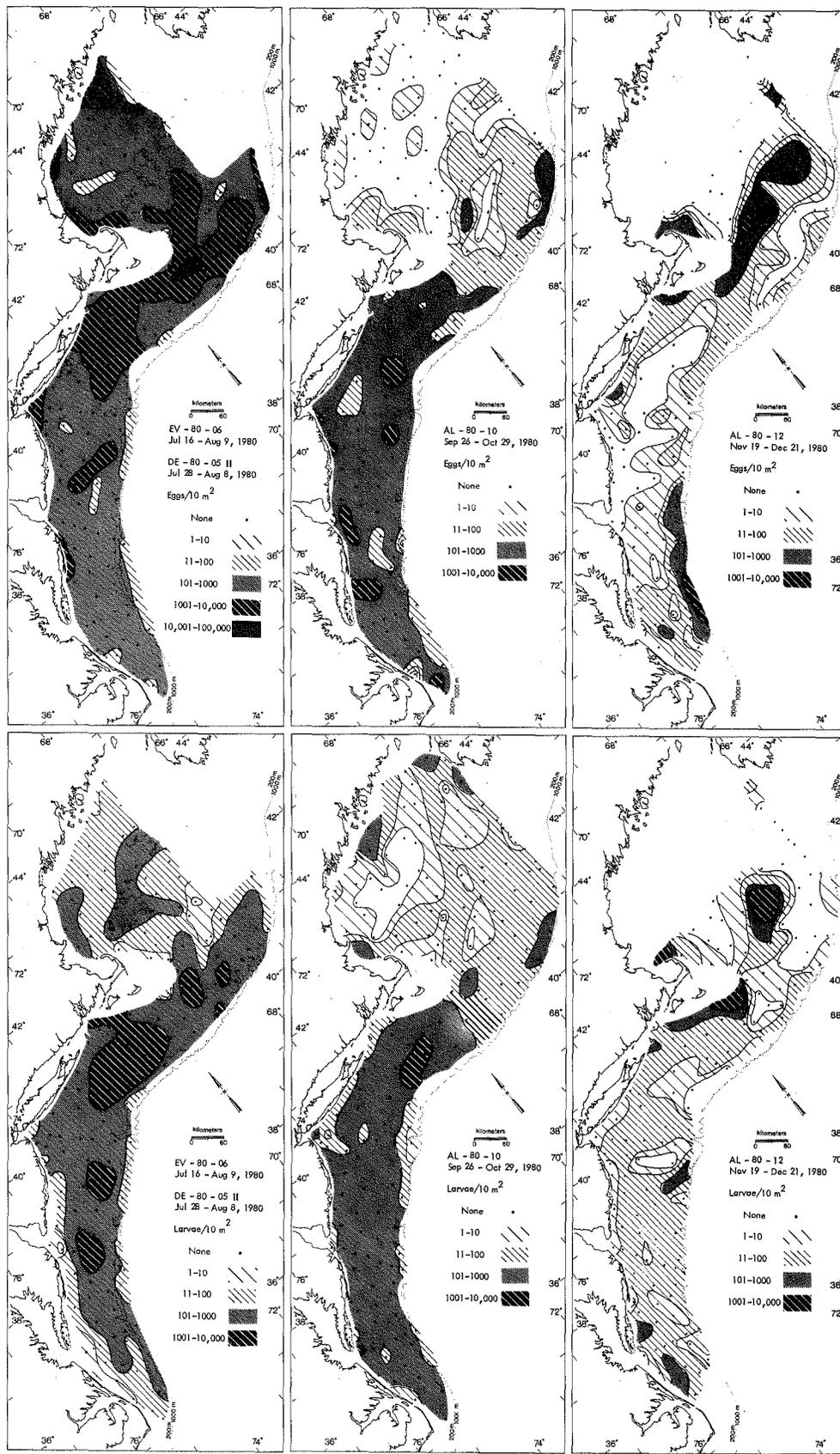


Figure 3. continued.

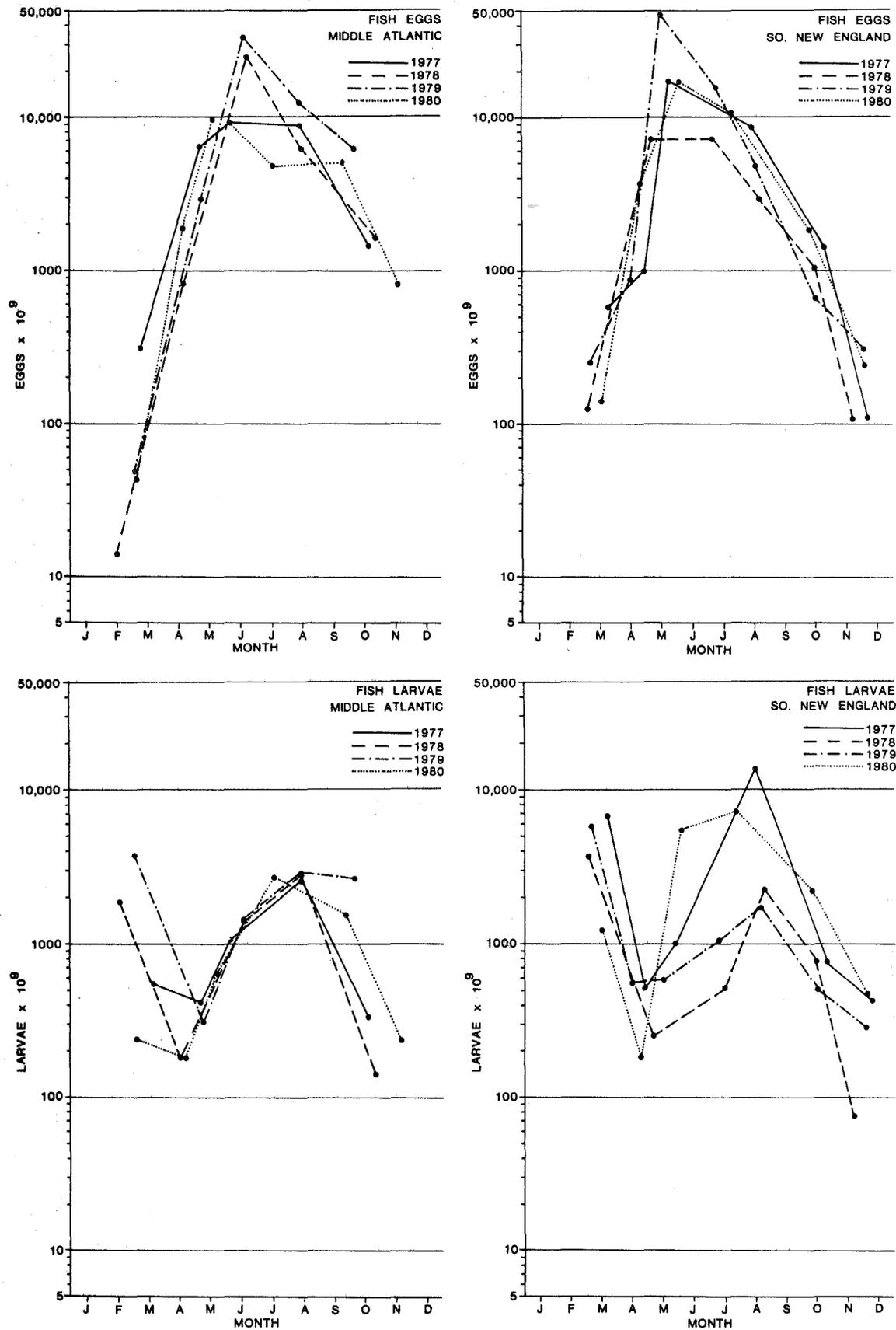


Figure 4. Seasonal changes in abundance of fish eggs (top) and fish larvae (bottom) in the Middle Atlantic and southern New England subareas for 1977-1980.

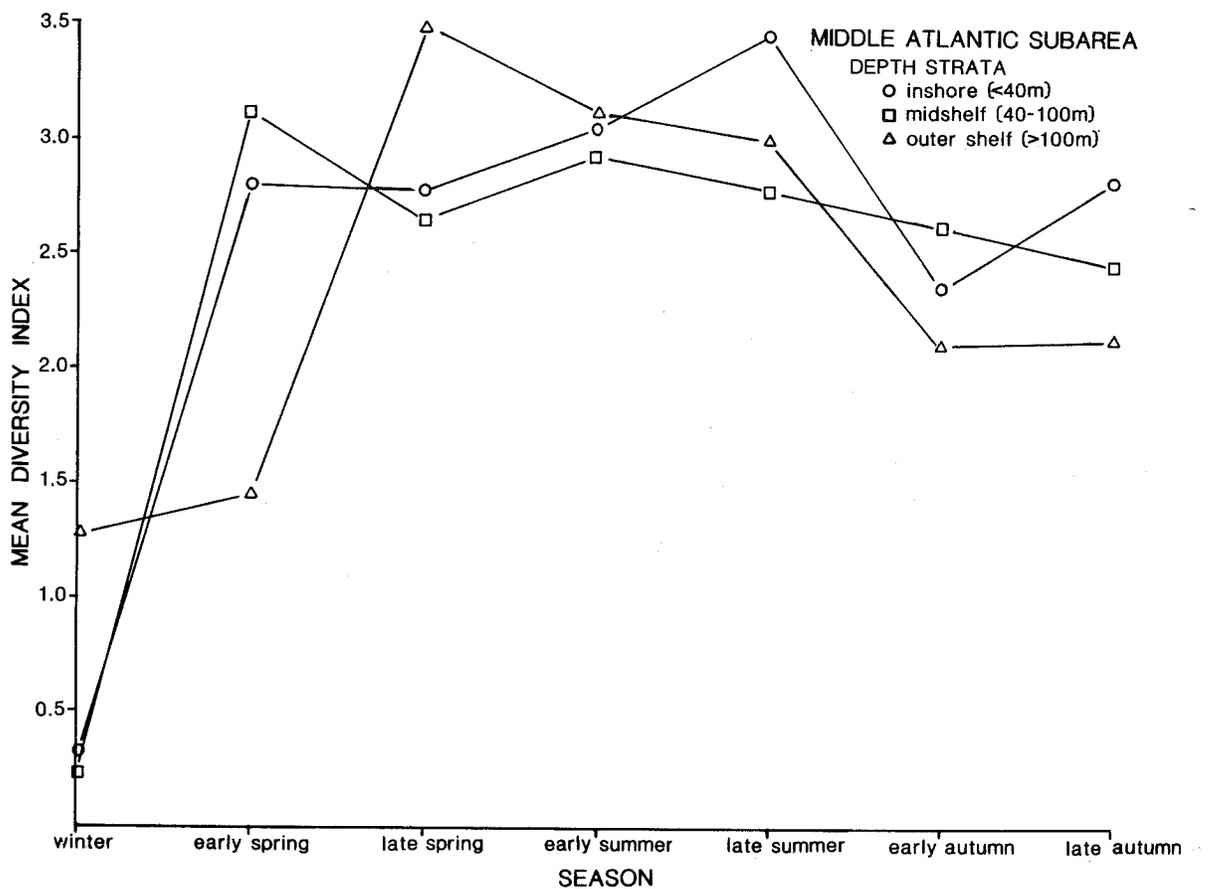
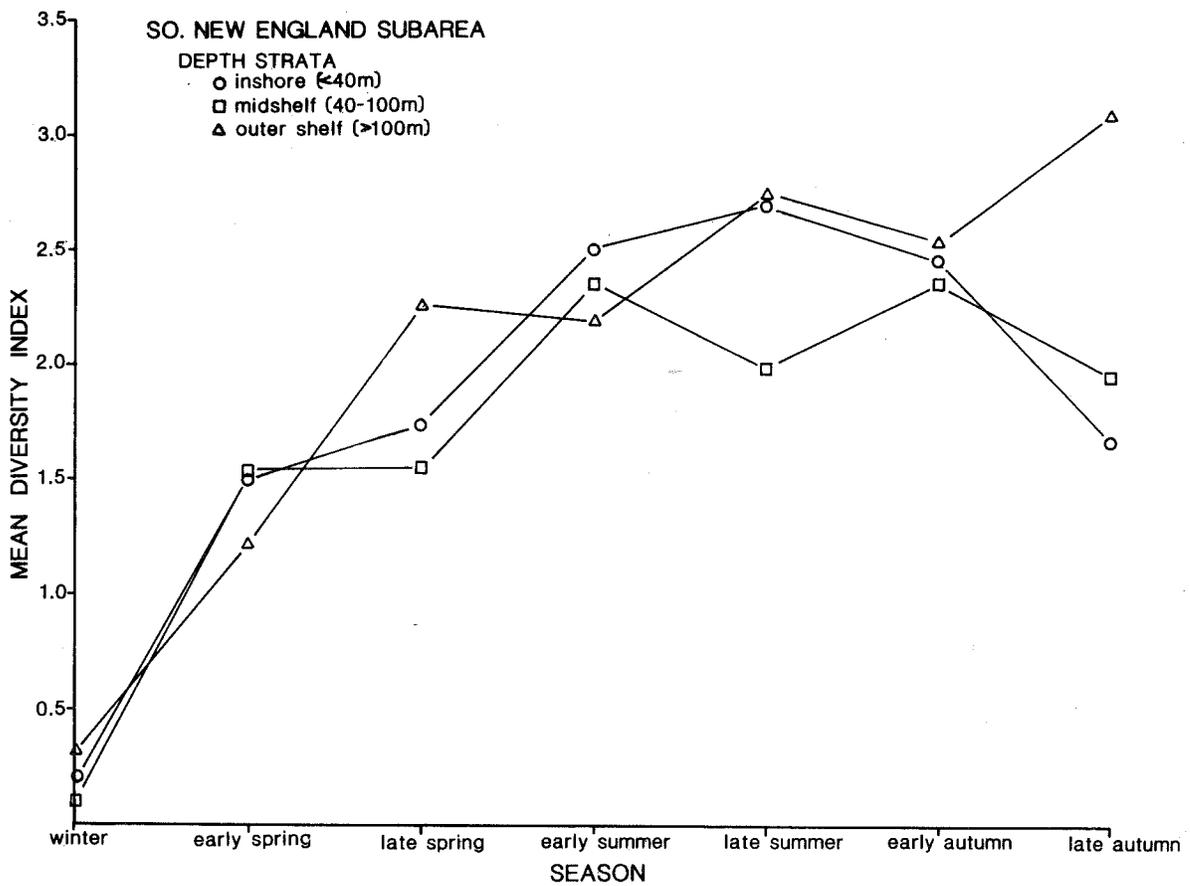


Figure 5. Diversity index of larval fish community by season, subarea and depth strata in Middle Atlantic Bight, 1977-80. Southern New England subarea extends from Hudson Canyon eastward to Great South Channel. The middle Atlantic subarea extends from Hudson Canyon southward to Cape Hatteras.

is higher than the others for two reasons: (1) the abundance of sand lance larvae is less than in the other strata; and (2) wayward larvae of species spawned south of Cape Hatteras occasionally drift into deep shelf waters off North Carolina. In early spring the index remains relatively low in all strata off southern New England because of the numerical dominance of three taxa: Atlantic mackerel, S. scombrus, and two myctophids, Benthosema glaciale and Hygophum benoiti.

In contrast to the southern New England subarea, the early spring indices increase sharply in the middle Atlantic subarea, reflecting an increase in the influx of larvae spawned south of Cape Hatteras and the onset of spawning off North Carolina due to early spring warming. The offshore diversity index in the middle Atlantic subarea remains low because of the numerical dominance of the myctophid, H. benoiti. Diversity indices continue to increase in the northern part of the bight through late spring and summer due in part to the emigration of warm water spawners from the south. Despite the increasing number of taxa represented in summer catches, a late summer depression in diversity occurs over mid-shelf depths off southern New England because of the numerical dominance of larval hakes, Urophycis spp. By late autumn indices decline in the inshore and mid-shelf strata off southern New England as sand lance larvae begin hatching in large numbers. Outer shelf spawning is light in the southern New England subarea. The larval community is represented by several taxa which are sparsely distributed, thus diversity is at an annual high over depths >100 m. In the middle Atlantic subarea, autumn diversity indices decline from high summer levels, largely because sea robin, Triglidae, and Atlantic croaker, Micropogonias undulatus, numerically dominate the larval community and the number of species represented in autumn is sharply reduced.

To further demonstrate the cyclic nature in both temporal and spatial distribution and abundance patterns of spawning products, we selected 18 of the principal taxa and tabulated larval occurrence and relative abundance by season over the three depth strata (Table 1). The results clearly show that the inshore area off southern New England is important for yellowtail flounder, L. ferruginea, Atlantic mackerel, Scomber scombrus, in the spring and windowpane, S. aquosus, during autumn. Butterfish, P. tricanthus, bluefish, P. saltatrix, sea robins, Triglidae, smallmouth flounder, E. microstomus, and croaker, M. undulatus, larvae are abundant during the summer and autumn months in shallow coastal waters from New Jersey southward. At different times of the year, concentrations of sand lance, Ammodytes spp., hakes, Urophycis spp., anchovies, Engraulidae, and summer flounder, P. dentatus, larvae occur nearshore throughout the bight.

Mid-shelf waters off southern New England are important to Atlantic cod, G. morhua, yellowtail flounder and Atlantic mackerel larvae in spring. In the southern part of the bight, bluefish, summer flounder, sea robins and smallmouth flounder larvae numerically dominate during summer and autumn at mid-depths. Sand lance, butterfish, hakes and Gulf Stream flounder, C. arctifrons, are abundant over mid-depths throughout the bight.

In deep outer shelf waters, larvae of Atlantic mackerel and Atlantic cod occur off southern New England; bluefish, yellowtail flounder, smallmouth flounder from New Jersey southward in spring and summer. Hakes, butterfish, Gulf Stream flounder and larvae of several slope water taxa, i.e.,

Paralepididae, H. benoiti, B. glaciale and C. maderensis, are abundant over deep waters throughout the bight on a seasonal basis.

#### DISCUSSION

The Middle Atlantic Bight serves as a spawning and nursery ground for many economically and ecologically important species. Although a few species have extended spawning seasons, the vast majority spawn over a period of a few months and spawning usually peaks during a period of weeks.

Many of the fishes in the bight are seasonal migrants that spawn during immigrations and emigrations. For example, Atlantic mackerel spawn during their northward migration in spring. Atlantic menhaden spawn in summer and during their autumn emigration. Because these movements are closely tied to water temperature, spawning is often localized at the outset but shifts seasonally and increases in areal extent with the advancing migrations. Sherman et al. (1984) discuss spawning strategies of important coastal species off northeastern United States, most of which spawn in the Middle Atlantic Bight. From observed spatial and temporal trends in distribution and abundance of larvae, they concluded that spawning strategies represent adaptations to topographic and circulation features and the annual production cycle of prey organisms. Our results support their findings. Because of the different adaptations of the diverse fish fauna in the Middle Atlantic Bight the entire shelf area between capes Hatteras and Cod provides spawning and nursery grounds for economically and/or ecologically important fishery resources.

Despite the dynamic and diverse nature of the larval fish community in the Middle Atlantic Bight, numerical dominance is shared by a limited number of taxa. In this regard, the incredibly high abundance of sand lance larvae during the 1977-80 reporting period is noteworthy. To our knowledge, no taxon has heretofore so numerically dominated a seasonal ichthyoplankton community on a sustained basis over such a broad geographic area off northeastern United States. This population explosion began in the mid-1970s and was discovered through the MARMAP surveys. The winter abundance estimate of sand lance larvae from Georges Bank to Cape Hatteras was  $490 \times 10^9$  in 1974. By 1979 the standing crop of larvae during the winter survey increased to  $9640 \times 10^9$  (Sherman et al., 1981). Population estimates for this time period indicate a 50-fold increase in the adult spawning biomass (Morse, 1982). Presumably, they will remain numerically dominant until directly or indirectly reduced through natural or man-induced changes such as: 1) a decline in the adult spawning biomass to a level that cannot produce enough young to maintain a numerical advantage over predators and/or competitors; 2) shifts in the temporal and spatial distribution and abundance of prey organisms which result in insufficient food organisms; 3) changes in circulation patterns which cause mass mortalities through errant transport; and 4) increased embryonic and larval mortality caused by the release of toxic materials over spawning and nursery areas. Grosslein and Azarovitz (1982) present an outstanding overview of the impact of natural and man-induced perturbations on coastal fishery resources, citing specific examples of both on marine organisms in the Middle Atlantic Bight. Their review is current and should be consulted by those with an interest in fisheries or multiuse management of coastal zones.

## SUMMARY

Within year species composition of fish eggs and larvae changes seasonally, coincident with marked changes of distribution and relative abundance are similar. Spawning is most intense during spring and summer months. Species diversity within the larval fish community is greatest in offshore waters along the southern part of the bight in spring, shifting to inshore waters in the same region in summer. This trend is attributed largely to an influx of larvae spawned south of the Middle Atlantic Bight in spring and an emigration of adult spawning populations during the spring and summer months.

## REFERENCES

- Berrien, P. 1981. Yellowtail flounder, Limanda ferruginea, estimates of egg abundance and population size during spring 1977 in Gulf of Maine, Georges Bank, southern New England and Middle Atlantic Bight waters. ICES C.M. 1981/G:65.
- Berrien, P. 1983. Silver hake, Merluccius bilinearis, egg census and adult population estimate for 1978 in waters off eastern United States. ICES C.M. 1983/G:46.
- Berrien, P., M. Fahay, A. Kendall, Jr. and W. Smith. 1978. Ichthyoplankton from the R/V Dolphin survey of continental shelf waters between Martha's Vineyard, Massachusetts and Cape Lookout, North Carolina, 1965-66. Sandy Hook Laboratory, Tech. Ser. Rept. 15. 152. p.
- Berrien, P., A. Naplin and M. Pennington. 1981. Atlantic mackerel, Scomber scombrus, egg production and spawning population estimates for 1977 in the Gulf of Maine, Georges Bank, and Middle Atlantic bight. Rapp. P.-v. Reun. int. Explor. Mer, 178: 279-288.
- Fahay, M. P. 1974. Occurrence of silver hake, Merluccius bilinearis, eggs and larvae along the Middle Atlantic continental shelf during 1966. Fish. Bull., U.S., 72(3): 813-834.
- Grosslein, M. and T. Azarovitz. 1982. Fish distribution. MESA New York Bight Atlas Monogr. 15. 182 p.
- Ingham, M., R. Armstrong, J. Chamberlin, S. Cook, D. Mountain, R. Schlitz, J. Thomas, J. Disagni, J. Paul and C. Warsh. 1982. Summary of the physical oceanographic processes and features pertinent to pollution distribution in the coastal and offshore waters of the northeastern United States, Virginia to Maine. NOAA Tech. Memo. NMFS/F/NEC-17. 160 p.
- Kendall, A. W., Jr. and J. Reintjes. 1975. Geographic and hydrographic distribution of Atlantic menhaden eggs and larvae along the Middle Atlantic coast from R. V. Dolphin cruises 1965-66. Fish. Bull. U.S., 73(2): 317-335.
- Kendall, A. W., Jr. and L. A. Walford. 1979. Source and distribution of bluefish, Pomatomus saltatrix, larvae and juveniles off the east coast of the United States. Fish. Bull., U.S. 77(1): 213-228.

- Mayer, G. F. (ed.). Ecological Stress and the New York Bight: Science and Management. Estuarine Research Foundation, Columbia, SC.
- Morse, W. 1982. Spawning stock biomass estimates of sand lance, Ammodytes sp., off northeastern United States, determined from MARMAP surveys, 1974-80. ICES C.M. 1982/G: 59.
- Pearce, J. B. (ed.). 1983. Status of estuaries and coastal waters between Cape Hatteras and Maine: A review. pp. 81-95. In: Reviews of water quality and transport of materials in coastal and estuarine waters. ICES Coop. Res. Rept. 118.
- Peet, R. K. 1974. The measurement of species diversity. Ann. Rev. of Ecol. and Systematics, Vol. 5: 285-307.
- Sette, O. E. 1943. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 1. Early life history including growth, drift and mortality of the egg and larval populations. U.S. Fish and Wildl. Serv., Fish Bull. 50: 149-237.
- Sherman, K. 1980. MARMAP, a fisheries ecosystem study in the NW Atlantic: Fluctuations in ichthyoplankton-zooplankton components and their potential for impact on the system. pp. 9-37. In: Advance Concepts in Ocean Measurements for Marine Biology. F. P. Diemer, F. J. Vernberg and D. Z. Mirkes (eds.). Belle W. Baruch Institute for Marine Biology and Coastal Research. Univ. South Carolina Press.
- Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western North Atlantic ecosystems. Nature 291(5815): 486-89.
- Sherman, K., W. Smith, W. Morse, M. Berman, J. Green and L. Ejsymont. 1984. Spawning strategies of fishes in relation to circulation, phytoplankton production and pulses in zooplankton off the northeastern United States. Mar. Ecol. Prog. Ser.
- Smith, W., W. Morse, A. Wells and D. McMillan. 1983. Fish eggs and larvae. 7-1 to 7-47. In: 106-mile site characterization update. J. Pearce, D. Miller and C. Berman (eds.). NOAA Tech. Memo NMFS-F/NEC-26.
- Smith, W., J. Sibunka and A. Wells. 1975. Seasonal distributions of larval flatfishes (Pleuronectiformes) on the continental shelf between Cape Cod, Massachusetts and Cape Lookout, North Carolina, 1965-66. NOAA Tech. Rept. SSR-F 691. 68 p.
- Smith, W., A. Wells and D. McMillan. 1979. The distribution and abundance of ichthyoplankton in the Middle Atlantic Bight as determined from coastal surveys and site specific studies, 1965-76. Sandyu Hook Laboratory Rept. No. 79-02. 263 p.
- Thompson, B. G. 1984. Fisheries of the United States, 1983. NMFS Current Fish Stat. No. 8320. 121 p.

# Fish and Fisheries of the Middle Atlantic Bight

by

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## INTRODUCTION

The Middle Atlantic Bight (MAB) is characterized by a broad continental shelf, widest off Long Island, some 125-150 miles, narrowing southward to less than 30 miles off Cape Hatteras (Figure 1). This large and productive shelf ecosystem provides an enormous feeding area for a multitude of temperate as well as semi-tropical and boreal fishes which inhabit the region during all or part of their life cycle. Although there are numerous areas of shallow water known by localized names, they are neither as numerous nor extensive as the fishing banks of New England, and for the most part are far less concentrated.

The MAB fish fauna, located as it is between the boreal waters north of Cape Cod and the semi-tropical region south of Cape Hatteras, is distinctive. Most characteristic of the MAB fauna is a group of some 60 or more species collectively known as "shorefishes." They are a seasonally migratory group and for generations their migratory patterns have determined the character and flavor of the regions fisheries. In the spring and summer they tend to move inshore and also tend to be more concentrated in the northern portion of their respective ranges. In the fall and winter they migrate to their offshore, and more southerly wintering grounds, or in some cases undertake long coastal migrations to semi-tropical waters. It should be noted that an excellent characterization of the fishes in the area was recently prepared by Grosslein and Azarovitz (1982).

In the early days of commercial harvesting the "shorefishes" were taken only during late spring, summer, and early fall when they were available inshore. In the early 1930s, the wintering grounds of many species were discovered, and gear and vessels were developed suitable for fishing offshore during the colder months of the year. Winter fisheries have continued at various degrees of intensity, working the offshore areas from off New York south to North Carolina.

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With few exceptions the commercial fisheries of the MAB are carried on by individual fishermen or by small associations of fishermen (cooperatives). The small scale of most of these fisheries operations has affected the method of catch handling, with the majority of the catch going directly into the fresh fish trade. However, it should be noted that during the last decade the processing of fisheries products has dramatically increased, i.e., filleting and/or breezing of an ever increasing number of species. In general, region-wide there has been a continued upgrading of shoreside facilities to increase the efficient processing of a variety of new as well as historical fishery products.

Steeped, and to some extent limited by tradition, the encroachment of efficient foreign vessels in the 1960s impacted heavily on domestic fishermen in the MAB. A multinational fleet of highly mobile fishing trawlers, factory processing ships, transports, and support vessels systematically harvested large quantities of 18 species important to the domestic commercial and recreational fisheries of the MAB. This produced a variety of stresses on the domestic fleets and the eventual responses of this encroachment was the Magnuson Fishery Conservation and Management Act of 1976 which extended fisheries jurisdiction of the United States to 200 miles.

Since the mid-1940s an increase in leisure time, reliable small craft, and surplus income have all acted to enhance and promote marine sportfishing as a large scale form of recreation. In 1960 the Bureau of Sport Fisheries and Wildlife made the first estimate of the magnitude of the recreational fisheries (Clark, 1962). The Magnuson Fishery Conservation and Management Act of 1976 has required management plans to consider recreational as well as commercial fisheries, hence angling surveys have been conducted annually since 1979. The statistics collected during these surveys have determined, with little doubt, that a large part of the fisheries removal associated with many MAB species is attributable to the recreational fishing community.

It is our intent herein to describe the fish and fisheries associated with the MAB. After an extensive search for existing data or information sources applicable to defining and describing the fish and fisheries resources of this large expanse of ocean, nine rather diverse, but loosely related, data sources were germane. These sources can be separated into two distinct categories, those that are either synoptic and/or of long duration, and those that are either limited temporarily and/or spatially, but nevertheless descriptive of the area. Included in the former grouping are: 1) governmental records of U.S. commercial catch and value, 2) results of NMFS Marine Recreational Fishery Statistic Surveys, 3) observed Japanese longline catch and effort, and 4) National Marine Fisheries Service (NMFS) autumn and spring research vessel surveys. Those data sources which fall into the latter grouping include: 1) bio-economic data which describe the New Jersey offshore recreational fishery, 2) tilefish fishery catch and effort information, 3) descriptive information pertinent to fishing grounds utilized by New Jersey commercial and recreational user groups, 4) governmental records of foreign landings and values for the years 1979-1983, and 5) a review of existing literature pertinent to deep-sea fishes associated with the MAB.

These sources, although somewhat diverse in scope and nature, when combined, analyzed, and synthesized provide the user with a comprehensive overview of fish and fisheries associated with the MAB. It should also be

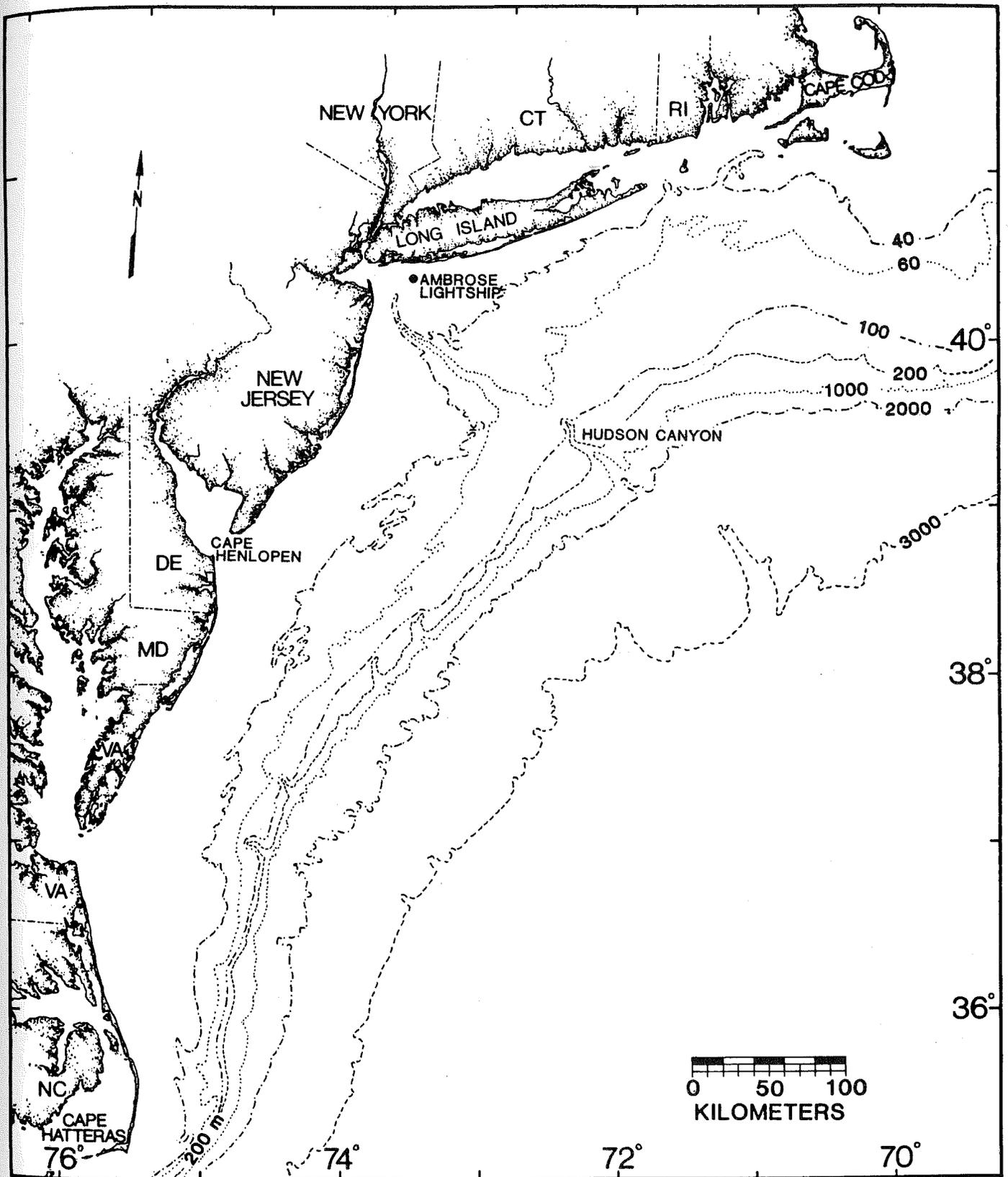


Figure 1. The Middle Atlantic Bight-coastline and shelf contours.

noted that whenever possible and applicable, dollar estimates of values are given to point out the magnitude of potential economic impact should the resources, in general, and the recreational and commercial harvesters specifically, be adversely affected by anthropogenic or natural changes.

## METHODS AND MATERIALS

The following sections are detailed descriptions of the nine sources with particular reference to collection methodology as well as techniques employed to present, interpret, synthesize, and analyze these data sources.

### U.S. Catch and Value

This data set includes 10 consecutive years (1973-1982) of landings and ex-vessel value (i.e., amount paid to fishermen) information for commercially important finfishes and invertebrates (Table 1, 2, 3). These data are collected at a state level, on a regular and timely basis, by either NMFS fishery reporting specialists or state agents under contract to NMFS. Subsequently, these data are first assigned to statistical reporting areas (i.e., capture locations) based on direct data management system to simplify data handling and retrieval. Figure 2 illustrates the statistical reporting areas within the scope of this paper.

To facilitate the use of these data as a descriptive tool, they were appropriately factored on the basis of the percent the MAB occupied a given statistical reporting area. In addition, based on first-hand working knowledge of particular fisheries, species were eliminated owing to the fact that they are absent from the MAB and therefore inappropriate in factored tabulations for specific statistical reporting areas (e.g., soft and hard clams and menhaden). All relative data were then tabulated on a state-year, year-statistical reporting area, and year-dominant species basis to provide catch and value trends for the MAB. At this point it should be noted: 1) only the years 1973-1982 were used in the year-dominant species tabulation owing to the completeness of those data; and, 2) where given, dollar values have not been adjusted for inflationary change.

### U.S. Recreational Landings

Recent data for the Middle Atlantic recreational fishery were abstracted from tabulations compiled for annual National surveys (U.S. Department of Commerce, 1984, 1985a, 1985b, 1986). Data for these annual reports are collected on a regional basis through the use of two complimentary surveys: 1) a telephone survey, and 2) an intercept survey of fishermen at fishing sites. Data from these two independent surveys are then combined to produce total participation, effort, and catch statistics.

The Middle Atlantic subregion includes New York, New Jersey, Delaware, Maryland, and Virginia. Total numbers of principal recreational species are given in Table 4 and Figure 3 for 1979-1985 the most recent statistics available using the aforementioned comparable gathering techniques. Biomass of the principal recreational species was calculated by adjusting type A catch (i.e., identified available catch) to include type B<sub>1</sub> catch (i.e., fish used for bait, filleted, and/or discarded dead). Results are given in Table 4 and illustrated in Figure 4.

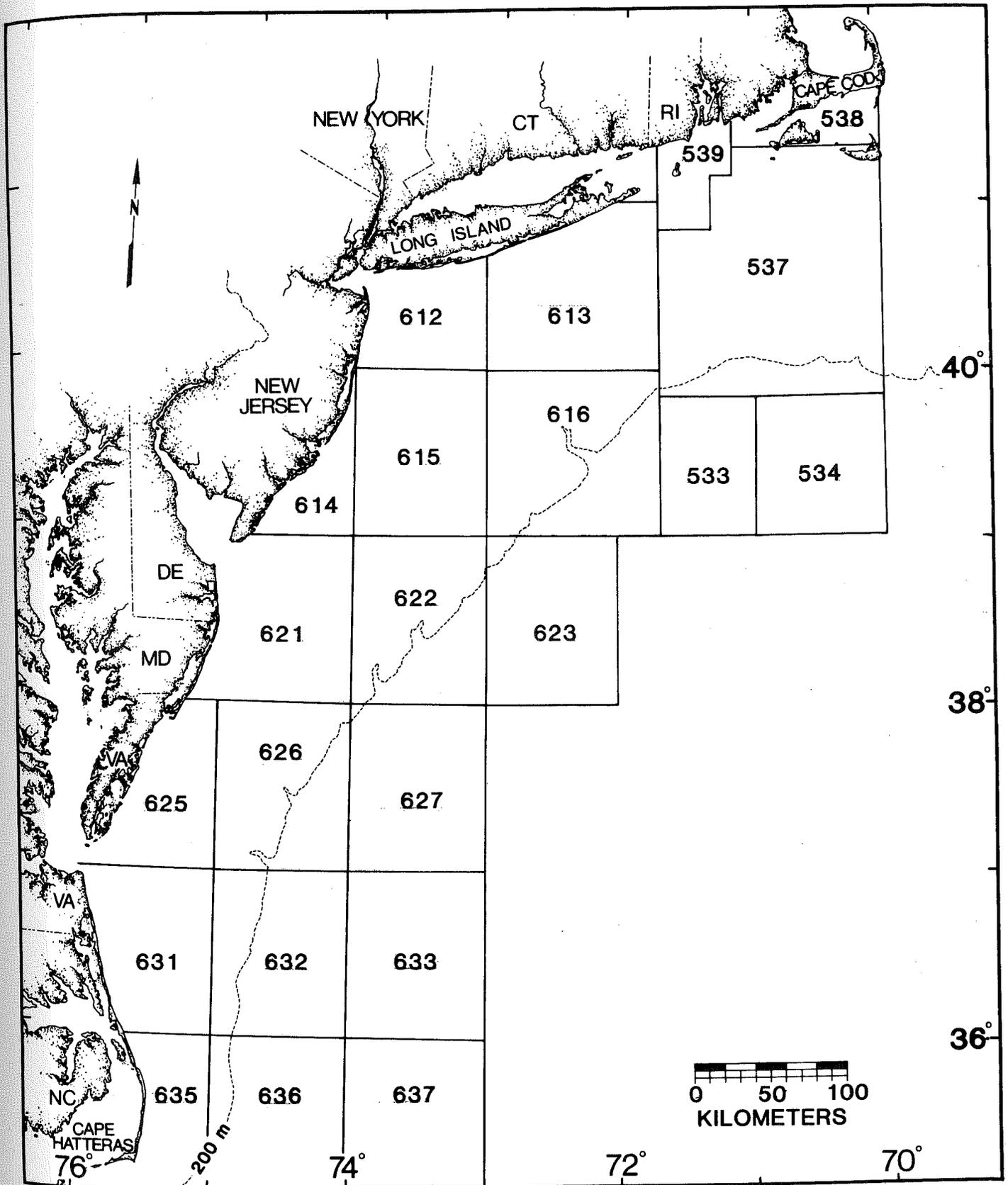


Figure 2. Commercial statistical reporting areas of the Middle Atlantic Bight.

# MIDDLE ATLANTIC ANGLER CATCH

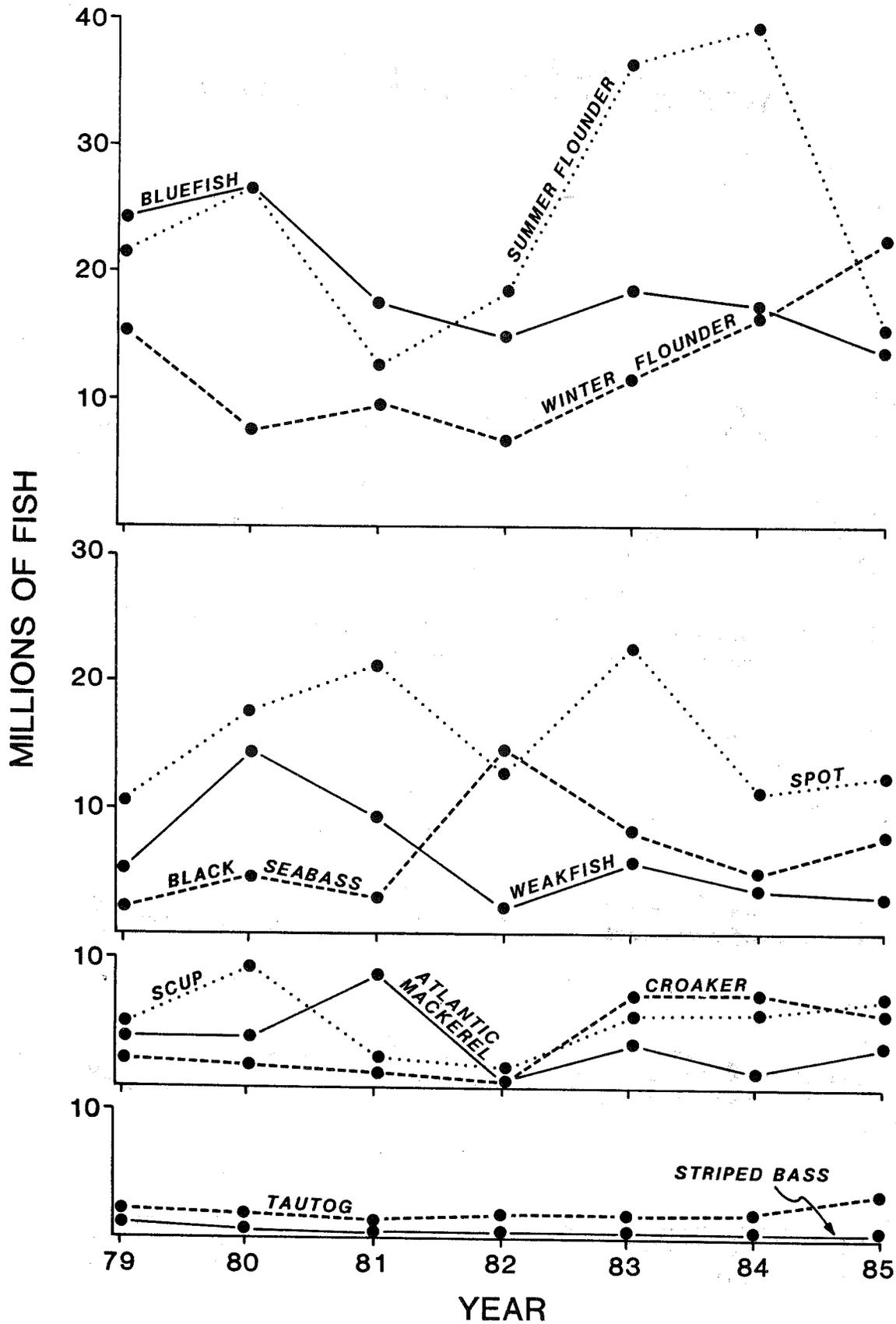


Figure 3. Angler catch of selected species-numbers.

## LANDED WEIGHT OF MIDDLE ATLANTIC ANGLER CATCH

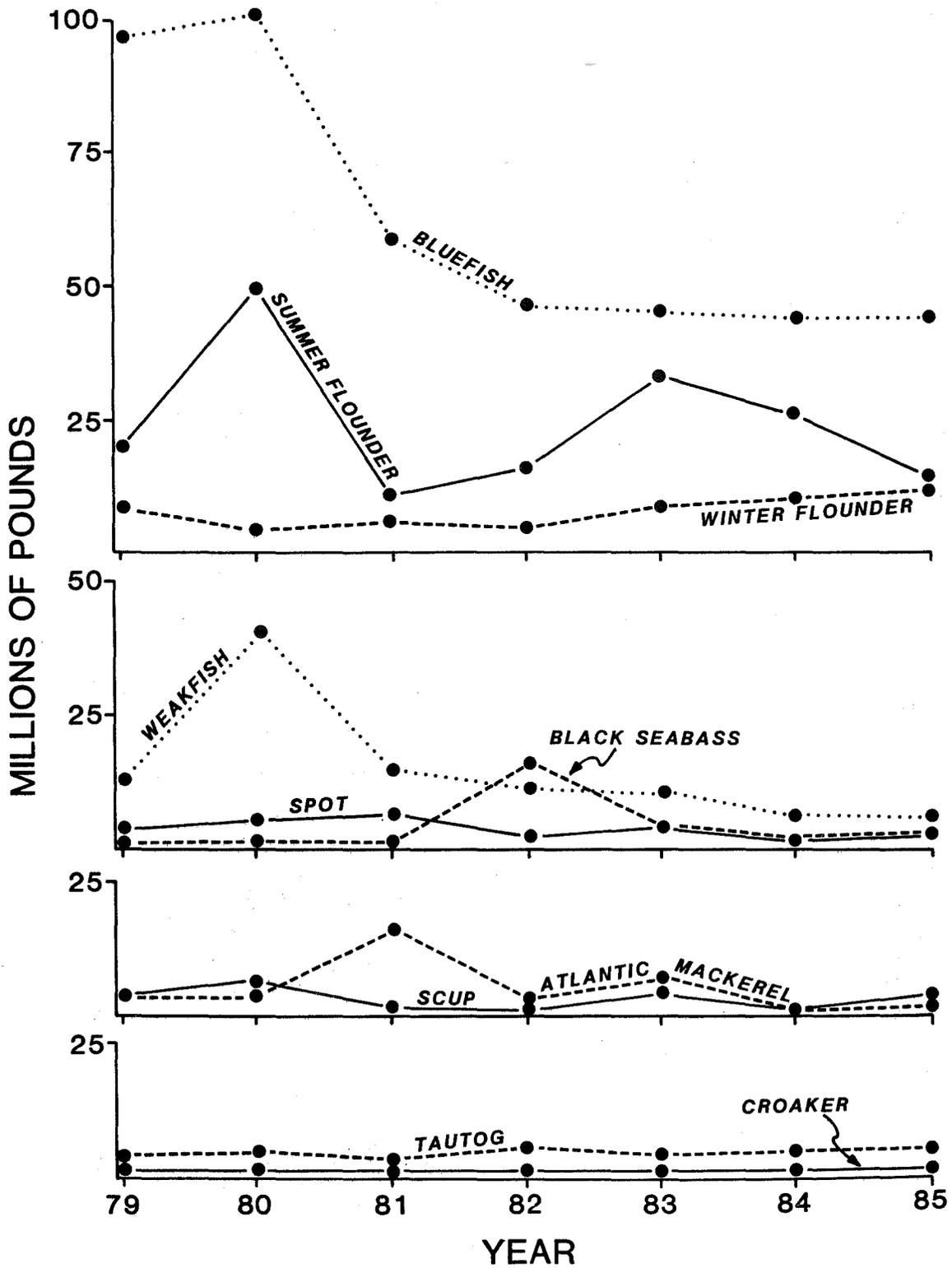


Figure 4. Angler catch of selected species-weight.

## Japanese Longline Catch and Effort

Four years (1978-1981) of longline catch and effort information from Fishery Reporting Zone No. 16, as recorded by U.S. Fisheries Observers stationed aboard Japanese longline vessels, comprise this data set. The particular "Reporting Zone" in question can generally be described as extending from just south of the mouth of Chesapeake Bay to approximately the 40°00'N latitude line off New Jersey, with its offshore boundary being the U.S. 200-mile Fisheries Conservation Zone (FCZ). Figure 5 illustrates the extent and location of Reporting Zone No. 16 as well as the MAB, which have been superimposed for purposes of this paper.

This data set was selected since it provides the most timely, quantitative, and unbiased series of information relative to tunas, billfishes, sharks, and associated oceanic finfishes which seasonally frequent this area of the western North Atlantic. An extensive review of additional data along these lines, including research survey cruises, U.S. commercial landings, and foreign catch information, have already been collected, tabulated, analyzed, and presented in previous reports concerning the MAB (U.S. Department of Commerce, 1977b). In addition, Thompson's (1982) statistical comparison of observed versus reported Japanese longline landings and associated effort adds credence to our choice of data sets pertinent to this particular fishery.

All data were tabulated by year and species and catch-per-unit-effort (CPUE), based on 10,000 hooks fished calculated for individual species, species groups (i.e., tunas, billfishes, sharks, and rays, and other finfish), and all species combined on both a yearly and grand total basis. As a matter of information and reference, these tabulations are based on over two and one-half million hooks fished over the four years represented herein.

### NMFS Research Vessel Surveys

NMFS, and its predecessor agencies, have conducted routine spring and autumn research vessel surveys over the continental shelf from Nantucket Shoals to Cape Hatteras since 1965. The finfish and invertebrate data collected during these synoptic bottom trawl surveys provide one of the most comprehensive records of seasonal and geographic trends in distribution and abundance on a species specific as well as community structure basis.

Surveys are based on a stratified random sampling design, thereby providing for; first, a statistically valid fisheries independent sample for population studies; and second, sampling in all trawlable areas down to 365 m and not just in those areas of known resource concentrations. Grosslein (1969, 1974) and more recently Azarovitz (1981) give detailed information and insight pertinent to the rationale, methodology, and history of this survey series.

For the purpose of this paper, cumulative plots were computer generated for spring and autumn trawl surveys of 26 and six selected species of finfish and invertebrates, respectively. These plots illustrate the density distribution of each species and their relationship over time and space to the MAB. It should be noted here, only positive catches are shown in the individual species plots. The spring survey plots include nine surveys

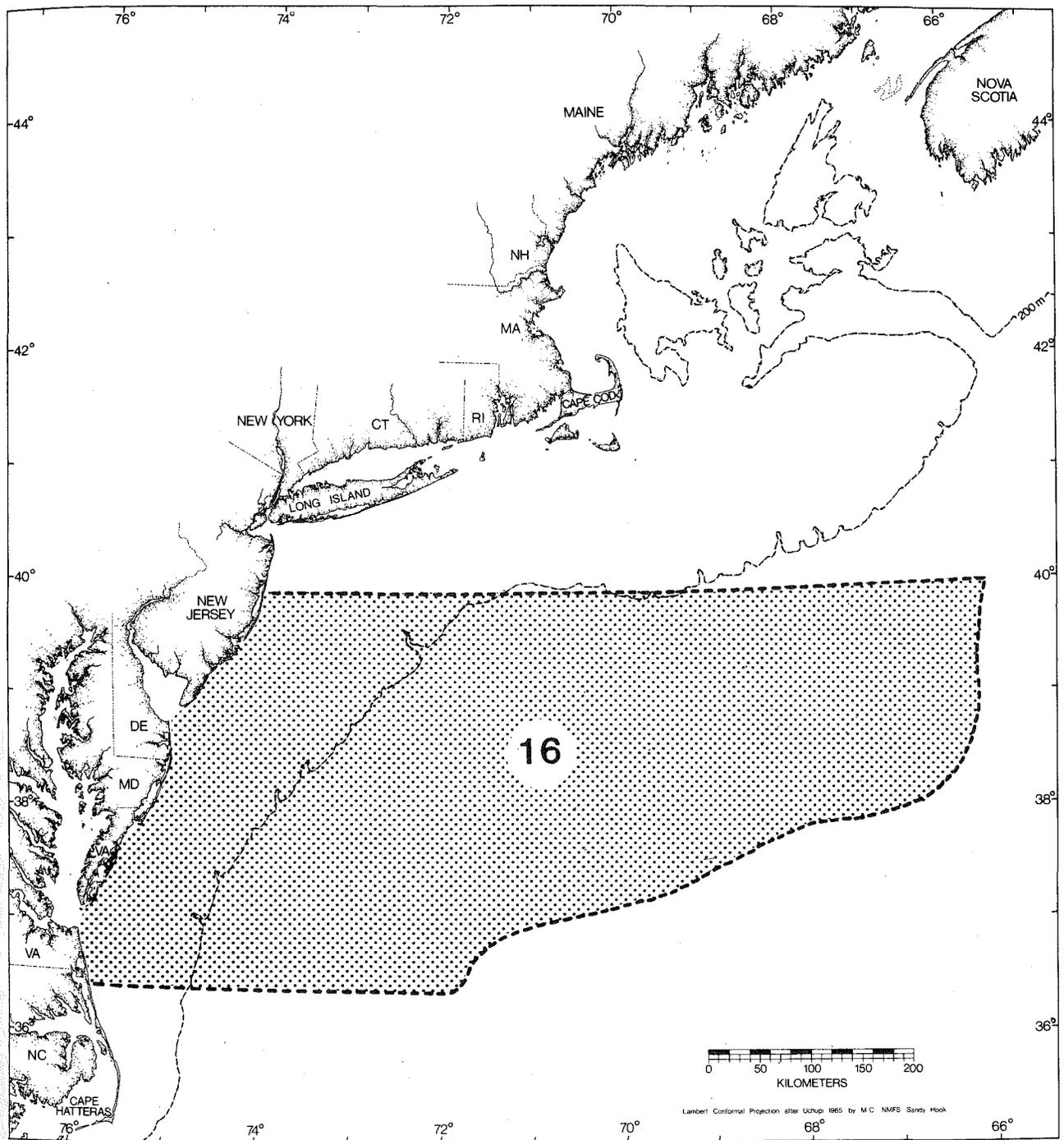


Figure 5. Reporting area for Japanese pelagic catch.

(1968-1974, 1976, and 1978) and the autumn plots include 12 surveys (1965-1975, and 1977). As points of reference, Figures 6 and 7 illustrate the cumulative station plots for spring and autumn, respectively.

### New Jersey Offshore Recreational Fishery

Beginning in 1981, and continuing to the present, personnel from the New Jersey Department of Environmental Protection, Division of Fish, Game and Wildlife, have collected information relative to the somewhat specialized offshore canyon fishery which takes place from May to October off the coast of New Jersey. The primary purpose of this program is to estimate, and secondarily to better understand participation, catch, effort, and value of this burgeoning offshore big-game recreational fishery. Figure 8 illustrates the extent of the survey area, which generally can be defined as the area found between the 30 (55 m) and 100 (183 m) fathom isobaths and the associated submarine canyon systems located therein.

Fisheries data were collected in the following manner: first, a list of canyon fishery boats was compiled by canvassing marinas, bait and tackle dealers, and identified canyon fishermen; second, each week a random telephone survey of canyon anglers was conducted to determine their catch (species and number) and effort (trips made) during the previous week; and finally, total catch was estimated by expanding the data collected from over 550 offshore trips. In addition, data concerning the economic value of the fishery were obtained by the direct mailing of questionnaires to known participants in the fishery. Figley and Long (1982) give detailed information relative to the history and background of the fishery as well as descriptions of the areas surveyed (i.e., various submarine canyon systems), and explanations of the collection and analysis methodology employed during this continuing project. Here, to satisfy the objectives of this paper, 1981 participation, catch, effort, and economic data are summarized and discussed.

### Tilefish Fishery Catch and Effort

This data set consists of nine years (1973-1981) of tilefish (*Lopholatilus chamaeleonticeps*) catch information and fishery effort projections based on preliminary interpretations and calculations of information gleaned from voluntary fishermen logbooks and governmental records of total catch. These data were cooperatively provided by C. Grimes, K. Able, and S. Turner of Rutgers University; New Brunswick, New Jersey. It should be noted that these researchers have focused considerable effort to determine the life history and fishery of this unique species for at least the last 10 years. Additional information on the biology and ecology as well as the fishery for tilefish can be found in Freeman and Turner (1977), Grimes et al. (1980a,b), Able et al. (1981), Turner et al. (1981), and Turner (thesis).

All data were extracted from logbook records on a yearly basis to determine the total number of vessels fishing, trips made per month, amount (units) of gear fished, and catch-per-unit-of-gear (kg). The unit of gear employed in this fishery is defined as a "tub" which equals approximately one-half mile of bottom longline gear. Total vessel years, i.e., that percent of a year a vessel was involved in the fishery, was determined from direct interviews and/or first-hand knowledge of the fishery. Total units of gear were then calculated by multiplying vessel years x trips per month x 12 months

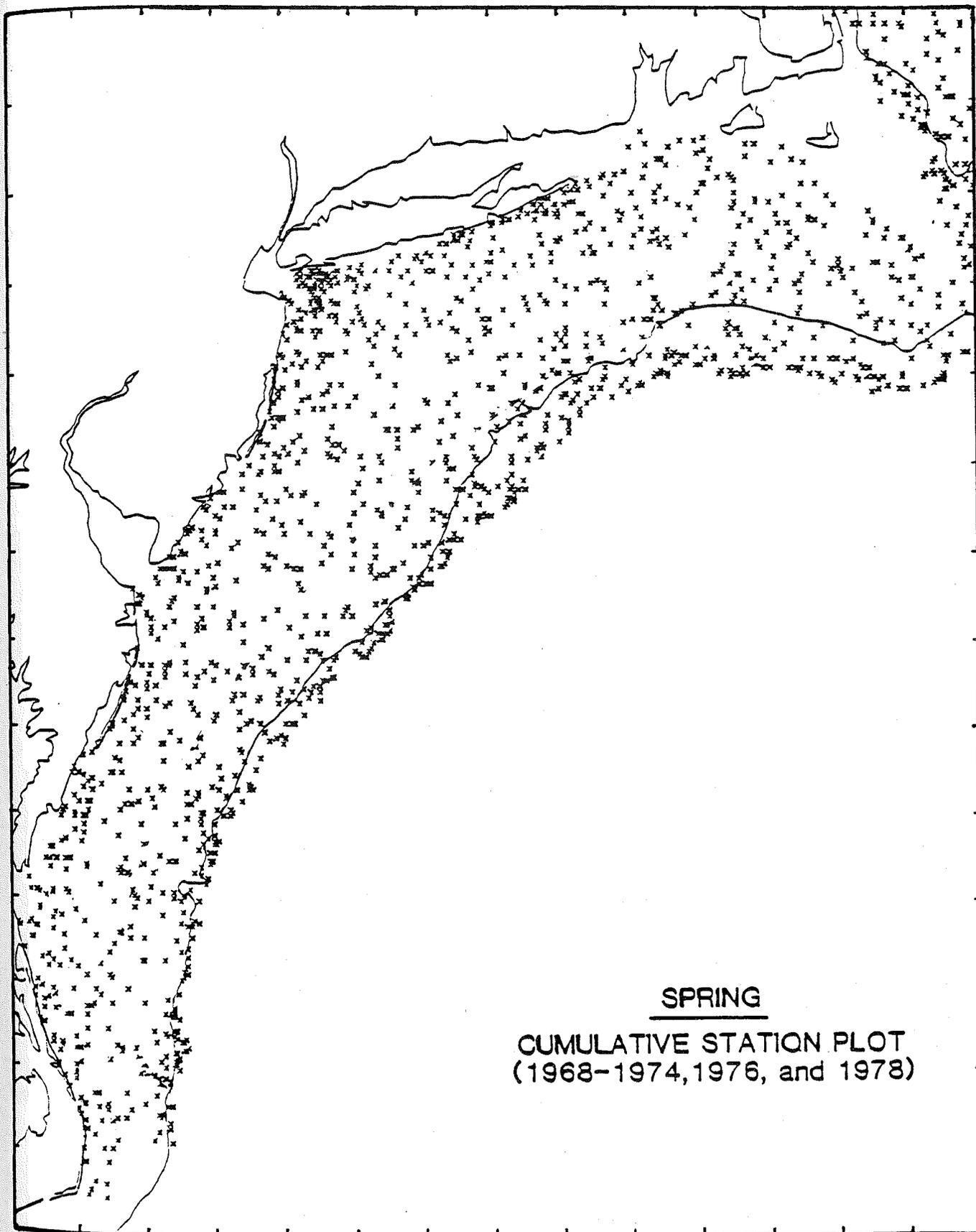


Figure 6. Stations in Northeast Fisheries Center spring survey-9 years.

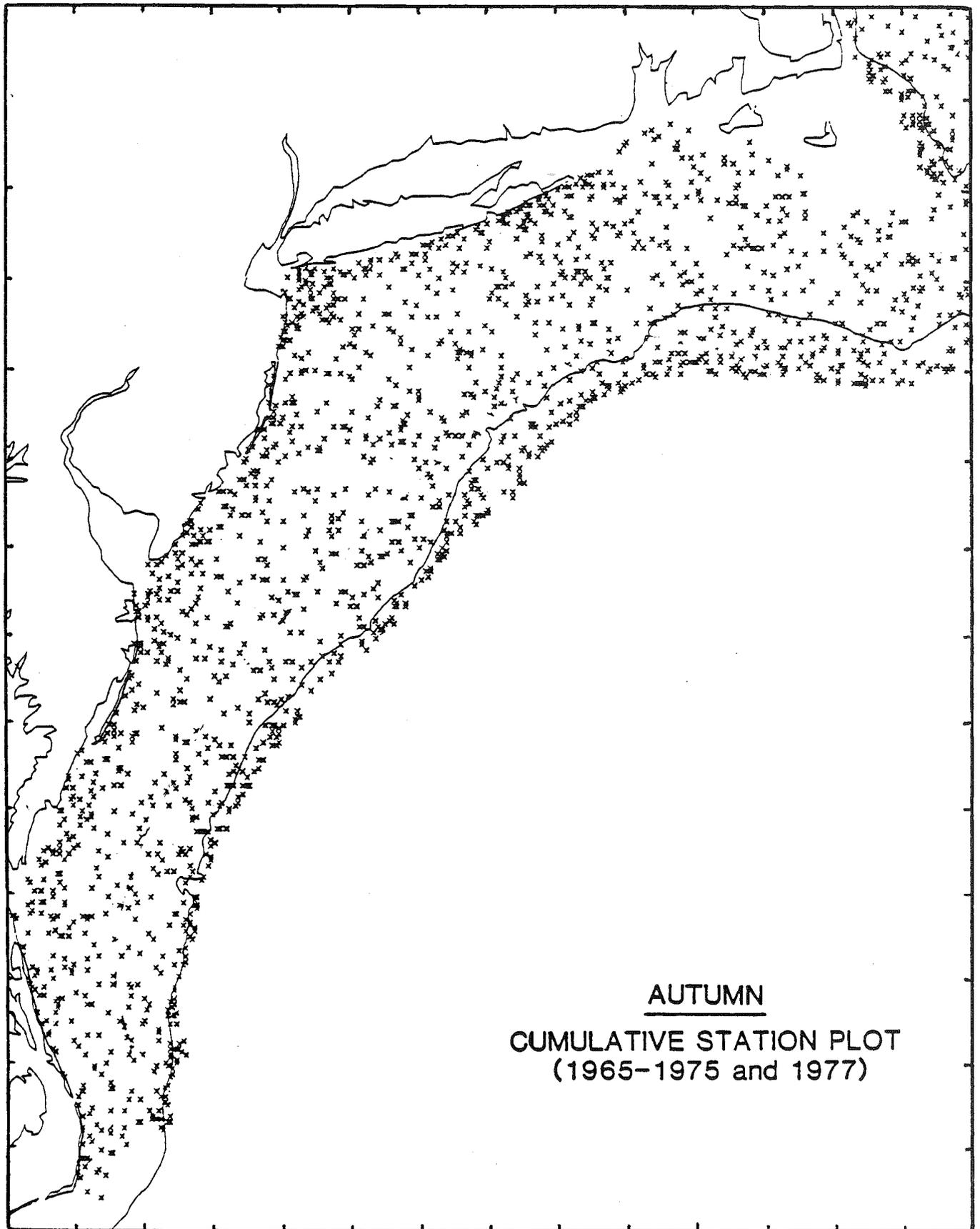


Figure 7. Stations in Northeast Fisheries Center autumn survey-12 years.

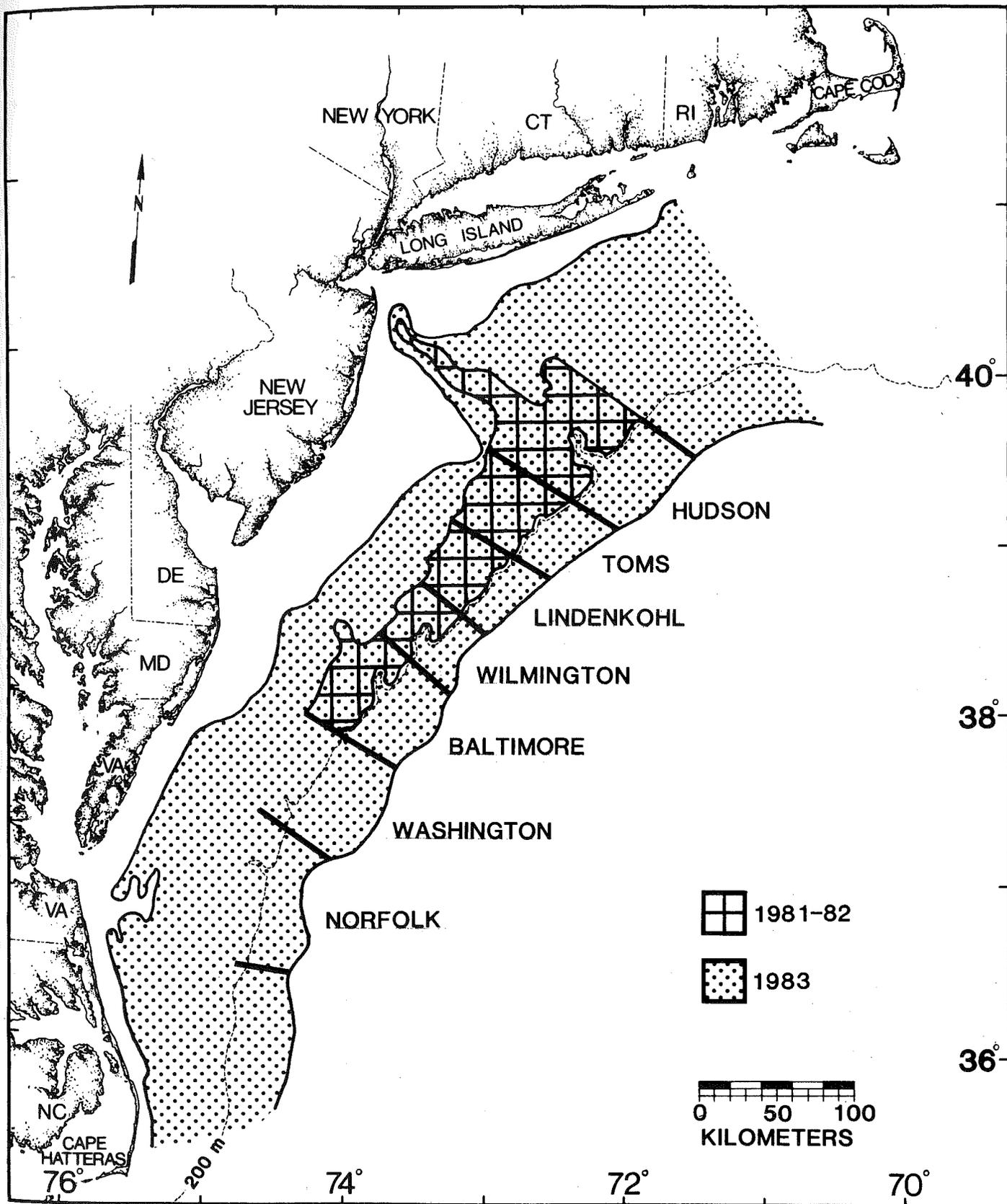


Figure 8. Sampling areas for New Jersey offshore pelagic survey.

x units of gear fished per month. All information was then tabulated along with governmental records of landings to provide the appropriate information for comparison of catch, effort, and participation trends over time.

### New Jersey Ocean Fishing Grounds

This non-quantitative, but highly descriptive and informative source delineates and describes geographically, in the form of charts and text, the ocean fishing grounds utilized by New Jersey recreational and commercial fishermen (Long and Figley, 1981). Definition, location, and seasonality of individual fishing grounds are based on a direct interview survey of over 340 currently active recreational and commercial fishermen. This survey was designed and conducted by the New Jersey Department of Environmental Protection's Division of Fish, Game and Wildlife personnel. This collection of information, although limited spatially, provides an additional dimension to this paper; however, it must be closely scrutinized and logically extended and expanded with the seasonality and geographic range of each species kept in perspective.

We have only used those data given in Long and Figley (1981) pertinent to those recreational and commercial fisheries which fall into the geographic scope of this paper (i.e., the MAB). Each fishery, or fishery complex, is graphically represented in the form of a chart which delineates recreational and commercial fishing grounds on a seasonal basis. We appreciate the cooperation of those members of the New Jersey Marine Division of Fish, Game and Wildlife who provided us with draft materials as well as a full-scale set of "fishing grounds" charts.

### Foreign Landings and Values

This somewhat limited, but nevertheless relevant, data set consists of 1978-1983 non-U.S. landing and dollar value information for selected finfish and invertebrate species groups. These data, as mandated by the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA), were collected by either U.S. foreign fisheries observers stationed aboard foreign vessels during fishing operations, or by international reporting agreements, or a combination of both methods. Under the auspices of MFCMA, fisheries are designated for particular species or species groups in predetermined amounts during particular fishing seasons in designated areas (i.e., "fishing windows").

We have tabulated the results of the 1978-1982 foreign fishing seasons for six major fisheries in those "fishing windows" which fall within the purview of this paper. Figure 9 illustrates the "fishing windows" in question (1-4) and their location in the MAB.

### Deep-Sea Fishes

This section is based on a review of current pertinent literature which identifies, enumerates, and/or discusses the biology and ecology of the pelagic and benthic deep-sea fish fauna generally found or associated with the MAB. "Deep-sea fishes" are here defined as those fish which for the most part, but not exclusively, inhabit deep shelf slope and abyssal oceanic waters

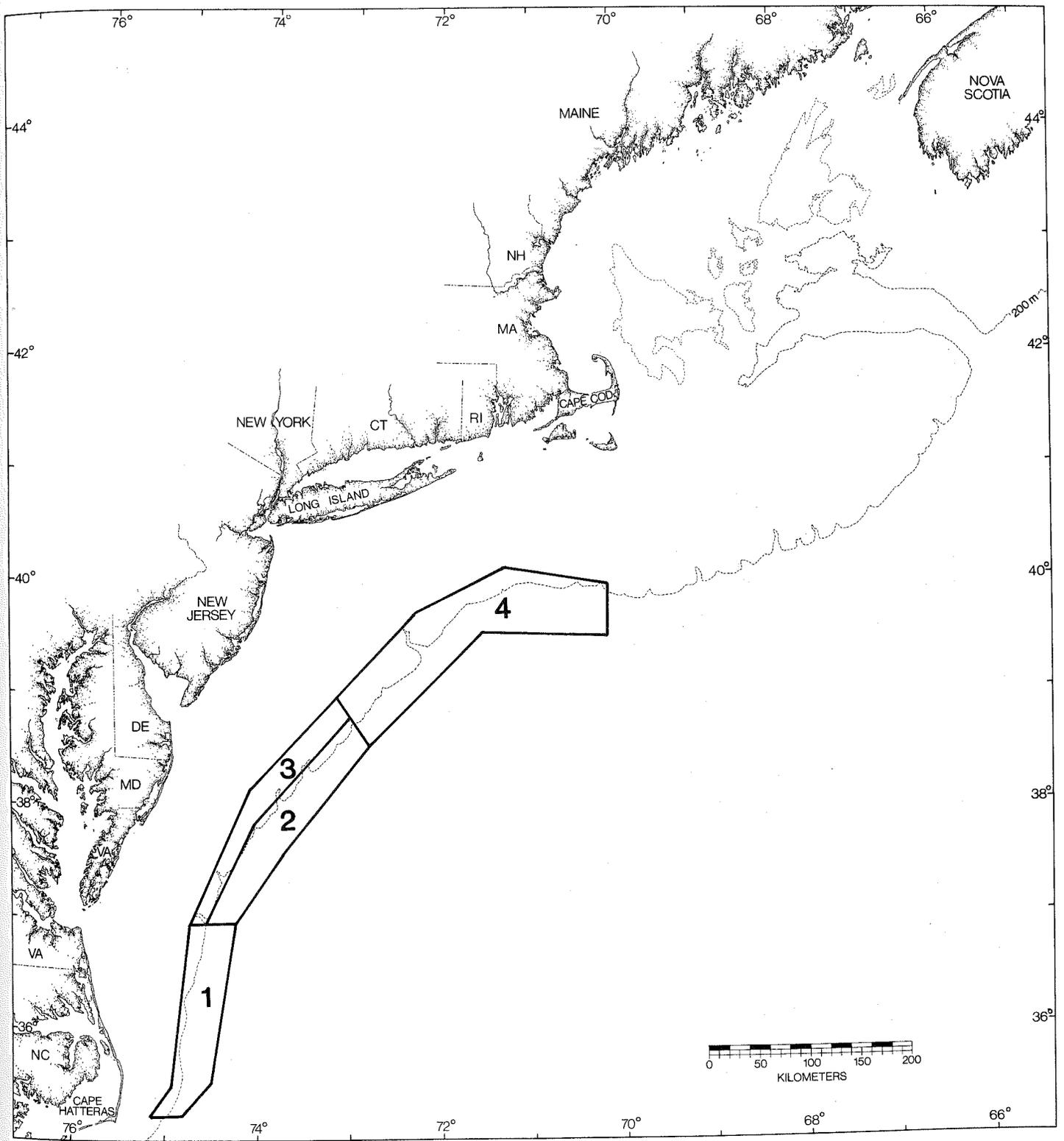


Figure 9. Statistical areas for Middle Atlantic Bight foreign fisheries catch.

usually in excess of 600 m, and further have little or no direct commercial value at the present time (e.g., Myctophids or "lanternfishes").

Although it provides no new information, this section is included for the purpose of rounding out this report by providing as complete a picture relative to as many possible finfish species associated with the MAB.

## RESULTS AND DISCUSSION

We have chosen to present results in a simplified, informative, tabular graphic format with or without a narrative as appropriate. For the sake of clarity and continuity, the results of our tabulations and graphic interpretations, are organized under the same nine headings identified in the "Methods and Materials" section.

### U.S. Commercial Catch and Value

Results of our tabulations by statistical reporting areas (Figure 2) are given in three tables. Table 1 gives the commercial landings and values by state by year, as well as on a total landings and values basis for each year (1973-1982). This tabulation demonstrates the almost continuous increase in landings and values that have occurred within the statistical limitations of these data. In addition, the continuous variability of landings and values is obvious on both an inter- as well as intra-state basis.

Table 2 summarizes catch and values by year and statistical reporting area for the MAB. This information provides a basis for comparing the catch and value of each statistical reporting area from year to year within years as well as providing those data necessary to compare the importance of a particular reporting area to another.

Table 3 gives landings and value by year (1973-1982) on a selected species basis, thus providing information for the purpose of demonstrating which resources are the most sought after in terms of weight and/or value over time. It is obvious from these data that American lobster (Homarus americanus) and sea scallop (Placopecten magellanicus) historically represent the "cash crops" in the invertebrate category, shared with ocean quahog (Arctica islandica) in more recent years (1979-1982). Under the finfish category, summer flounder (Paralichthys dentatus), tilefish (Lopholatilus chamaeleonticeps), scup (Stenotomus chrysops), and swordfish (Xiphias gladius), dominate, in both catch and value, historically as well as currently.

### U.S. Recreational Landings

The Middle Atlantic subregion was consistently highest in terms of biomass of fish landed by anglers in the Atlantic and Gulf of Mexico based on the recreational fishery statistics surveys conducted between 1979 and 1985 (U.S. Department of Commerce 1984, 1985a, 1985b, 1986). The Middle Atlantic subregion, based on the seven years surveyed, comprised from 30 to 49 percent of the Atlantic and Gulf combined total.

The principal recreational species of the subregion are bluefish and summer flounder (fluke) in terms of numbers and biomass harvested (Table 4 and Figures 3 and 4). There are a number of species targeted by recreational

Table 1. Catch and value of commercial fishery, 1973-1982, by state. (Weight in thousands of pounds, value in thousands of dollars.\*=<\$500; -= no data.)

Year	ME		MA		RI		CT		NY		NJ		DL		MD		VA		TOTALS	
	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$
1973	-	-	16,691	3,563	71,870	6,716	-	-	22,606	6,930	199,823	14,305	6,818	829	9,298	1,632	54,268	8,864	381,373	42,839
1974	-	-	20,724	7,008	72,163	6,522	-	-	21,454	7,492	103,868	11,286	6,044	843	7,750	1,494	101,453	12,077	333,455	46,722
1975	-	-	11,864	9,211	57,269	7,874	-	-	19,767	6,062	113,817	15,258	2,696	499	9,236	1,807	98,135	12,401	312,783	53,111
1976	-	-	19,273	17,130	50,970	9,087	-	-	18,188	6,835	183,113	28,837	706	188	11,380	4,966	71,495	16,101	355,124	83,144
1977	-	-	14,926	12,315	48,936	10,848	-	-	16,685	6,788	170,412	34,578	329	112	13,813	6,457	62,144	18,983	327,246	90,081
1978	-	-	18,353	15,512	71,510	20,785	-	-	20,676	9,381	158,996	43,942	287	158	15,369	7,316	51,141	30,818	336,331	127,912
1979	-	-	15,445	10,377	71,639	25,307	-	-	22,636	11,104	152,825	50,721	204	147	18,330	8,138	71,982	39,425	353,061	145,219
1980	3	*	16,423	9,368	62,300	32,456	44	12	23,757	13,120	79,996	42,905	242	217	22,340	9,939	35,794	36,457	240,897	144,474
1981	326	92	17,642	9,462	61,840	30,137	7,998	9,558	22,467	14,547	155,666	43,413	377	279	23,431	10,460	27,020	22,069	316,766	140,019
1982	119	43	16,420	10,339	95,661	42,698	7,519	10,950	23,552	15,333	89,666	43,857	483	415	22,266	10,088	28,200	18,466	283,886	152,189

Table 2. Catch and value of commercial fishery by statistical areas, 1973-1982. (Weight in thousands of pounds, value in thousands of dollars.  
\* = <\$500; - = no data.)

Statistical Area	1973		1974		1975		1976		1977		1978		1979		1980		1981		1982	
	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$										
533	*	+	49	22	5	1	1	*	-	-	18	19	-	-	467	205	342	131	8	5
534	-	-	2	*	-	-	244	63	-	-	7	6	-	-	266	115	1	2	32	3
537	31,223	4,866	29,990	6,154	25,624	6,829	15,865	6,394	22,313	7,495	33,743	11,767	35,937	11,985	31,179	13,705	34,398	17,667	56,566	24,931
538	5,539	1,104	11,919	1,421	3,927	1,192	11,720	3,047	6,161	1,843	6,714	2,199	16,605	4,716	12,579	3,610	8,365	3,359	8,506	3,941
539	37,354	1,628	46,531	1,814	29,930	1,710	55,681	2,440	24,382	3,884	62,291	11,473	59,143	15,634	27,771	20,495	52,708	17,284	42,177	23,241
611	124,083	5,709	47,097	3,957	22,287	1,740	8,218	1,419	17,256	1,915	14,050	3,291	17,481	3,197	8,164	2,907	31,662	13,934	13,722	12,664
612	18,104	3,362	23,380	3,847	27,496	3,774	88,590	5,954	47,201	5,957	31,525	7,219	36,470	8,393	23,375	8,747	27,195	7,854	15,448	7,012
613	14,821	2,886	11,815	2,777	14,570	3,667	10,349	5,980	12,042	6,311	9,405	5,148	16,592	13,196	15,342	17,259	13,033	12,040	13,338	12,783
614	12,119	1,814	14,478	1,977	35,355	4,844	29,298	6,231	37,586	7,170	12,016	3,727	14,258	3,491	6,933	4,251	26,339	12,715	26,495	13,786
615	23,607	2,943	7,459	3,006	9,289	4,828	8,505	8,126	7,668	5,631	4,489	7,032	5,157	12,767	5,173	11,969	8,738	7,394	4,884	4,146
616	2,337	1,745	2,955	2,708	3,454	4,246	10,413	10,212	8,519	6,777	8,657	9,038	8,176	10,196	6,282	5,855	11,684	11,891	13,808	10,527
621	55,285	6,719	35,604	6,006	39,380	6,737	42,840	15,504	63,249	19,764	60,052	29,604	65,303	29,745	64,828	27,205	48,979	15,371	39,162	16,346
622	1,921	691	1,135	1,300	4,641	2,828	2,976	2,967	5,123	3,833	4,735	5,447	4,021	6,585	4,926	9,065	10,758	4,816	16,108	6,048
623	-	-	3	4	-	-	71	97	-	-	62	122	3	2	10	18	11	27	17	34
625	34,196	4,617	14,473	1,785	8,141	1,944	4,682	1,619	25,815	7,942	41,046	5,415	8,644	3,770	5,358	2,171	12,863	2,259	2,037	960
626	2,213	1,817	1,771	1,279	2,228	1,209	4,750	4,564	13,311	8,070	23,295	21,038	22,512	15,227	21,973	14,108	22,350	10,208	22,146	10,847
627	-	-	-	-	1	2	16	20	43	10	44	26	-	-	-	-	3	6	3	7
631	16,062	1,979	82,673	7,702	85,199	7,141	60,299	8,269	34,058	2,486	20,296	2,235	39,591	3,694	4,192	1,324	3,440	1,496	5,758	3,026
632	1,670	907	1,531	780	1,245	419	254	77	2,043	786	2,135	2,419	2,415	2,004	1,788	1,198	2,238	1,316	2,985	1,545
633	-	-	7	8	-	-	2	1	-	-	4	4	-	-	-	5	1	-	-	-
635	233	38	534	93	10	2	350	59	432	147	1,690	647	433	140	182	59	1,338	126	393	168
636	51	11	51	82	-	-	1	1	42	61	44	13	319	479	59	88	241	97	79	105
637	-	-	-	-	-	-	-	-	-	-	15	21	-	-	7	12	71	25	8	3
TOTALS	381,360	42,835	333,455	46,722	312,783	53,112	355,124	83,144	327,246	90,081	336,331	127,912	353,061	145,219	240,849	144,366	316,762	140,017	283,679	152,129

Table 3. Catch and values of commercial fishery, 1973-1982 by species. (Weight in thousands of pounds, value in thousands of dollars. \* = < \$500:- = no data.)

Dominant species	1973		1974		1975		1976		1977		1978		1979		1980		1981		1982	
	Wt	\$	Wt	\$	Wt	\$	Wt	\$	Wt	\$										
<b>FINFISH</b>																				
<b>Flounder</b>																				
fluke	9,079	3,341	12,654	3,823	15,382	6,098	21,569	9,708	17,039	8,933	15,710	9,665	21,087	11,732	16,206	8,920	11,749	8,547	14,158	10,650
blackback/lemon	6,461	1,185	3,750	781	3,205	771	2,848	815	4,167	1,247	7,627	3,107	7,139	2,394	9,958	2,966	13,074	4,772	11,480	4,378
yellowtail	15,857	2,667	9,278	2,171	3,362	1,147	1,532	672	3,989	1,877	2,864	1,587	7,646	3,683	7,086	3,261	9,749	5,441	17,680	9,857
Gray seatrout	4,178	589	4,529	641	6,678	837	7,127	771	4,852	867	6,415	1,422	10,325	1,861	7,853	1,731	5,674	2,002	3,611	1,600
Whiting	11,488	1,392	14,122	1,288	14,339	1,400	17,614	1,553	17,607	1,879	23,120	3,365	26,411	4,223	23,731	4,189	21,585	4,405	24,278	5,604
Tilefish	863	273	1,250	377	1,427	484	1,928	830	3,529	1,621	4,966	2,522	4,456	2,520	4,428	3,531	4,626	4,284	3,046	3,000
Butterfish	2,860	685	3,437	824	3,455	853	2,311	649	2,280	622	7,600	2,774	5,237	1,871	10,438	3,415	9,192	2,784	18,329	4,738
Scup/porgies	7,998	2,137	11,934	2,170	11,700	2,596	12,349	2,713	12,723	2,505	17,239	4,065	15,499	4,996	15,910	5,778	18,916	6,467	16,538	7,088
Black seabass	2,376	730	2,183	706	3,578	1,023	3,346	1,109	4,260	1,317	3,620	1,559	2,680	1,533	2,101	1,514	1,859	1,363	2,163	1,576
Striped bass	2,561	864	2,589	888	1,783	948	1,009	677	799	641	1,166	1,350	5,980	909	481	773	874	1,387	595	995
Swordfish	219	259	273	347	117	180	251	369	274	380	972	1,325	674	1,068	957	1,876	654	1,467	870	2,358
Bluefin tuna	1,620	357	1,367	371	2,937	731	2,334	735	2,281	733	1,706	751	1,037	624	1,218	857	1,519	1,512	498	752
Menhaden	169,205	4,151	107,888	2,589	103,308	2,414	172,858	4,817	102,266	216	14,811	363	8,982	233	1,028	59	72,530	2,859	8,990	251
Bluefish	2,124	265	2,248	260	2,466	365	2,081	256	2,581	376	3,891	630	3,765	646	3,264	628	3,918	913	4,557	1,168
Atlantic croaker	403	52	689	82	3,188	291	3,730	422	3,668	396	2,895	599	519	165	108	36	53	14	26	9
Atlantic cod	2,979	591	3,628	838	2,216	640	1,489	478	2,363	632	4,124	1,148	2,312	871	1,888	767	2,936	1,208	2,972	1,310
Red hake	1,886	139	1,553	96	2,050	146	3,517	280	1,871	172	2,135	236	3,695	486	3,202	370	2,732	400	2,334	399
White hake	168	17	92	14	70	10	51	9	30	5	58	11	15	3	50	10	143	29	73	15
Atlantic mackerel	1,988	228	1,324	189	2,484	301	2,845	315	994	138	1,865	360	2,696	597	2,864	457	5,187	690	5,838	737
Dogfish	169	10	231	15	229	30	205	21	224	28	220	33	1,129	112	1,295	132	3,991	260	4,874	396
Conger eel	16	4	237	44	39	9	24	3	46	7	41	8	38	8	67	15	48	14	34	8
Anglerfish	133	13	112	14	211	39	169	41	382	108	868	204	2,172	653	2,917	1,214	1,924	1,037	2,022	1,102
Gray sole	141	34	143	34	67	19	57	18	77	27	109	49	93	36	102	35	173	75	308	111
Sand flounder	3	+	1	+	751	135	714	155	671	146	1,083	221	827	172	734	101	1,462	326	1,119	303
Skipjack tuna	207	50	-	-	6	1	-	-	42	10	138	62	644	225	866	450	2,171	1,166	1,645	634
<b>INVERTEBRATES</b>																				
Hard clam	456	474	624	805	297	281	14	13	481	940	2,728	5,623	3,135	8,083	4,593	14,097	4,481	13,146	5,725	14,343
Surf clam	82,308	9,847	96,071	12,213	86,883	12,543	49,032	23,293	50,810	26,318	39,109	20,809	34,786	19,195	37,812	19,142	46,264	23,508	49,047	25,378
Ocean quahog	*	+	-	-	-	-	4,100	1,237	16,497	4,946	22,815	6,676	34,605	10,197	34,118	10,279	32,932	10,250	35,936	11,052
Lobster	3,776	6,013	3,760	6,461	3,048	5,690	2,747	5,186	2,853	5,723	3,222	6,926	2,756	6,373	2,527	6,086	3,355	8,630	4,767	12,079
Longfin squid	-	-	-	-	-	-	-	-	-	-	1,072	512	6,939	2,652	7,884	2,734	4,190	1,958	7,286	2,661
Shortfin squid	-	-	-	-	-	-	-	-	-	-	423	33	1,047	516	42	4	7	2	7,876	888
Sea scallop	1,896	3,372	3,483	5,064	5,796	10,666	13,776	23,624	12,803	19,734	17,087	41,024	14,487	46,430	11,154	43,175	4,397	19,704	4,112	15,474
Oyster	562	819	616	946	510	362	5	5	1,553	2,018	1,553	2,018	1,676	2,363	757	1,146	1,394	3,978	1,641	5,356
Jonah crab	-	-	319	93	94	27	201	57	310	88	279	43	185	38	622	231	278	81	74	31
Red crab	125	28	818	239	679	184	1,314	378	323	130	12	4	12	9	147	115	168	132	83	73
Rock crab	279	29	381	33	186	13	150	10	197	24	137	21	153	27	139	30	74	15	56	7
Blue crab	2,216	307	3,111	343	2,828	472	2	+	241	38	1,103	428	1,118	389	2,739	918	3,214	926	1,067	349
Squid sp.	3,296	660	4,768	902	3,144	609	5,834	1,255	2,707	1,043	1,228	593	764	266	443	101	417	110	692	243
<b>TOTALS</b>	<b>339,895</b>	<b>41,592</b>	<b>299,458</b>	<b>45,663</b>	<b>288,510</b>	<b>52,317</b>	<b>339,127</b>	<b>82,475</b>	<b>184,243</b>	<b>83,869</b>	<b>216,009</b>	<b>122,125</b>	<b>231,328</b>	<b>138,159</b>	<b>221,727</b>	<b>141,144</b>	<b>297,907</b>	<b>135,860</b>	<b>266,308</b>	<b>146,973</b>

Table 4. Numbers and weight of selected species taken by recreational anglers in the Middle Atlantic subregion.

	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>
<b>BLUEFISH</b>							
No.	24308	26830	17755	14998	18843	17308	13647
Wt.	95297	99352	58249	46666	41415	37794	37202
<b>SUMMER FLOUNDER</b>							
No.	21813	26799	12381	18637	36939	39612	15236
Wt.	19796	49790	10624	15072	33046	26567	14674
<b>WINTER FLOUNDER</b>							
No.	15819	7783	9811	6971	11392	16329	22632
Wt.	9882	4622	6239	5216	8714	10965	14023
<b>WEAKFISH</b>							
No.	5153	14570	9206	2050	5779	3671	3099
Wt.	12206	41241	15024	11150	11341	6651	5746
<b>BLACK SEA BASS</b>							
No.	2455	4890	2916	14626	8027	4664	7934
Wt.	613	1687	1054	17070	4824	1461	3348
<b>SCUP</b>							
No.	4802	9271	2066	1439	5621	5624	7008
Wt.	3716	5205	1632	603	3711	1544	3628
<b>ATLANTIC MACKEREL</b>							
No.	3998	3966	8953	856	3472	1060	3300
Wt.	3533	3936	16220	1793	5865	1322	2259
<b>ATLANTIC CROAKER</b>							
No.	1805	1781	1557	350	7071	7553	5553
Wt.	1795	497	644	237	807	1760	1283
<b>SPOT</b>							
No.	10528	17717	21131	12883	22584	11194	12142
Wt.	2642	4369	5892	2330	3986	988	3258
<b>STRIPED BASS</b>							
No.	1764	454	251	220	414	370	220
Wt.	4574	1217	702	367	1800	867	389
<b>TAUTOG</b>							
No.	2054	1826	1241	1891	1989	2092	3573
Wt.	3247	3166	2125	4715	3010	4385	4310

fisheries which have relatively short lives. The periodic success of certain year classes has a profound effect on yearly abundance and several of the most important recreational species exhibit relatively erratic oscillations in year to year availability. For example, during the seven years summarized, numbers of fish taken expressed as a ratio of the high to the low catch is as follows: bluefish, 2.0:1; summer flounder, 2.2:1; winter flounder, 3.2:1; weakfish, 7.1:1; black sea bass, 6.0:1; scup, 6.4:1; Atlantic mackerel, 10.4:1; spot, 2.0:1; striped bass, 8.0:1; and tautog, 2.9:1.

The magnitude of the Middle Atlantic recreational landings are impressive. Compared to the 1985 total Atlantic and Gulf commercial catch, recreational removals for the same time period, on a percentage basis (i.e., Middle Atlantic recreational catch/Atlantic and Gulf commercial catch X 100), are as follows: bluefish, 271; black sea bass, 82; winter flounder, 60; summer flounder, 42; Atlantic mackerel, 35; striped bass, 32; scup, 23; and Atlantic croaker, 12. Compared to the recreational catch of all other Atlantic and Gulf subregions, the Middle Atlantic is consistently highest in both numbers and biomass caught.

#### Japanese Longline Catch and Effort

Table 5 gives observed Japanese longline catch-per-unit-effort (CPUE) from Fishery Reporting Zone No. 16 (Figure 5) by species and species group (i.e., tunas, billfishes, sharks, rays, and other finfish) for the years 1978-1981. The MAB falls almost entirely within this particular fishing zone; therefore, the species composition and calculated catch rates can be termed as representative of the MAB area. Thus, it is interesting to note, that the big-eye tuna (Thunnus obesus), yellowfin tuna (Thunnus albacares), albacore (Thunnus alalunga), swordfish (Xiphias gladius), blue shark (Prionace glauca), and lancetfish (Alepisaurus ferox) make up, on an average, greater than 86% of the CPUE from this reporting zone. Also of interest, the first three species mentioned above are generally considered to be the target species of the Japanese longline fishery within the MAB and adjacent oceanic waters.

At present, this fishery is dominated primarily by the Japanese distant water longline fleets, with little if any U.S. participation, except in the area of swordfishing. If and when this situation begins to reverse, these valuable migratory oceanic fishery resources will obviously become more important to domestic fishermen and any adverse man-induced and/or natural change in abundance and/or distribution could have economic ramifications throughout the fishery. The data presented, regarding the present fishery, indicate the potential for U.S. participation, and therefore, the possibility of any change in species abundance must be taken into account.

#### NMFS Research Vessel Surveys

This seasonal research vessel bottom trawl survey data set, for purposes of this paper, was distilled to a series of spring (1968-1974, 1976, and 1978) and autumn (1965-1975, and 1977) computer-generated cumulative plots. Twenty-six species of finfish and six species of invertebrates were selected to illustrate seasonal and geographic trends in distribution and abundance relative to the MAB.

Table 5. Japanese longline catch, 1978-1981 in waters of the Middle Atlantic Bight.

GROUP/Species	CPUE (no./10,000 hooks)				
	1978	1979	1980	1981	1978-1981
<b>TUNAS</b>					
Bluefin	0.27	0.84	2.43	2.73	2.24
Bigeye	91.39	52.20	84.23	66.79	71.96
Yellowfin	28.66	50.04	34.16	15.43	24.25
Skipjack	0.15	1.18	0.10	0.07	0.19
Albacore	38.94	96.75	57.16	35.05	46.21
Blackfin	0.73	-	0.02	0.26	0.23
Little	0.04	-	0.09	0.02	0.04
Atlantic bonito	-	-	0.14	0.01	0.04
Uncl. tuna	-	0.13	0.10	0.38	0.25
<b>TOTAL</b>	<b>160.18</b>	<b>201.14</b>	<b>178.43</b>	<b>120.74</b>	<b>145.41</b>
<b>BILLFISHES</b>					
Blue marlin	0.89	0.51	0.28	0.28	0.36
White marlin	1.47	8.74	2.60	3.07	3.33
Sailfish	0.08	0.08	-	0.01	0.02
Spearfish	0.12	0.17	0.19	0.13	0.14
Swordfish	17.11	9.84	10.60	8.42	9.93
Uncl. billfish	0.19	-	0.02	0.07	0.07
<b>TOTAL</b>	<b>19.86</b>	<b>19.34</b>	<b>13.69</b>	<b>11.98</b>	<b>13.85</b>
<b>SHARKS AND RAYS</b>					
Slky	0.08	-	-	0.02	0.02
Blacktip	-	0.04	-	0.01	0.01
Whitetail	0.27	0.04	0.09	0.03	0.07
Dusky	0.27	2.96	0.05	0.20	0.43
Blue	77.76	132.05	85.59	57.10	72.67
Tiger	2.59	0.04	0.10	0.01	0.29
Hammerhead	0.15	0.30	0.41	0.38	0.36
Porbeagle	0.04	-	0.10	0.13	0.11
Brown	0.12	-	0.02	-	0.02
White	-	1.39	0.38	0.12	0.29
Uncl. dogfish	0.04	-	-	-	*
Bignose	0.04	0.08	0.03	-	0.02
Lemon	0.04	-	0.03	-	0.01
Shortfin mako	0.12	-	1.89	2.03	1.62
Longfin mako	0.15	-	0.15	0.17	0.15
Uncl. mako	2.47	6.55	1.60	0.37	1.44
Bigeye thresher	0.39	-	0.15	0.78	0.05
Uncl. thresher	0.50	0.89	0.43	0.43	0.48
Atlantic sharpnose	-	-	-	-	*
Bull	-	-	-	-	0.01
Seven gill	-	-	-	-	0.02
Uncl. sharks	4.48	7.52	1.53	4.61	4.17
Uncl. stingrays	29.67	36.91	25.56	4.84	15.03
Manta ray	-	0.13	-	0.11	0.08
<b>TOTALS</b>	<b>119.18</b>	<b>188.90</b>	<b>118.11</b>	<b>71.36</b>	<b>97.37</b>
<b>OTHER FINFISH</b>					
Uncl. dolphin	0.19	0.25	0.28	0.11	0.17
Wahoo	0.12	0.46	0.26	0.05	0.14
King mackerel	0.50	0.21	0.29	0.03	0.16
Lancetfish	27.93	61.06	74.21	65.70	63.45
Oilfish	11.24	8.87	8.43	0.68	4.27
Ocean sunfish	1.24	1.35	1.51	4.25	3.06
Multicolored opah	4.09	1.86	1.76	0.54	1.30
Barracuda	0.04	-	-	0.02	0.02
Uncl. eel	0.08	-	0.02	0.01	0.02
Amberjack	-	0.25	-	-	0.02
Bigscale pomfret	0.66	3.25	0.69	0.29	0.69
Frigate mackerel	-	-	-	0.01	*
Jack crevalle	0.04	-	-	-	*
Escolar	-	0.04	-	0.01	0.01
Uncl. puffer	-	-	-	0.07	0.02
Remora	-	-	-	0.03	0.02
Uncl. finfish	1.62	3.04	4.75	1.47	2.38
<b>TOTAL</b>	<b>47.75</b>	<b>80.64</b>	<b>92.27</b>	<b>73.20</b>	<b>75.75</b>
<b>GRAND TOTAL</b>	<b>346.97</b>	<b>490.59</b>	<b>402.59</b>	<b>277.28</b>	<b>332.38</b>

Selected finfish species are illustrated in Figures 10-35 and include the following: spiny dogfish (Squalus acanthus), little skate (Raja erinacea), blueback herring (Alosa aestivalis), alewife (Alosa pseudoharengus), goosefish (Lophius americanus), Atlantic cod (Gadus morhua), offshore hake (Merluccius albidus), silver hake (Merluccius bilinearis), red hake (Urophycis chuss), spotted hake (Urophycis regia), ocean pout (Macrozoarces americanus), black sea bass (Centropristis striata), bluefish (Pomatomus saltatrix), scup (Stenotomus chrysops), weakfish (Cynoscion regalis), Atlantic mackerel (Scomber scombrus), butterfish (Peprilus triacanthus), northern searobin (Prionotus carolinus), longhorn sculpin (Myxocephalus octodecemspinosus), Gulf Stream flounder (Citharichthys arctifrons), summer flounder (Paralichthys dentatus), fourspot flounder (Paralichthys oblongus), windowpane (Scophthalmus aquosus), witch flounder (Glyptocephalus cynoglossus), yellowtail flounder (Limanda ferruginea), and winter flounder (Pseudopleuronectes americanus).

Plots of invertebrate species are given in Figures 36-41 and include: sea scallop (Placopecten magellanicus), Jonah crab (Cancer borealis), rock crab (Cancer irroratus), American lobster (Homarus americanus), shortfin squid (Illex illecebrosus), and longfin squid (Loligo pealei).

A number of conclusions and hypotheses can be drawn from these series of plots regarding the relationship between individual species and the MAB, some of the most obvious include:

1. Several species such as offshore hake (Figure 16), Gulf Stream flounder (Figure 29), American lobster (Figure 39), and sea scallop (Figure 36), tend to remain in the MAB throughout the year based on their narrow range of ecological requirements (i.e., temperature and/or depth) or sessile nature.
2. Other species tend to migrate inshore and offshore seasonally and therefore are more or less abundant in the MAB at particular intervals in time and space. Included in this category are the following species: spiny dogfish (Figure 10), little skate (Figure 11), blueback herring (Figure 12), alewife (Figure 13), silver hake (Figure 17), red hake (Figure 18), spotted hake (Figure 19), black sea bass (Figure 21), scup (Figure 23), butterfish (Figure 26), northern sea robin (Figure 27), summer flounder (Figure 30), fourspot flounder (Figure 31), and longfin squid (Figure 40).
3. Those species which either winter or summer in or near the MAB and then for all practical purposes migrate either north or south entirely out of the area. An example of this type of relationship would be the Atlantic mackerel (Figure 25) which winters in the offshore waters of the MAB and with the advent of spring moves inshore to spawn and then north and east out of the MAB to summer.
4. Those species which are found in relatively large numbers year-round in the MAB, even though they might be equally abundant in adjacent areas as well (i.e., South Atlantic Bight and Southern New England). Examples of this species category include: ocean pout (Figure 20), longhorned sculpin (Figure 28), windowpane flounder (Figure 32), yellowtail flounder (Figure 34), and winter flounder (Figure 35).

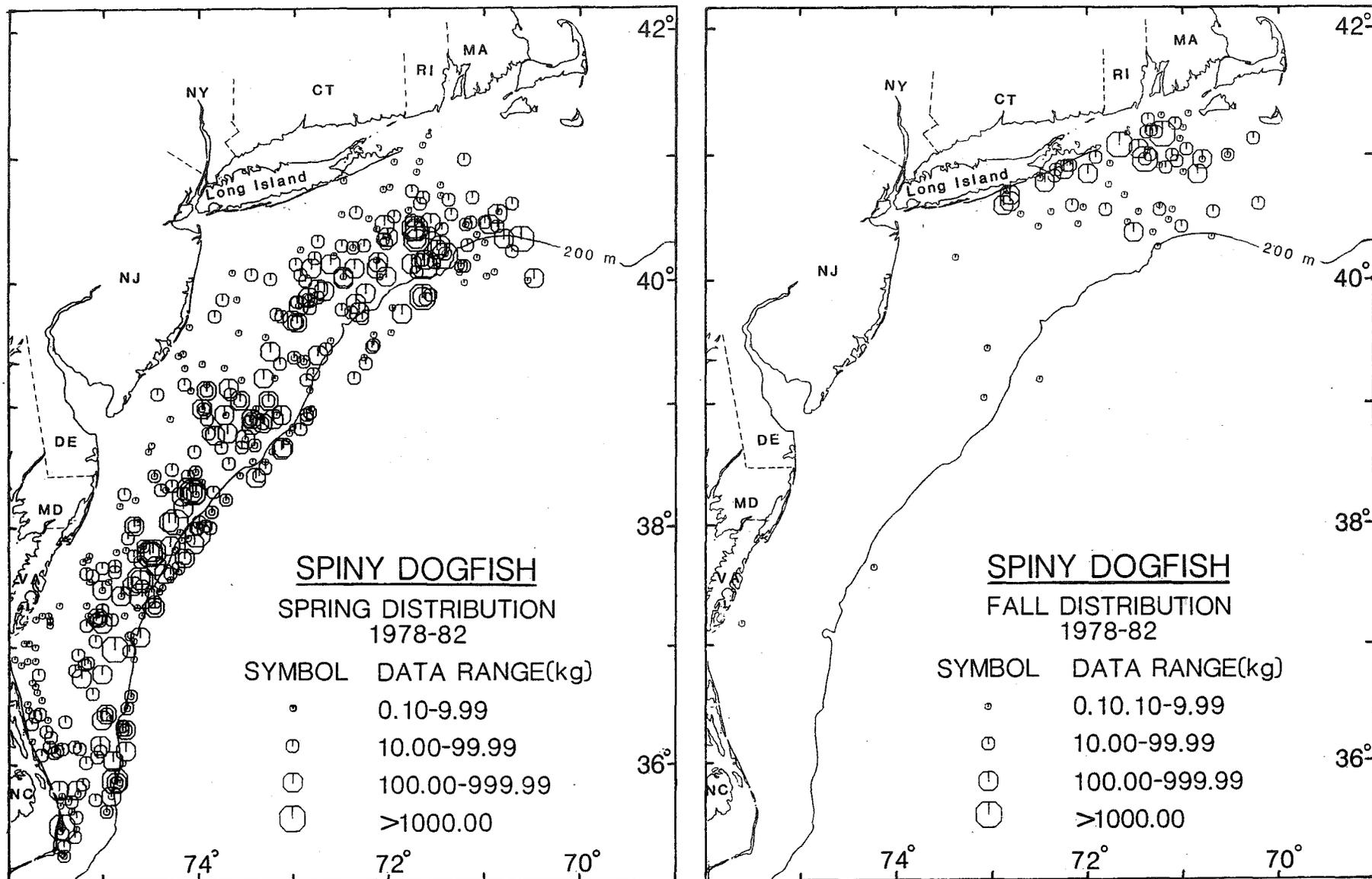


Figure 10. Spiny dogfish-spring and fall distribution from Northeast Fisheries Center resource cruises.

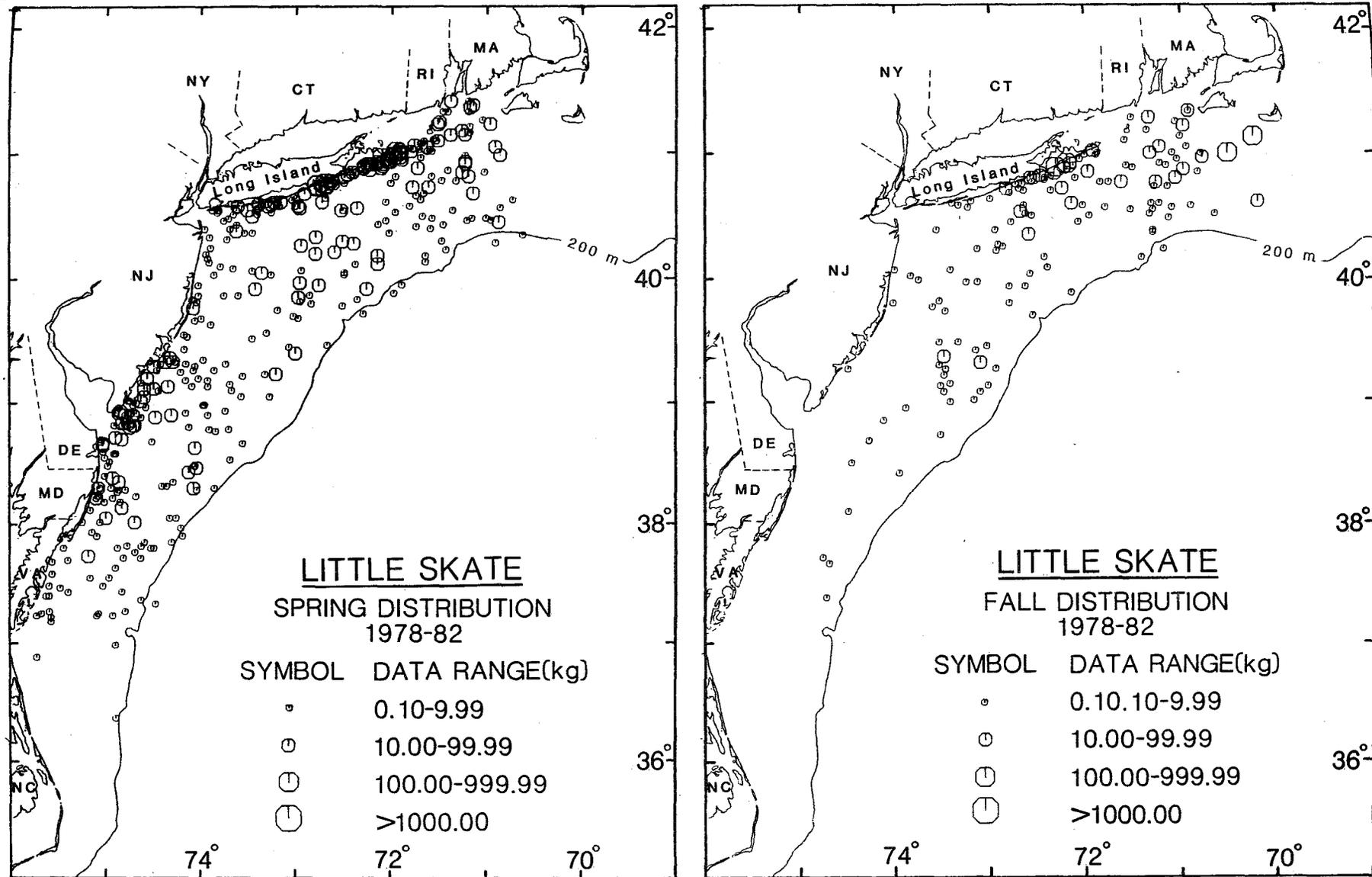


Figure 11. Little skate-spring and fall distribution from Northeast Fisheries Center resource cruises.

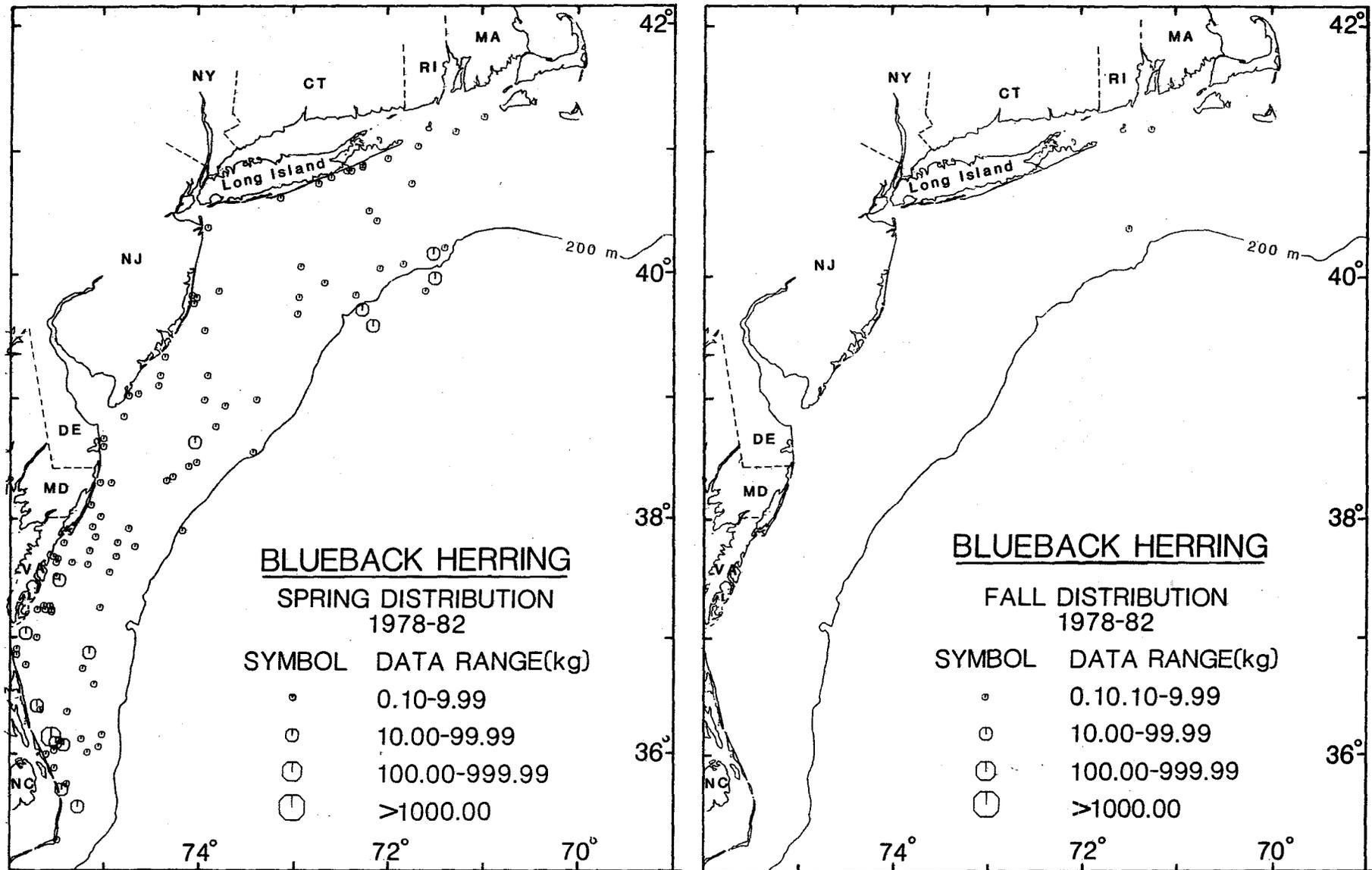


Figure 12. Blue herring-spring and fall distribution from Northeast Fisheries Center resource cruises.

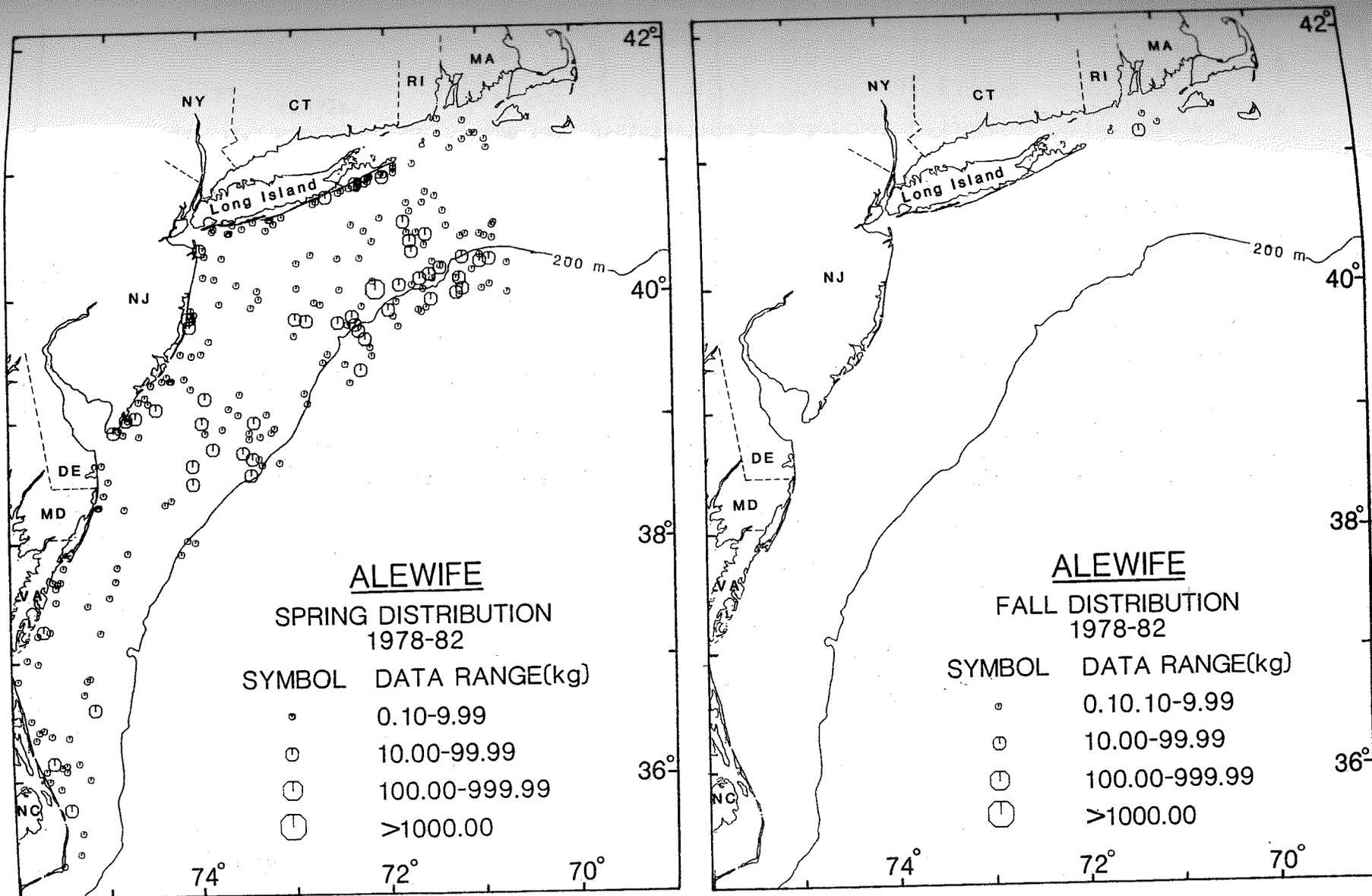


Figure 13. Alewife-spring and fall distribution from Northeast Fisheries Center resource cruises.

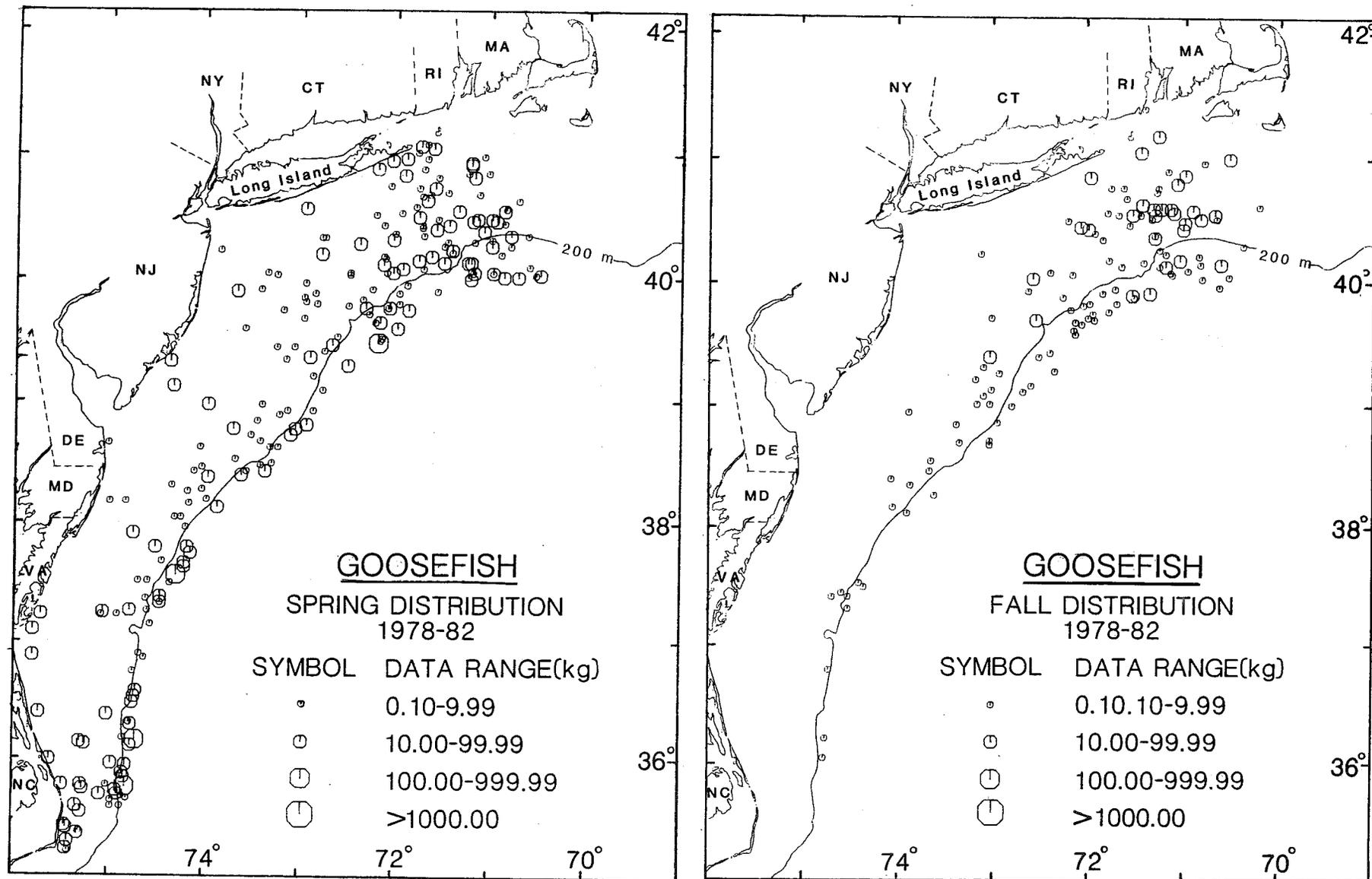


Figure 14. Goosefish-spring and fall distribution from Northeast Fisheries Center resource cruises.

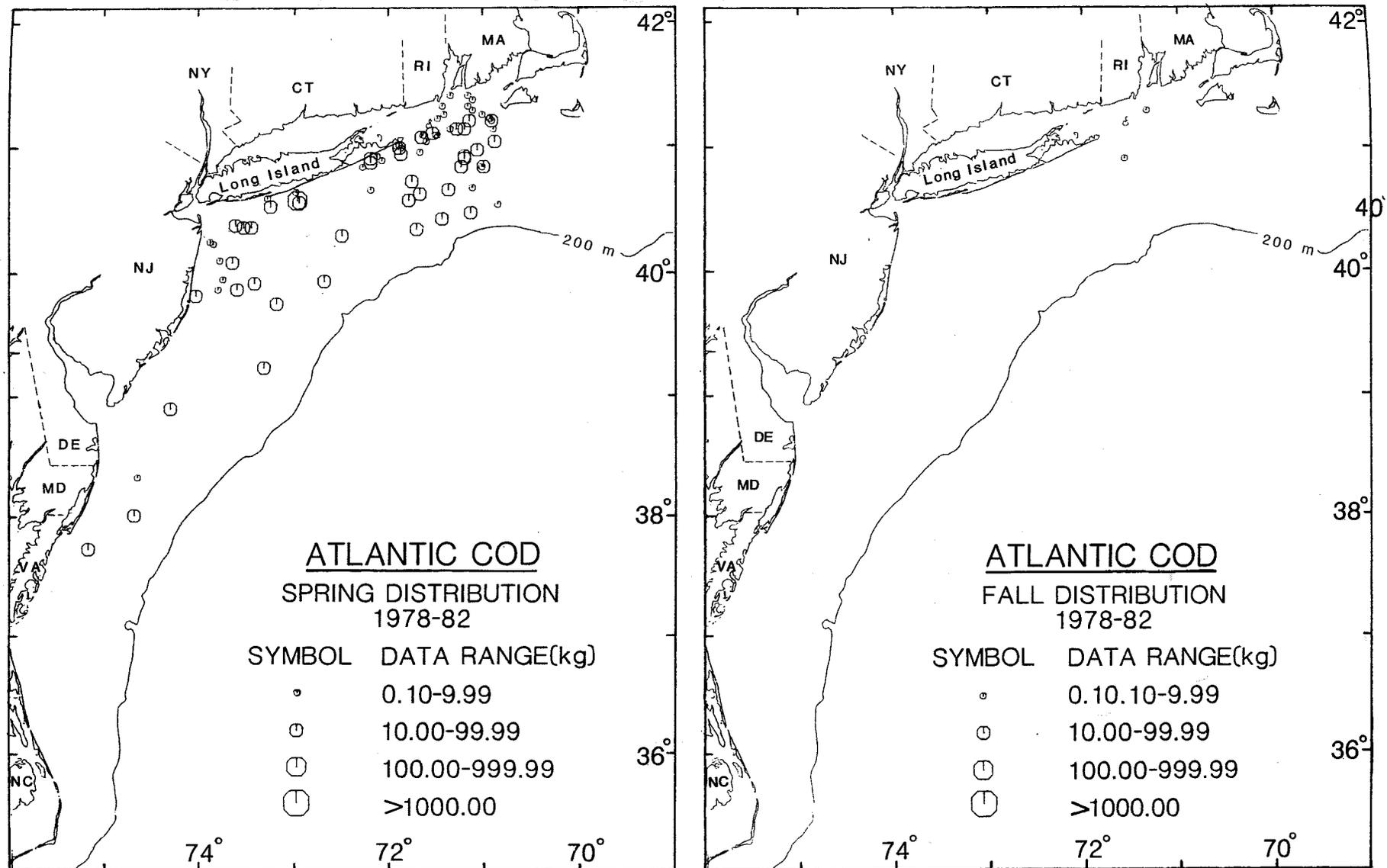


Figure 15. Atlantic cod-spring and fall distribution from Northeast Fisheries Center resource cruises.

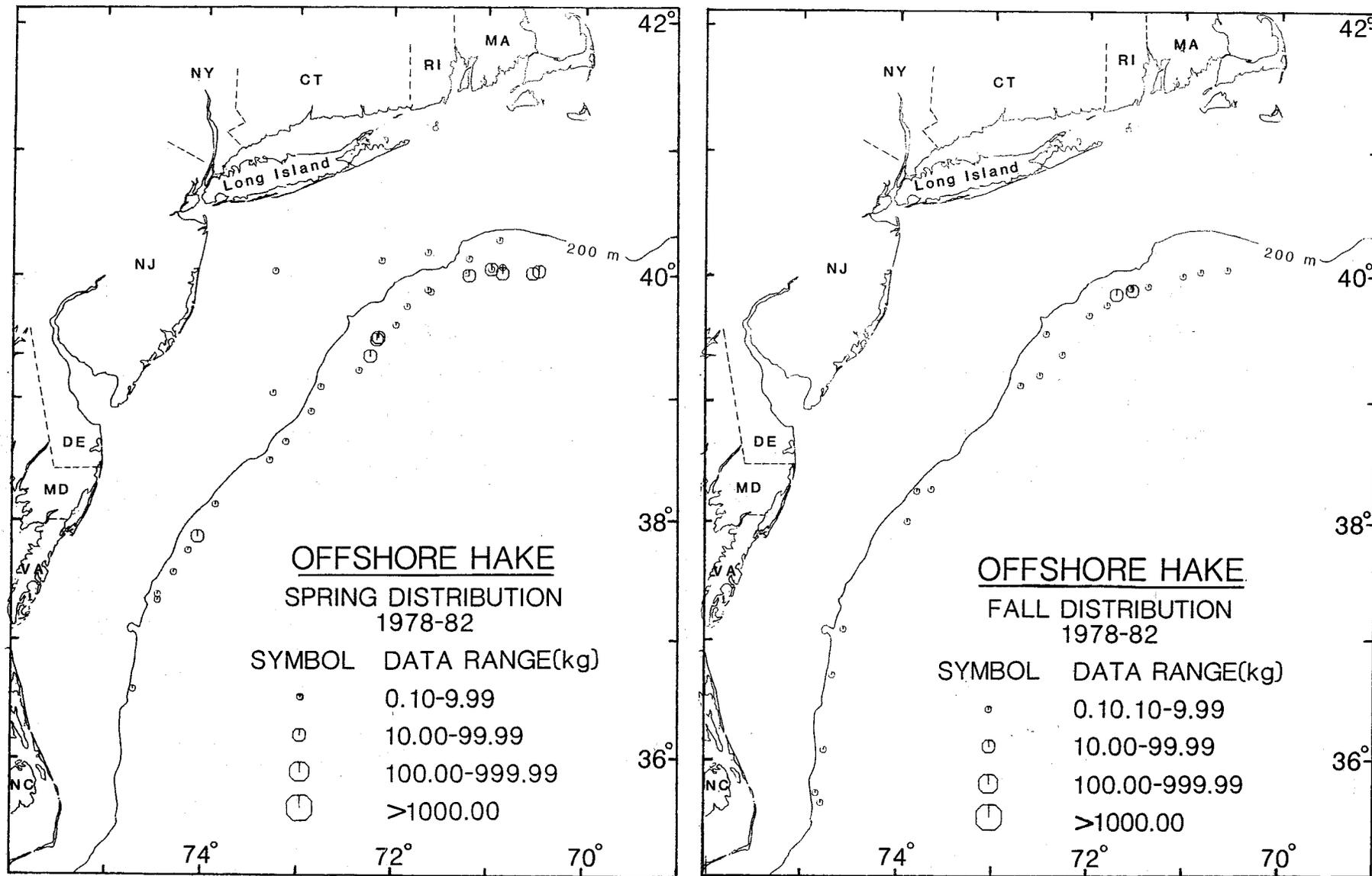


Figure 16. Offshore hake-spring and fall distribution from Northeast Fisheries Center resource cruises.

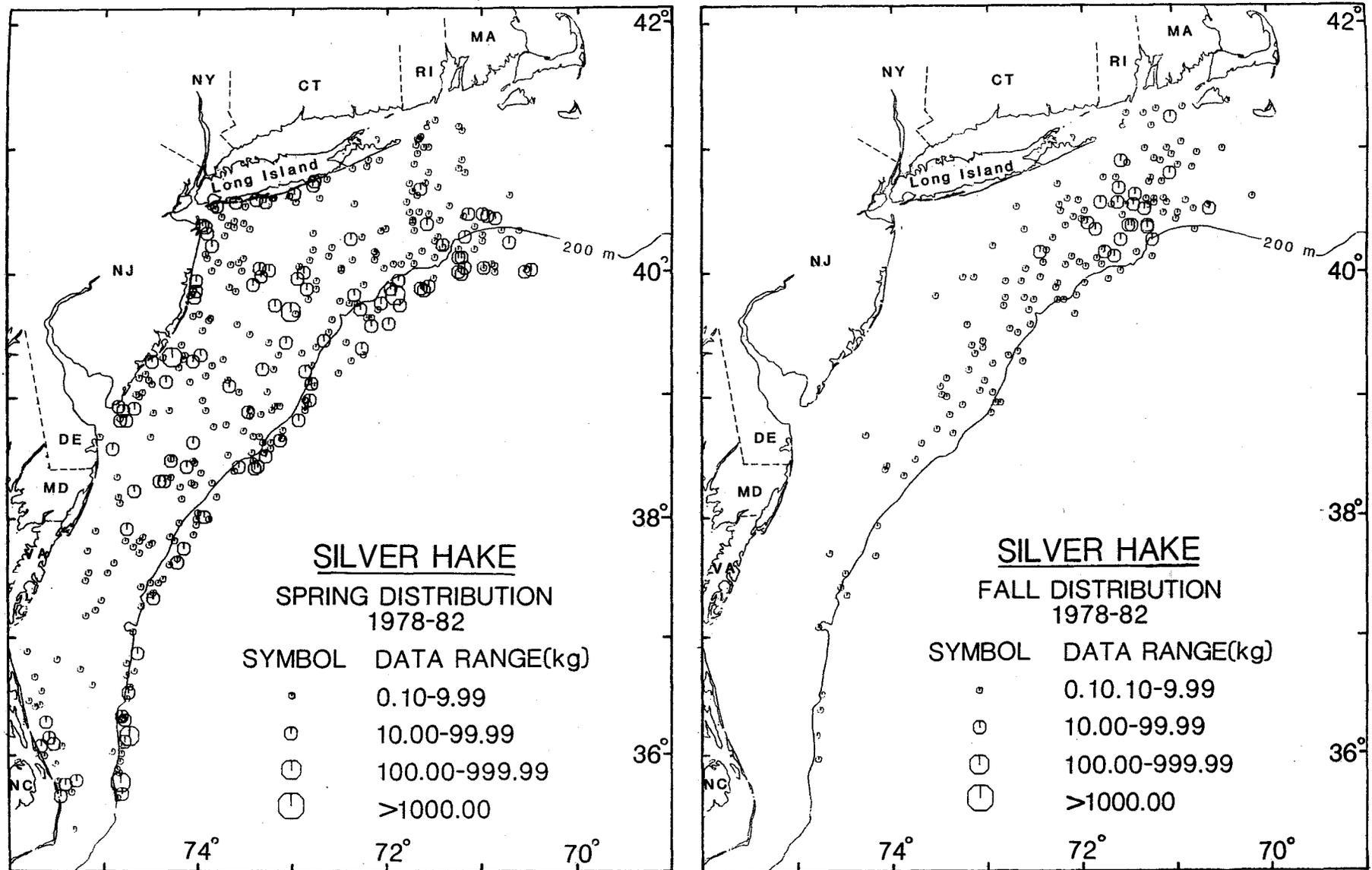


Figure 17. Silver Hake-spring and fall distribution from Northeast Fisheries Center resource cruises.

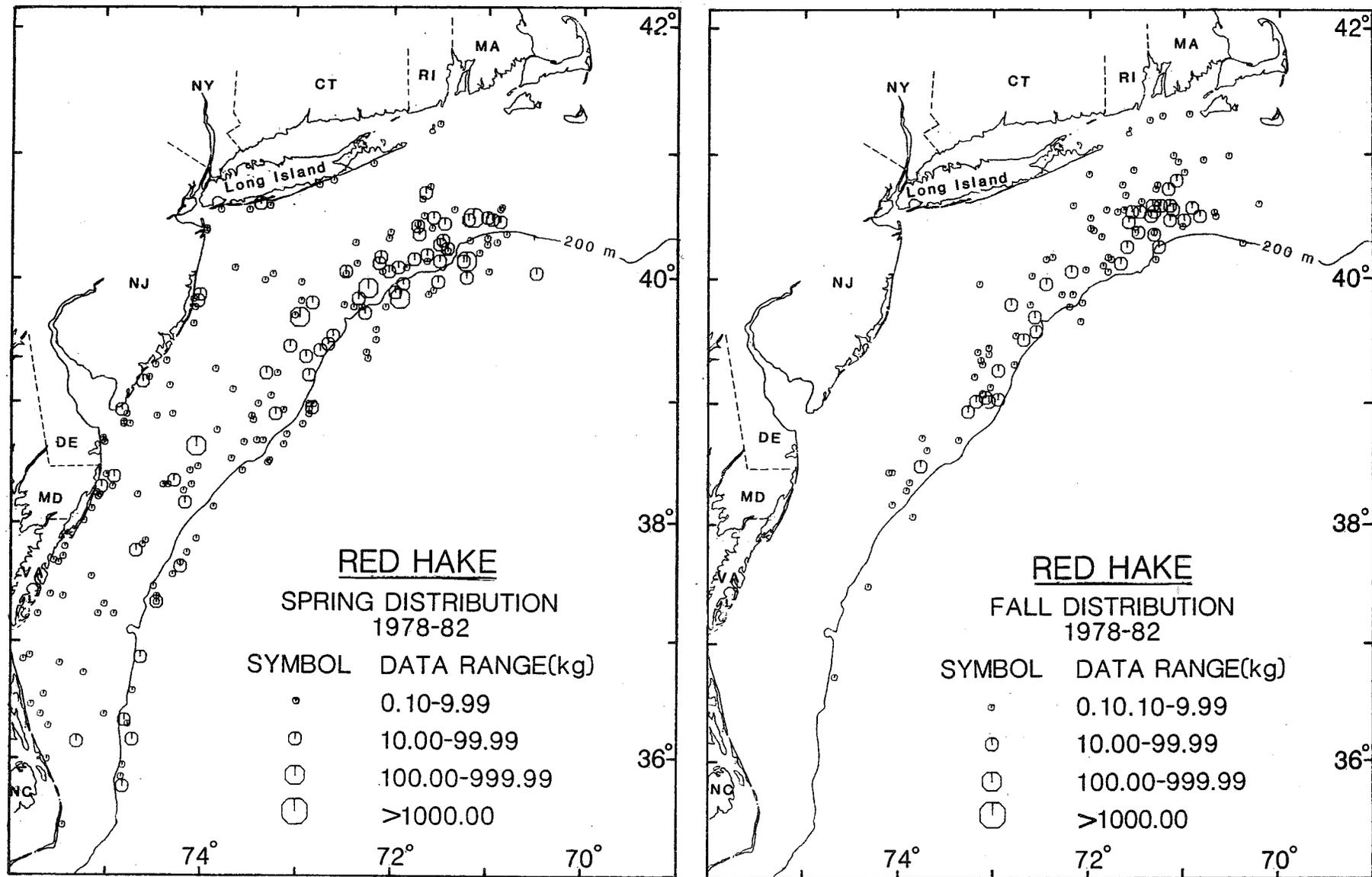


Figure 18. Red hake-spring and fall distribution from Northeast Fisheries Center resource cruises.

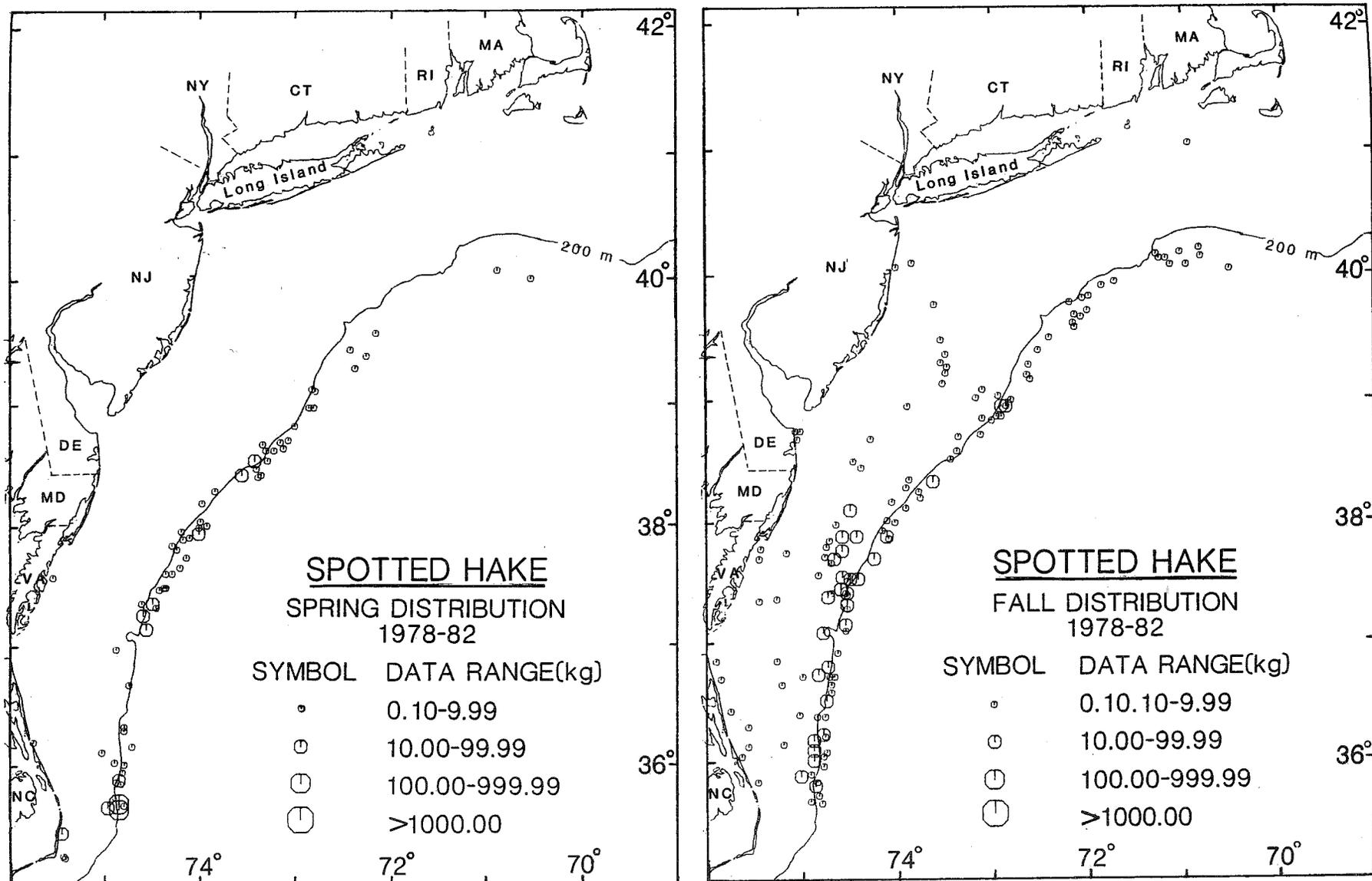


Figure 19. Spotted hake-spring and fall distribution from Northeast Fisheries Center resource cruises.

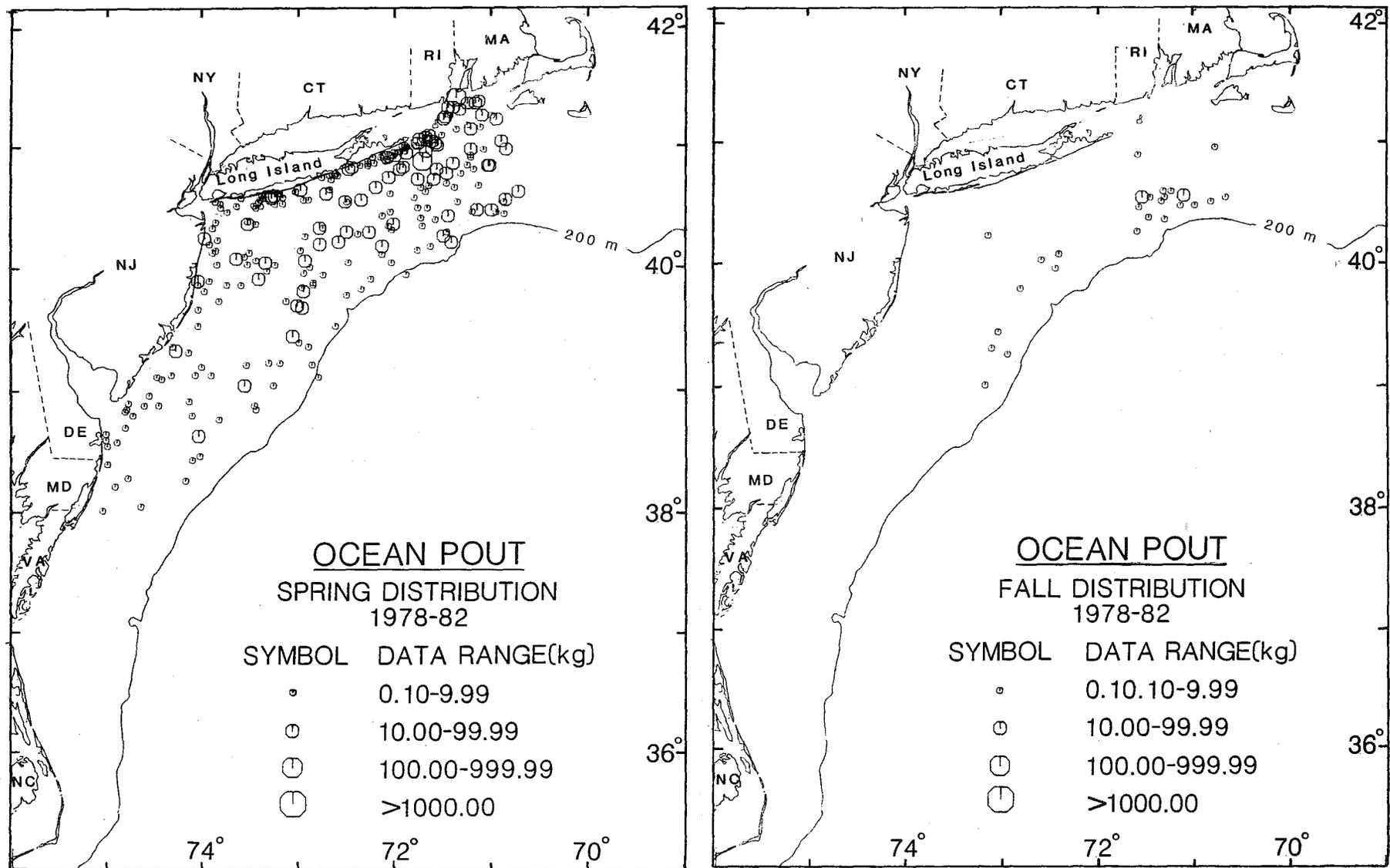


Figure 20. Ocean pout-spring and fall distribution from Northeast Fisheries Center resource cruises.

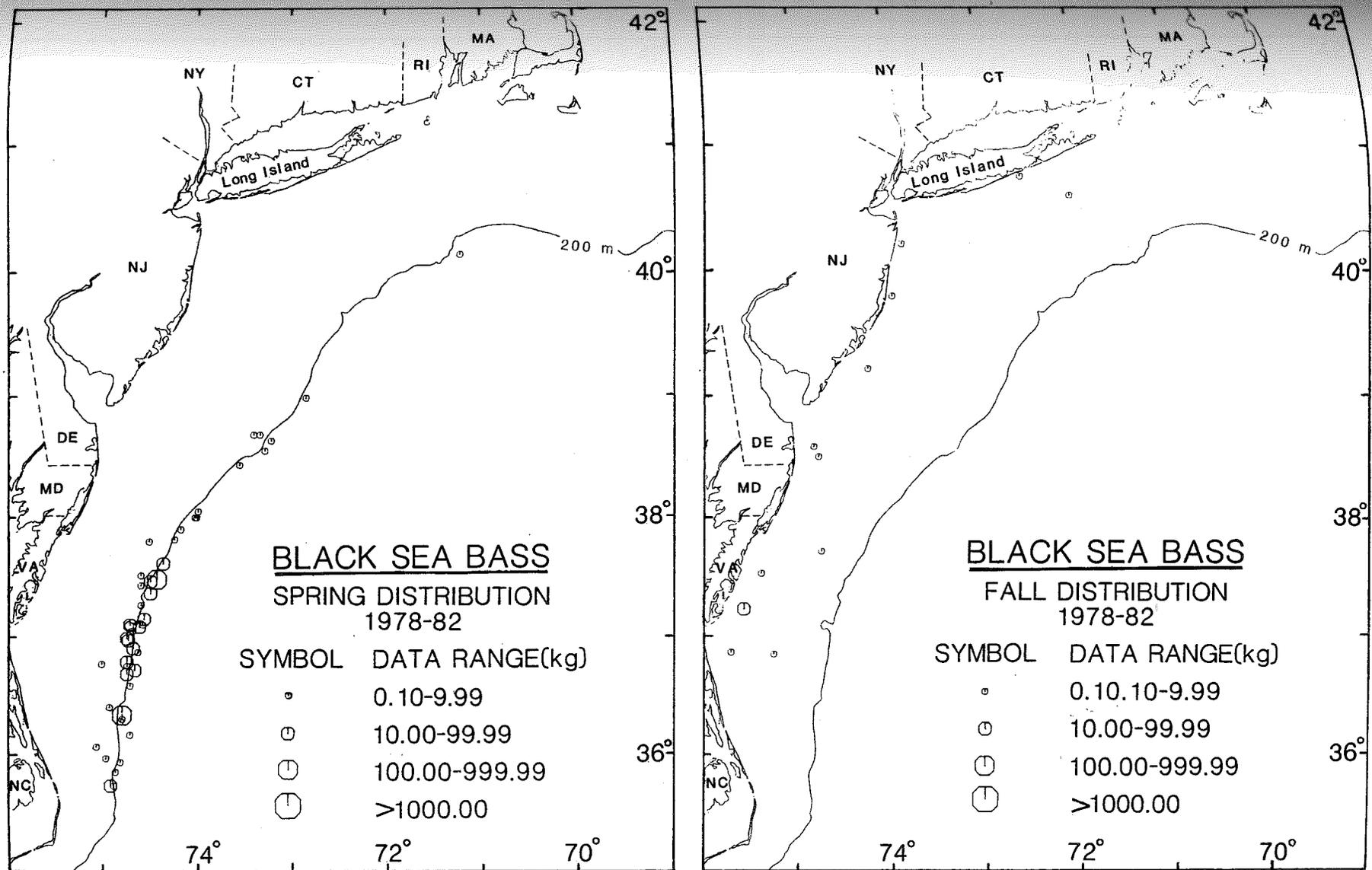


Figure 21. Black sea bass-spring and fall distribution from Northeast Fisheries Center resource cruises.

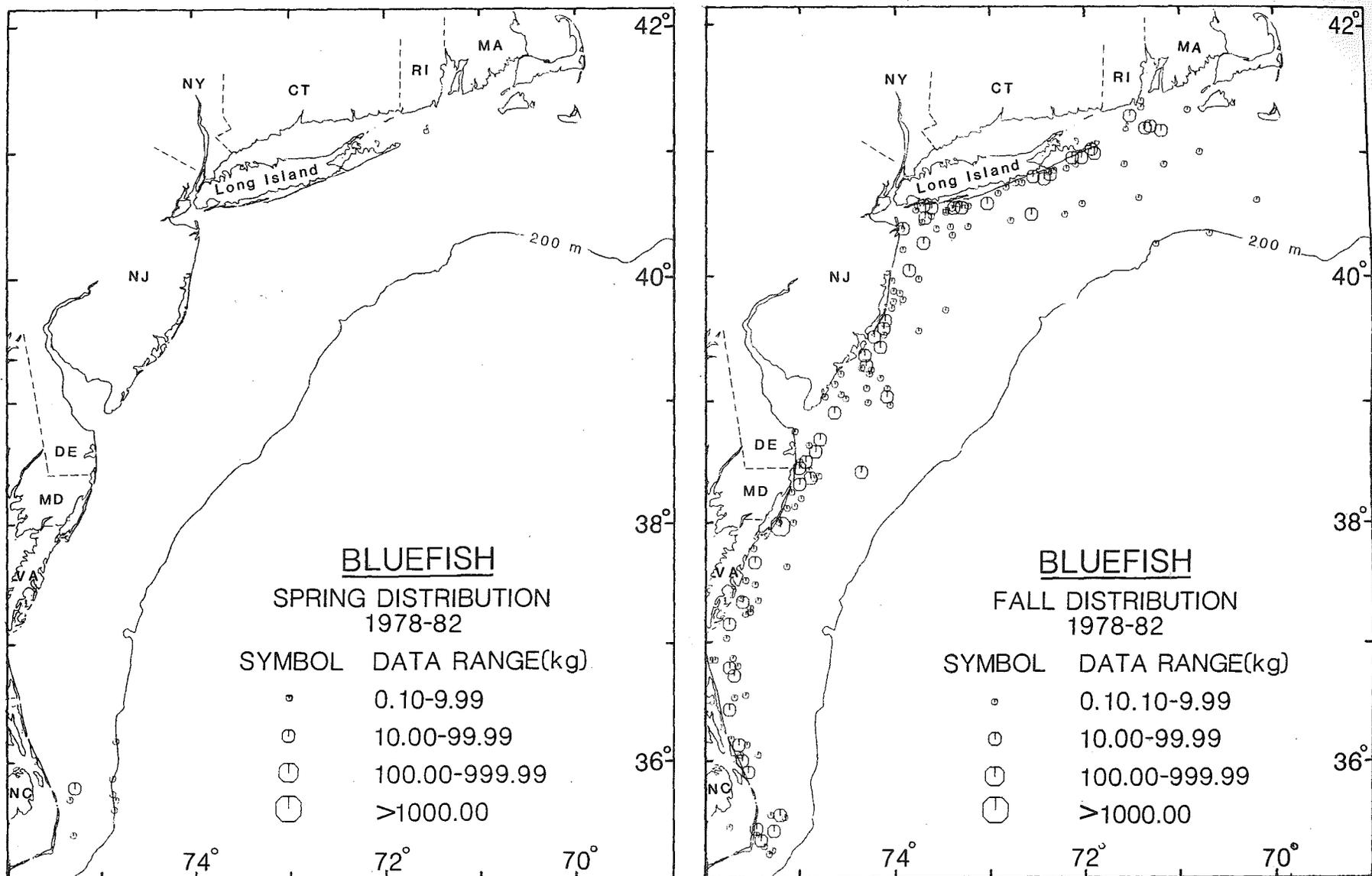


Figure 22. Bluefish-spring and fall distribution from Northeast Fisheries Center resource cruise.

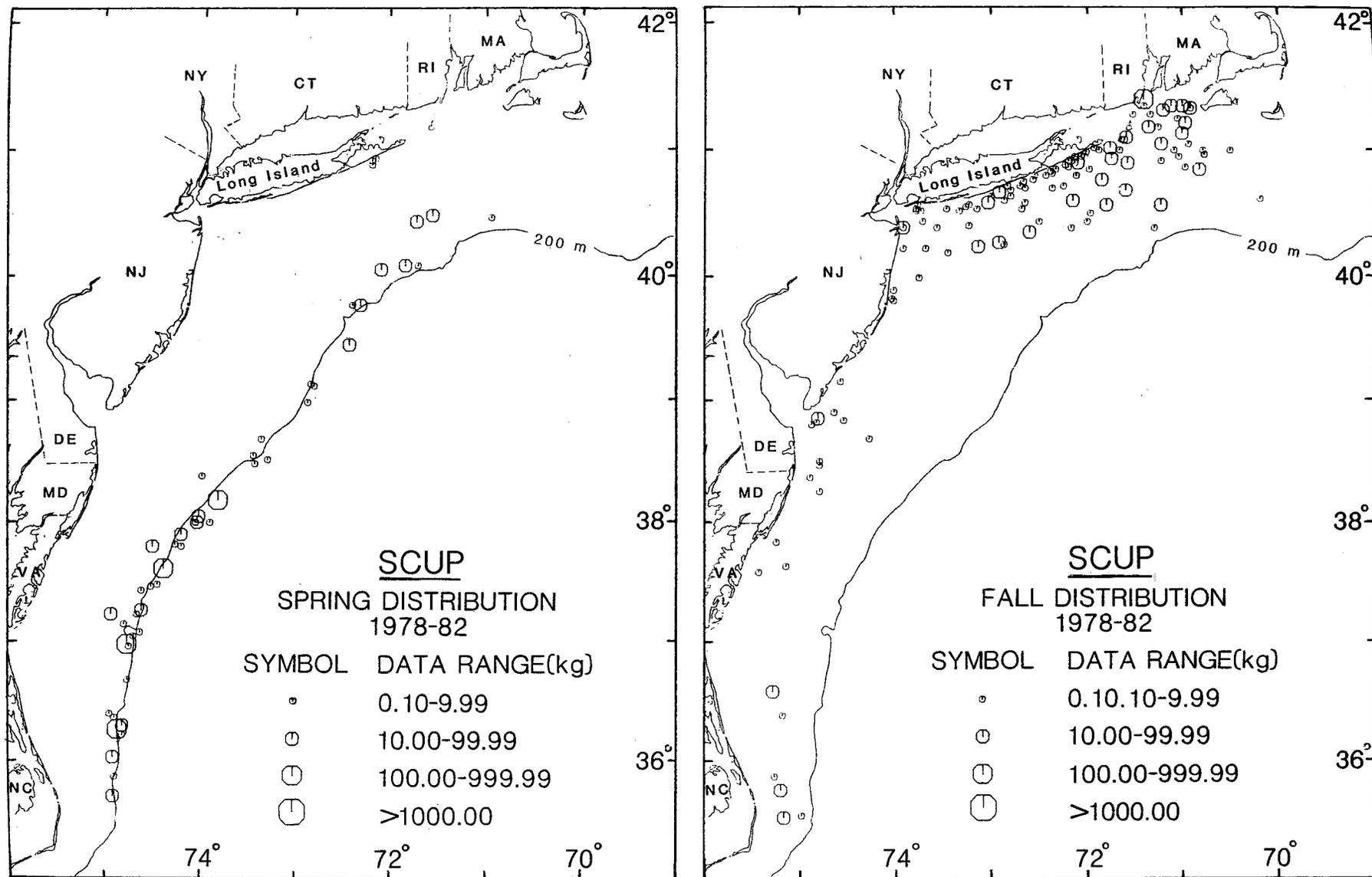


Figure 23. Scup-spring and fall distribution from Northeast Fisheries Center resource cruises.

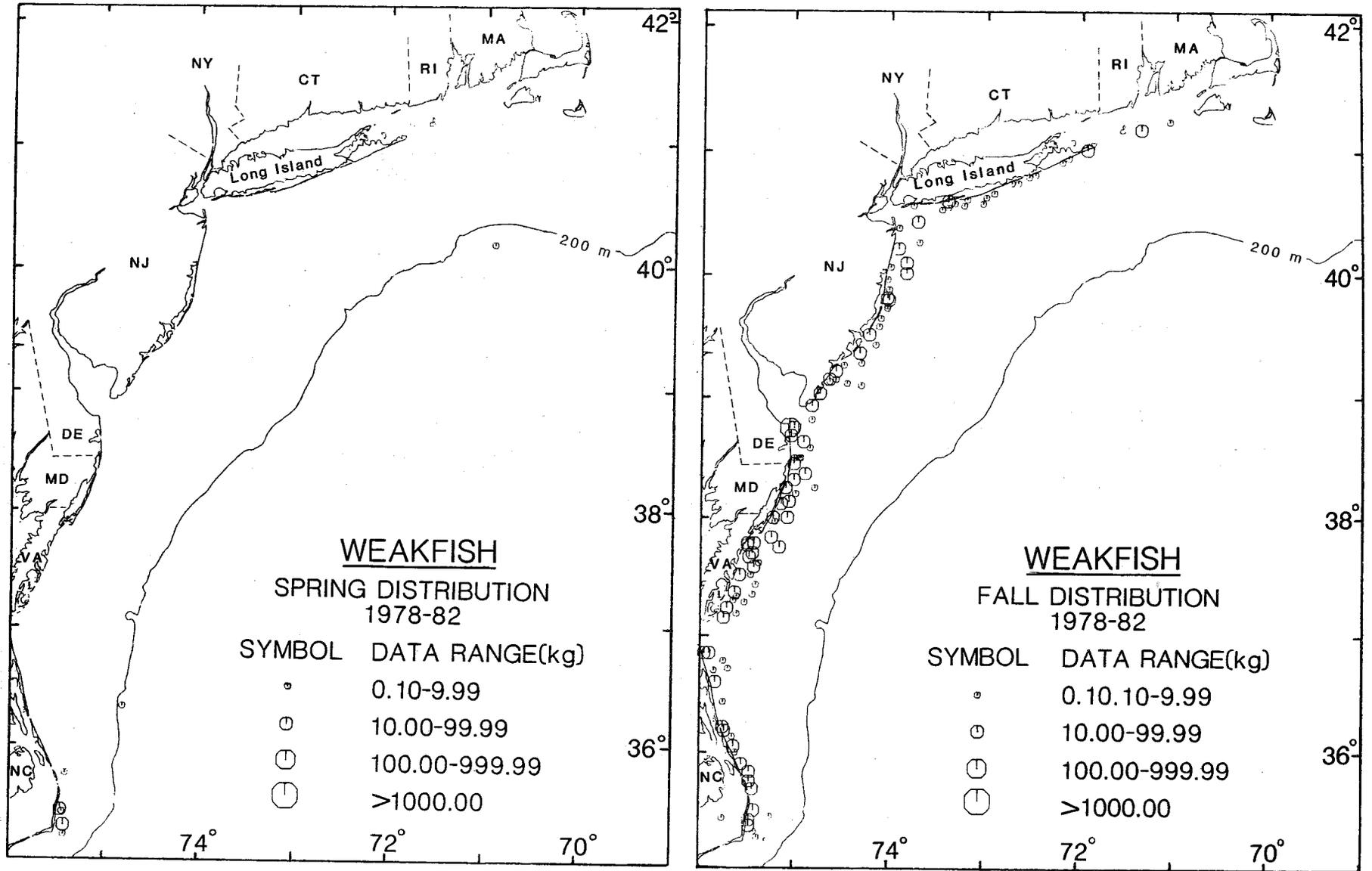


Figure 24. Weakfish-spring and fall distribution from Northeast Fisheries Center resource cruises.

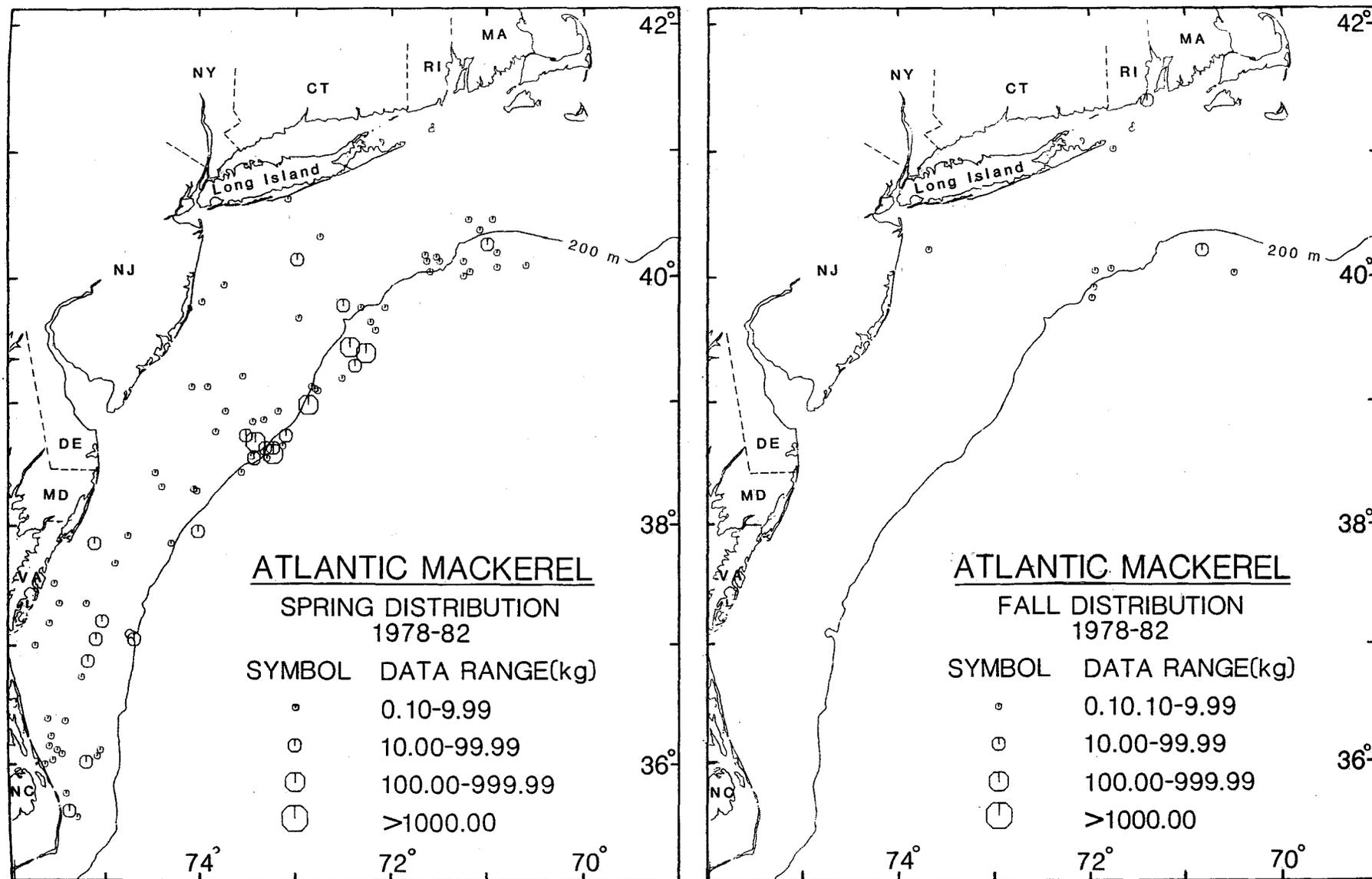


Figure 25. Atlantic mackerel-spring and fall distribution from Northeast Fisheries Center resource cruises.

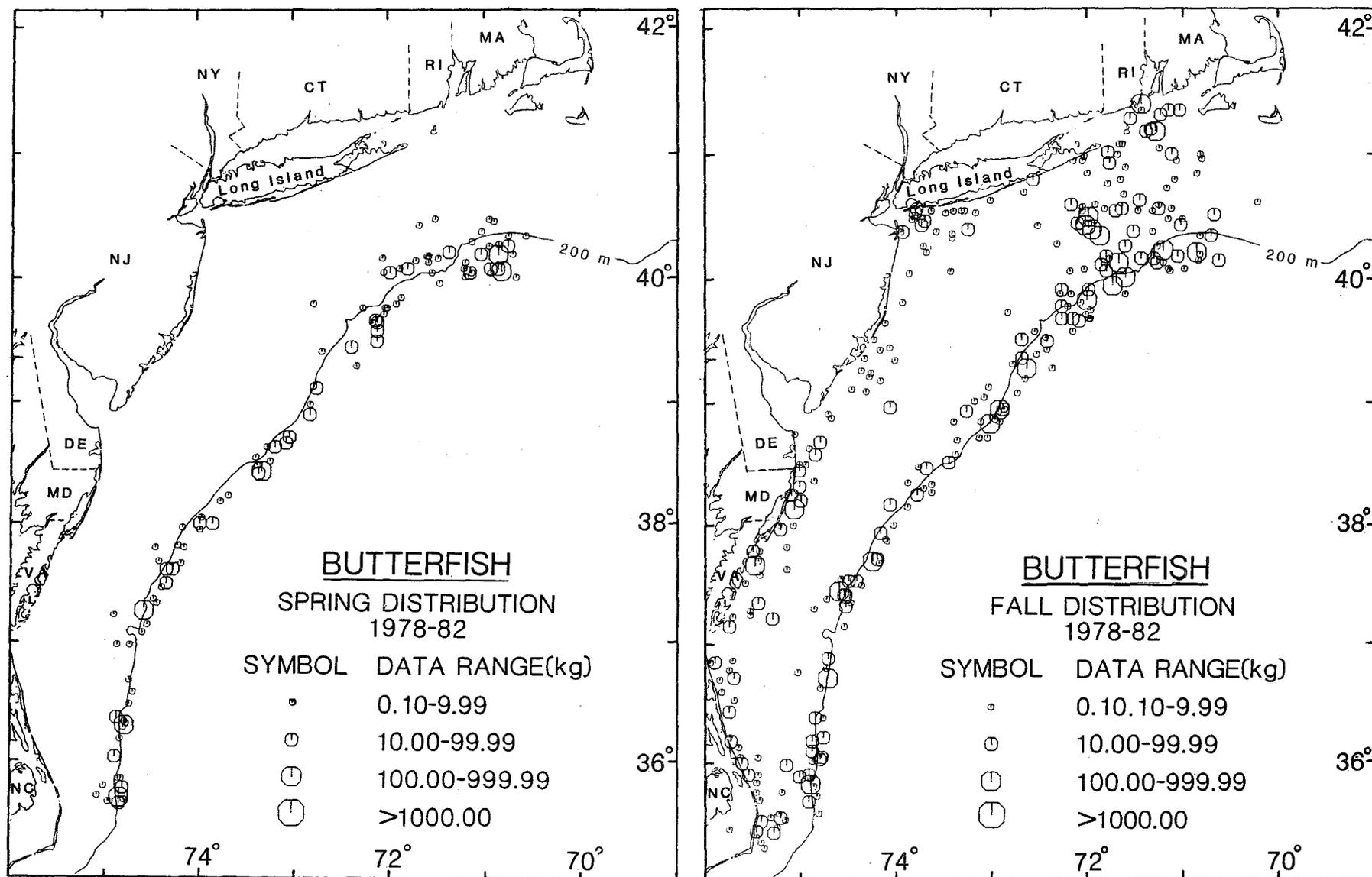


Figure 26. Butterfish-spring and fall distribution from Northeast Fisheries Center resource cruises.

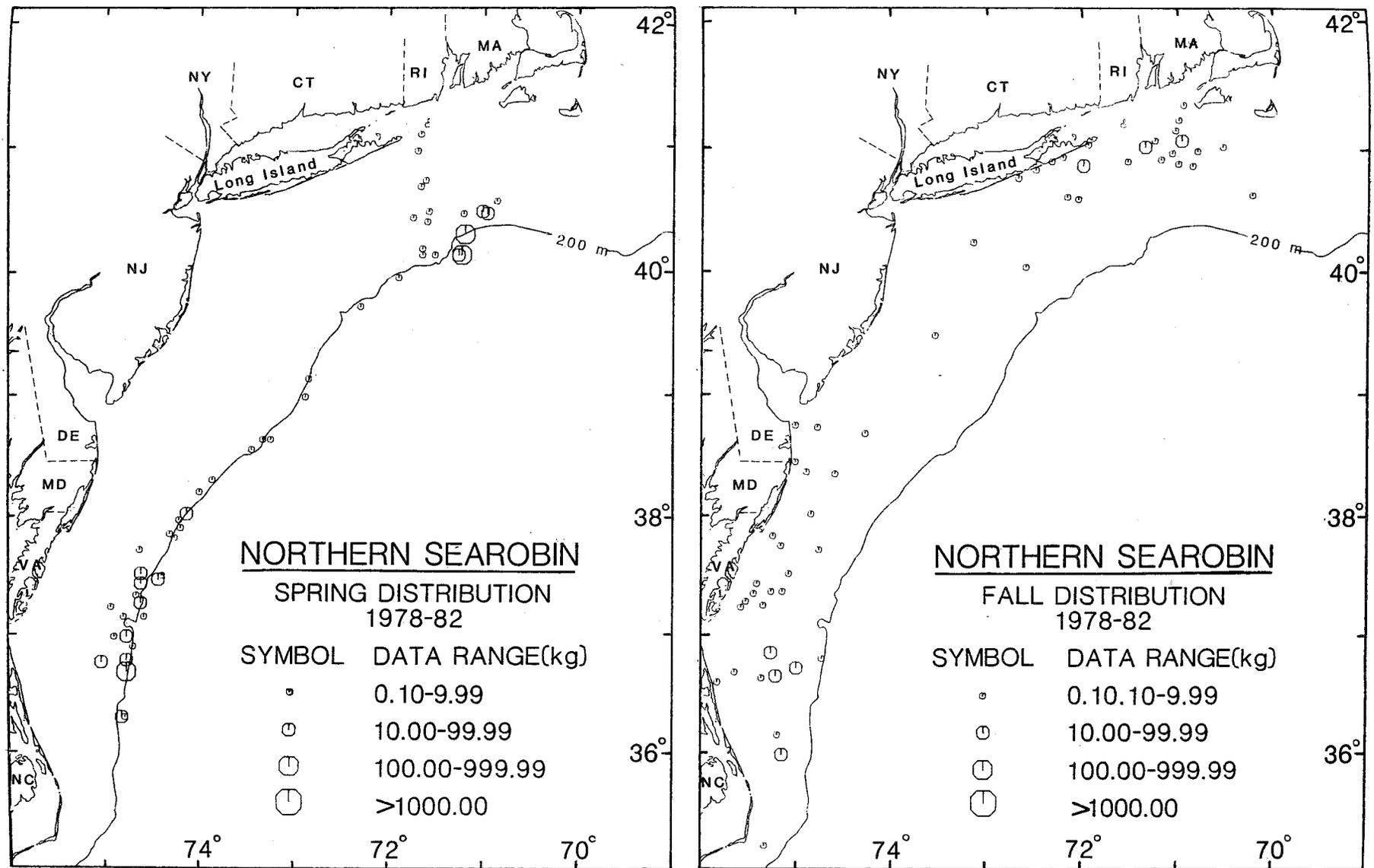


Figure 27. Northern seabobin-spring and fall distribution from Northeast Fisheries Center resource cruises.

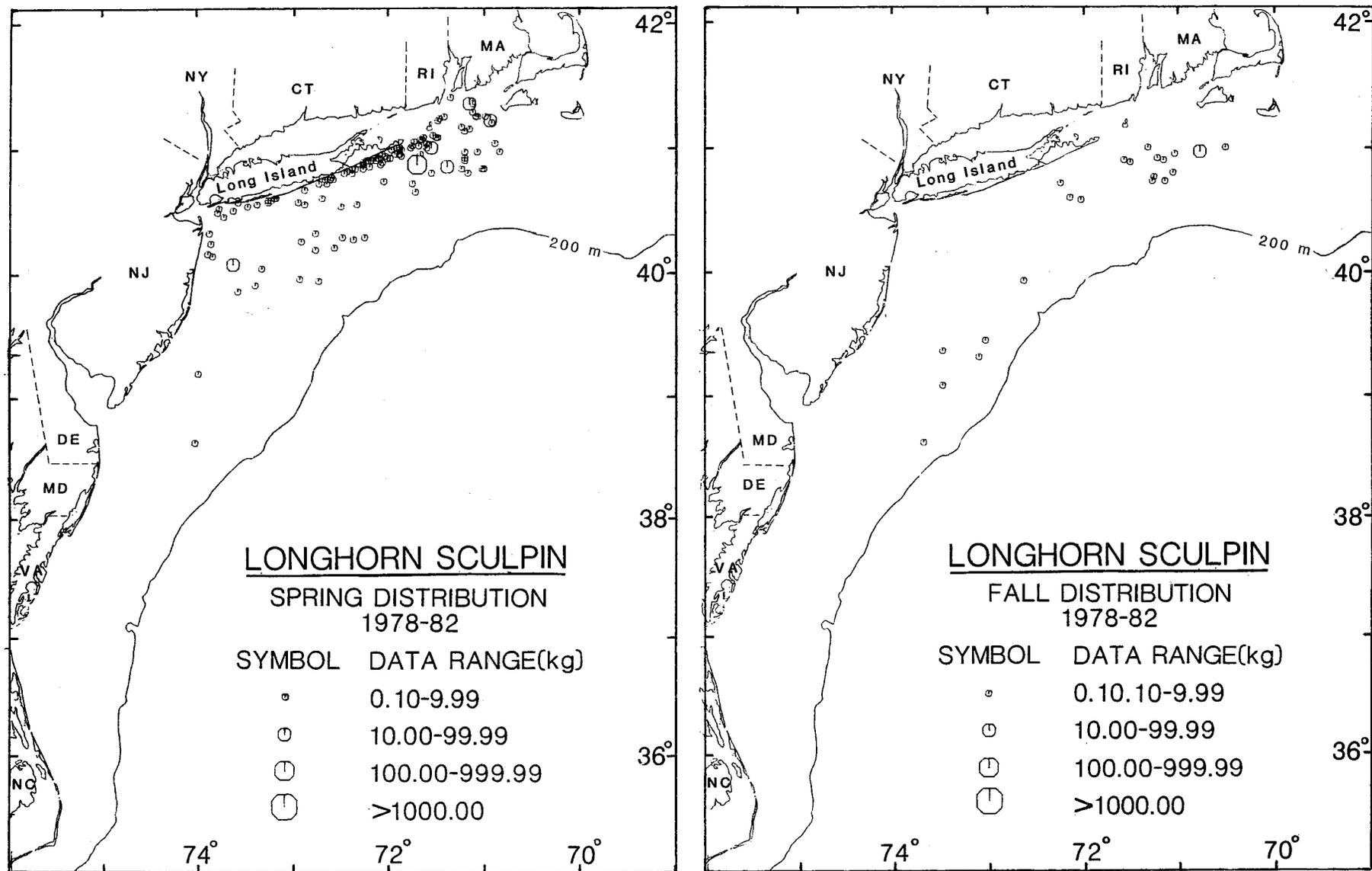


Figure 28. Longhorn sculpin-spring and fall distribution from Northeast Fisheries Center resource cruises.

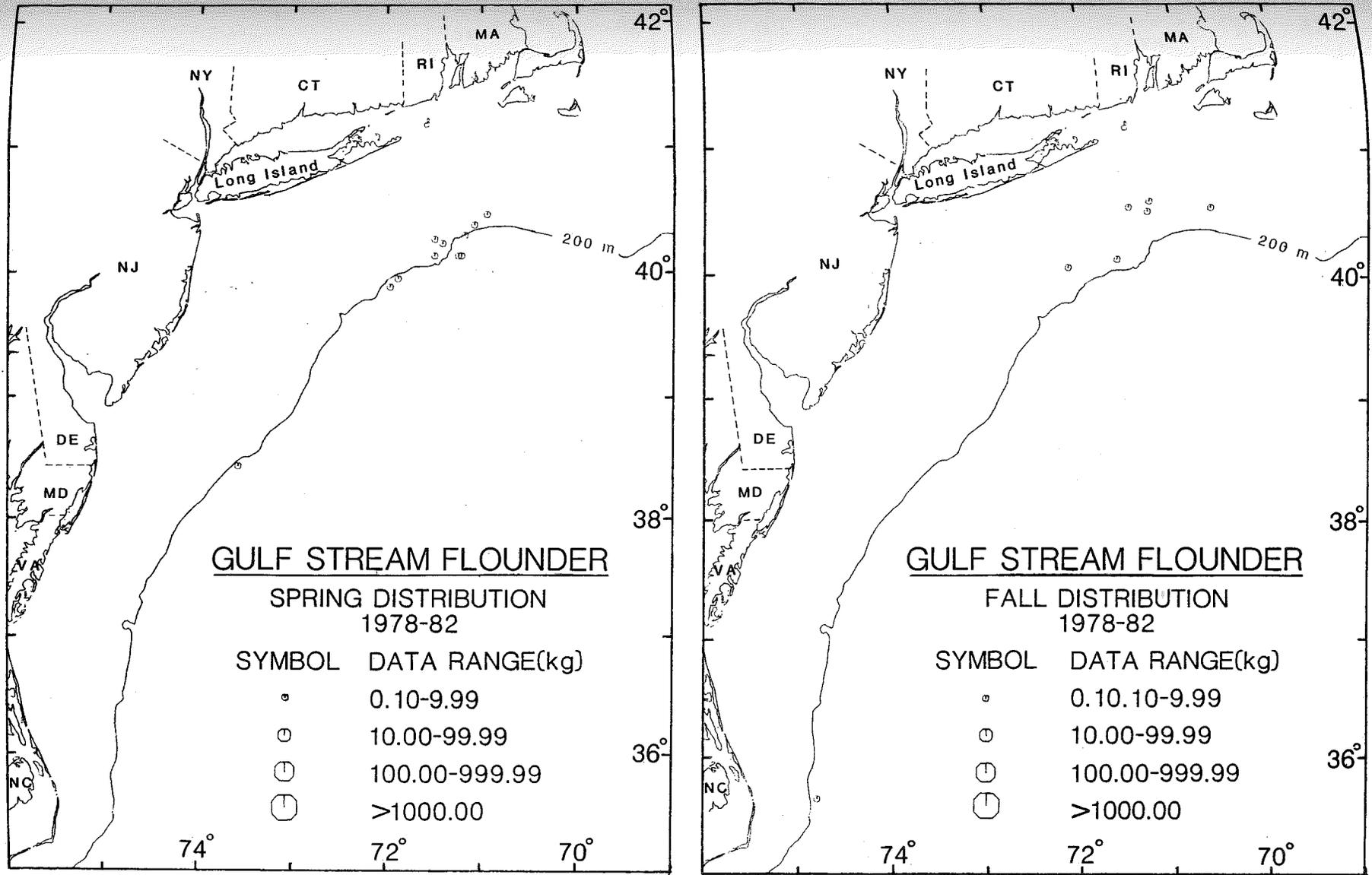


Figure 29. Gulf stream flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

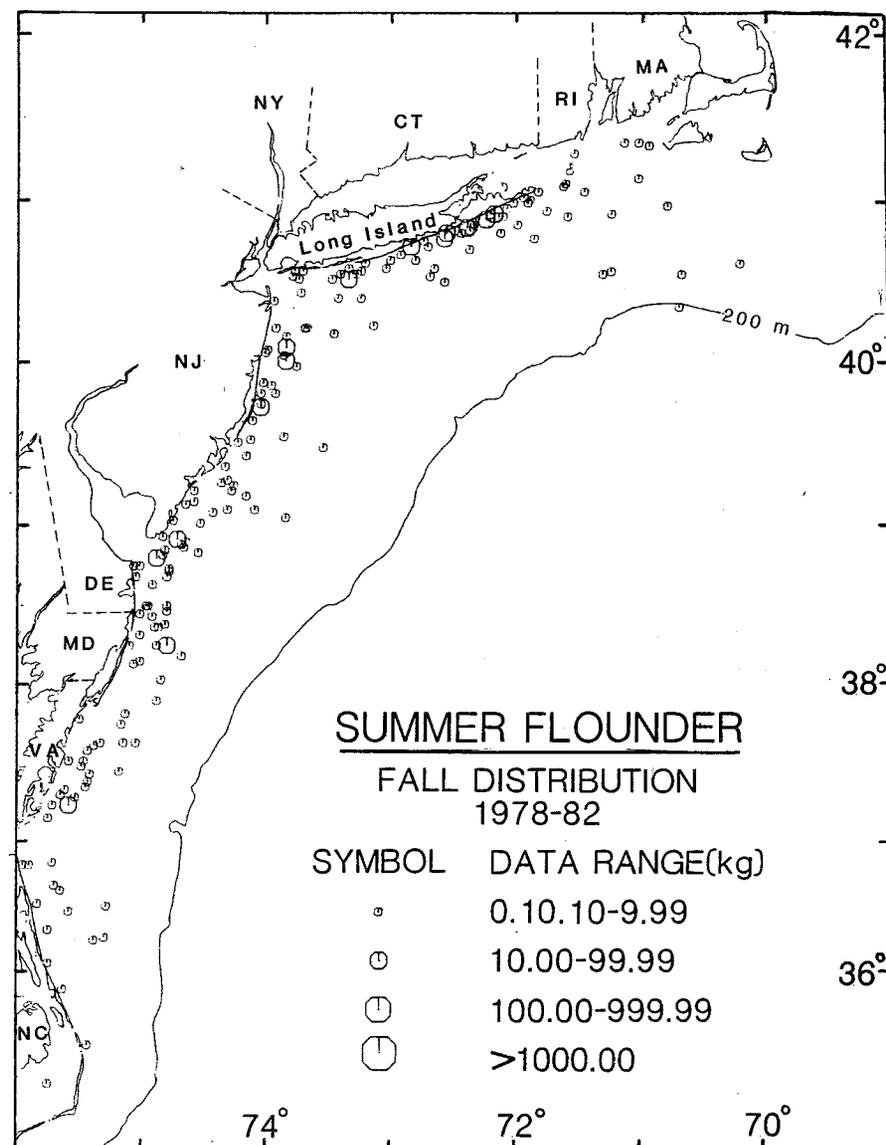
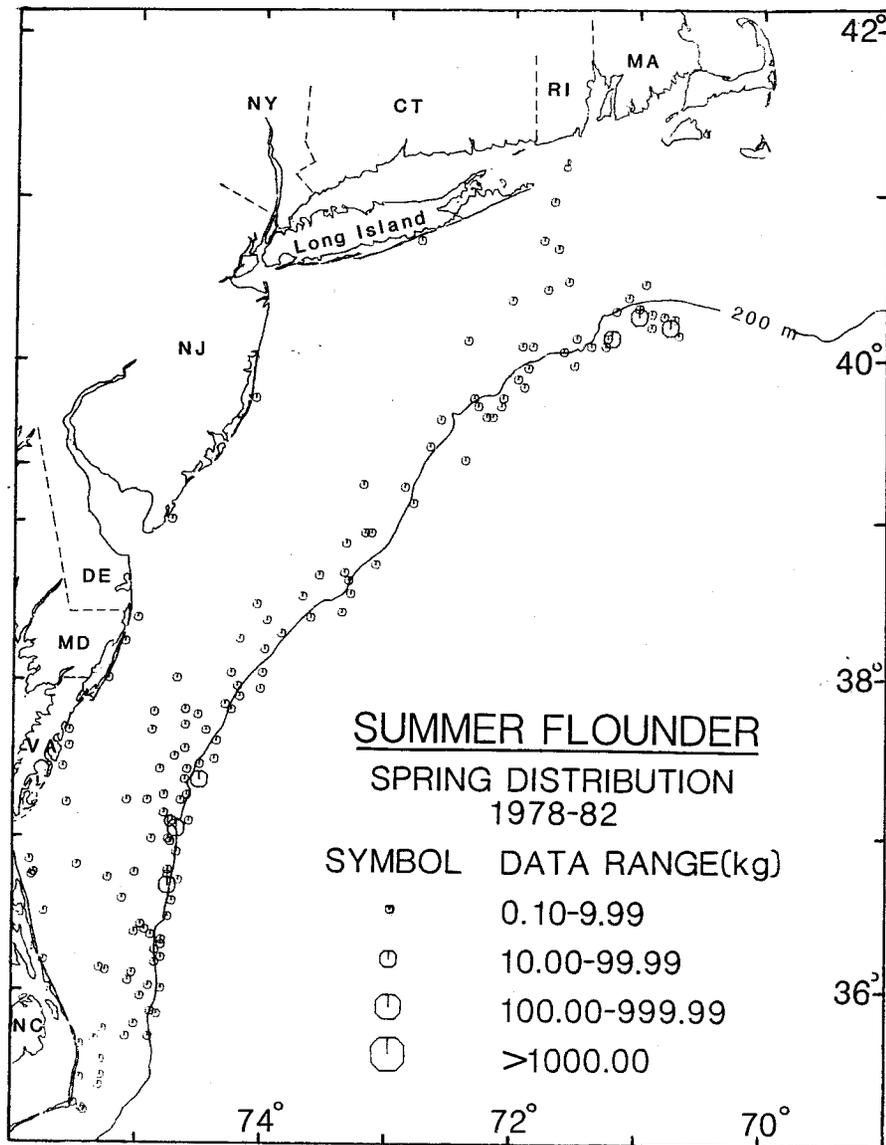


Figure 30. Summer flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

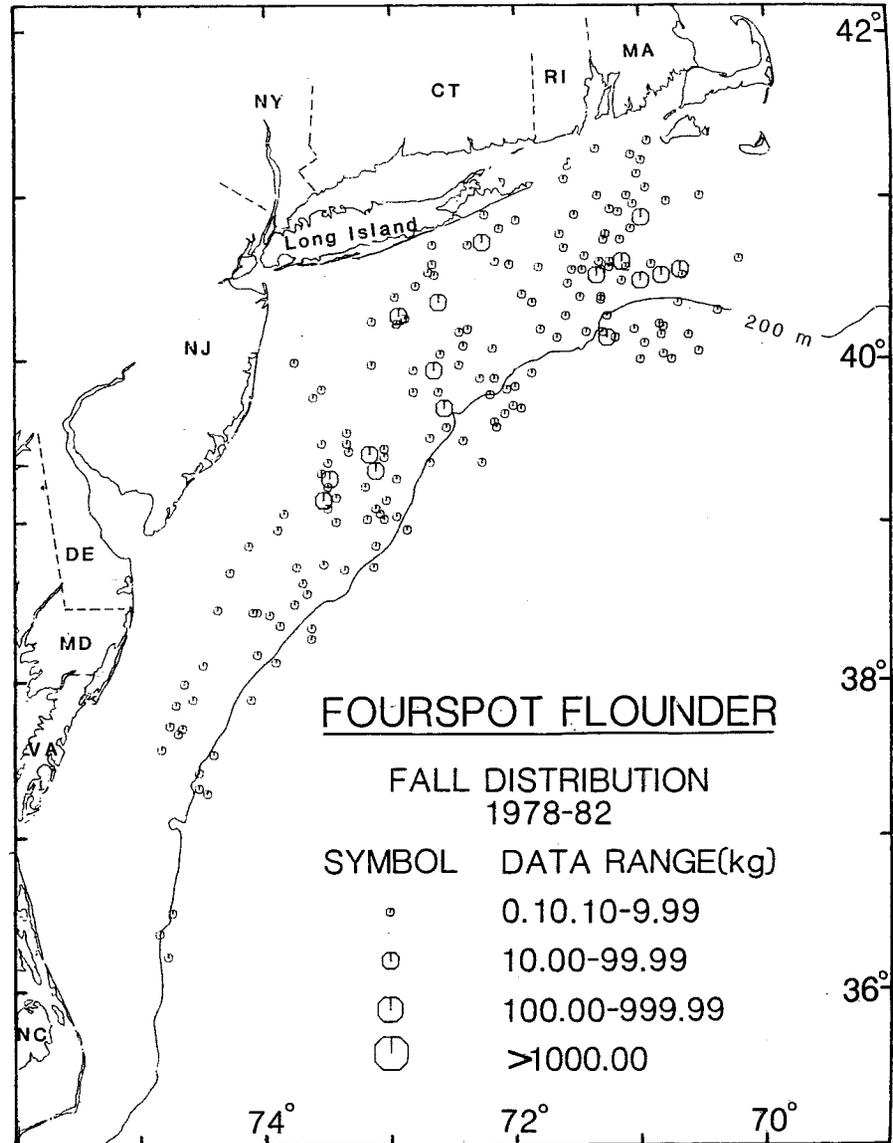
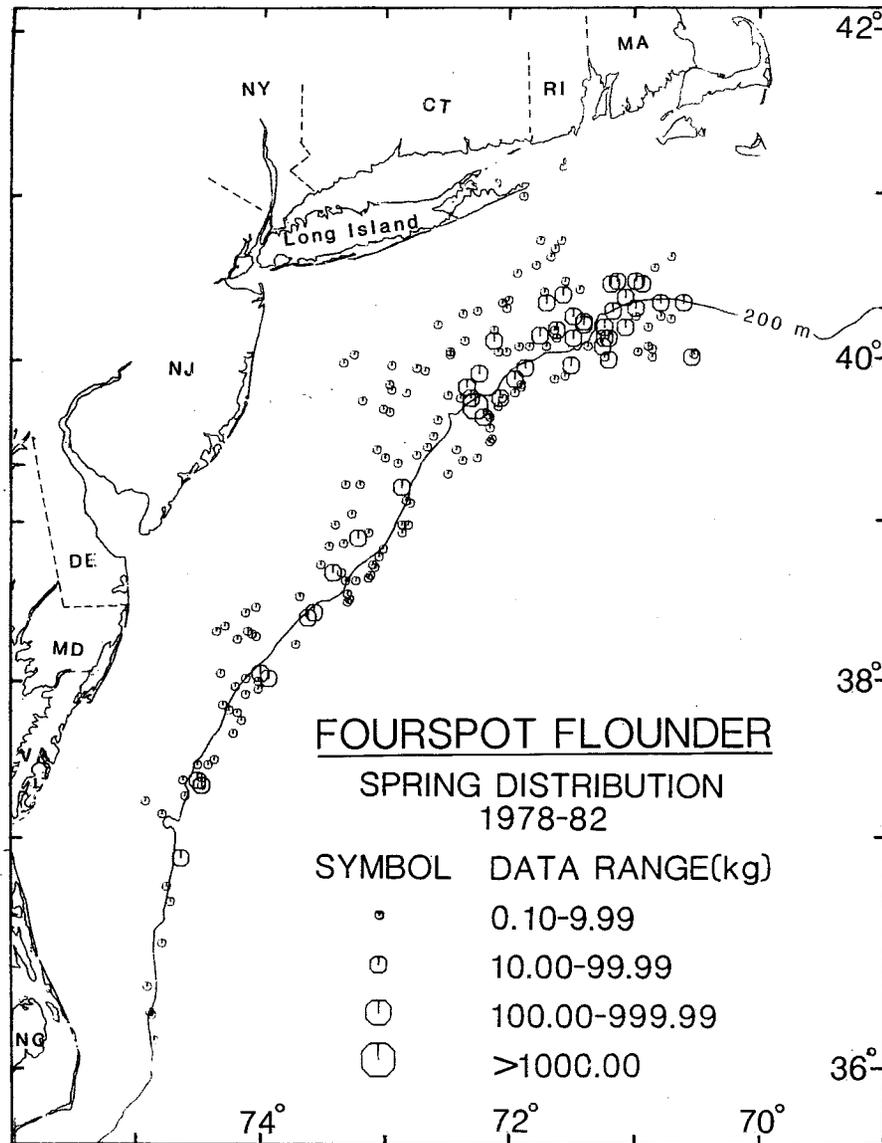


Figure 31. Fourspot flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

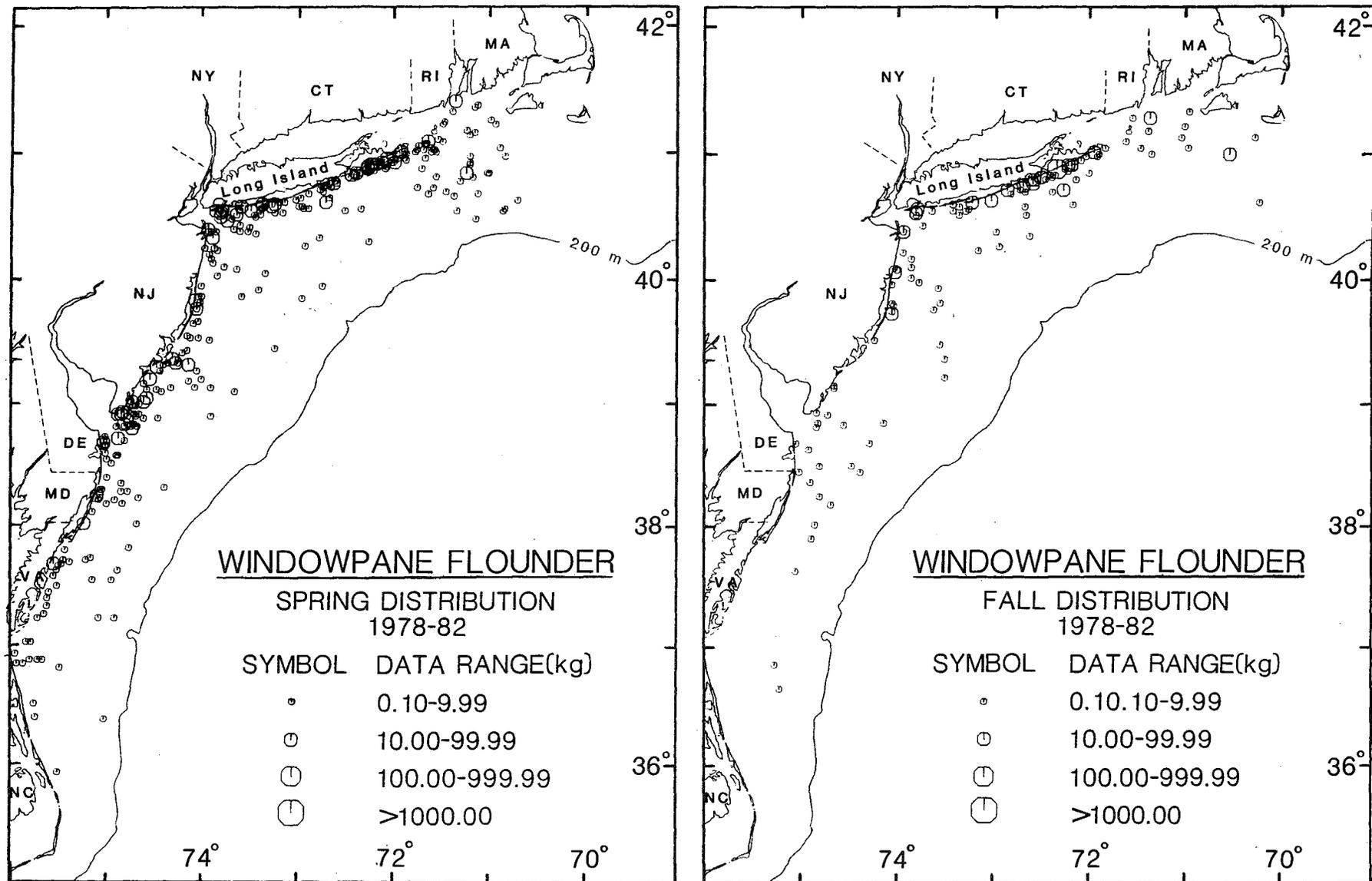


Figure 32. Windowpane flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

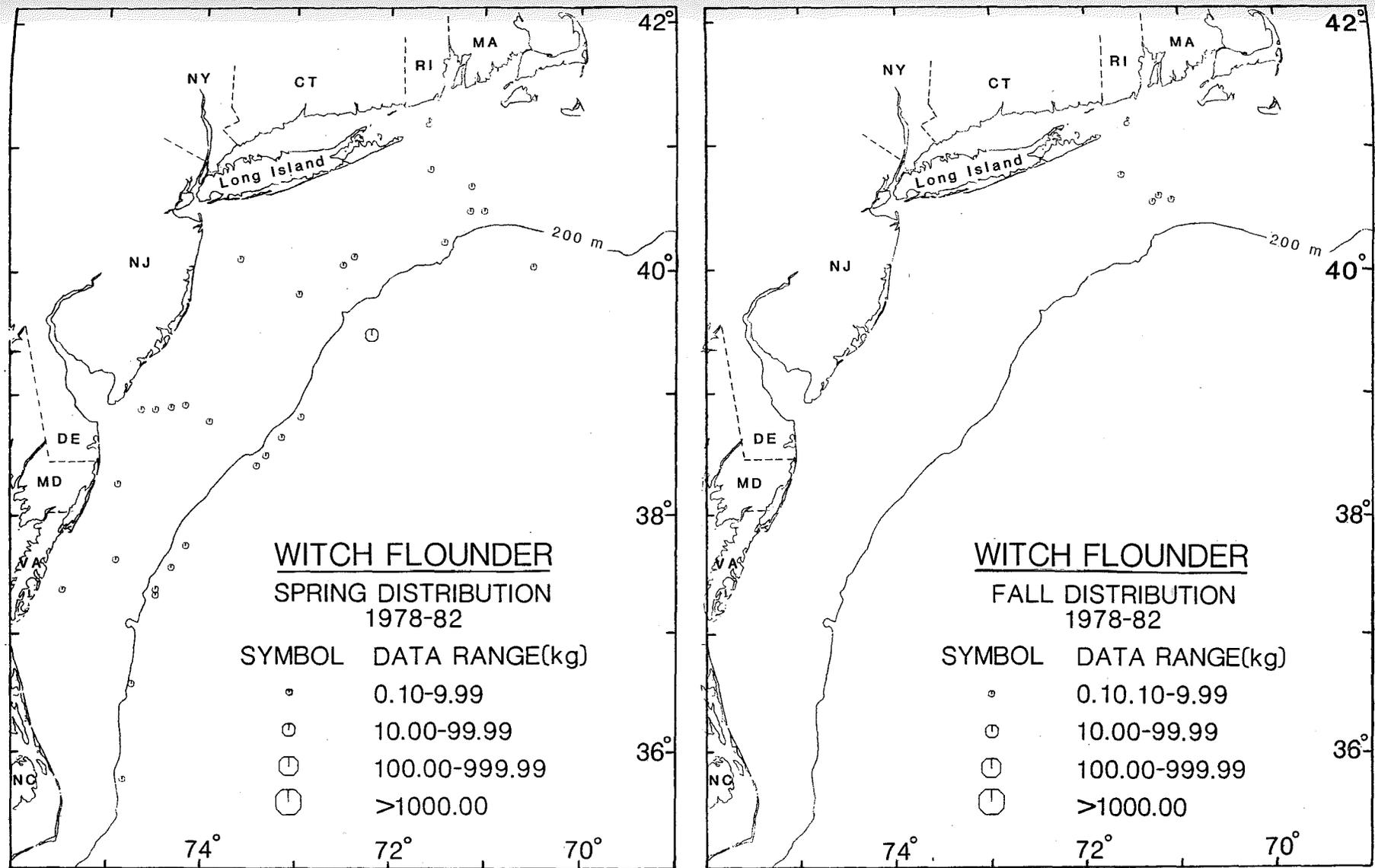


Figure 33. Witch flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

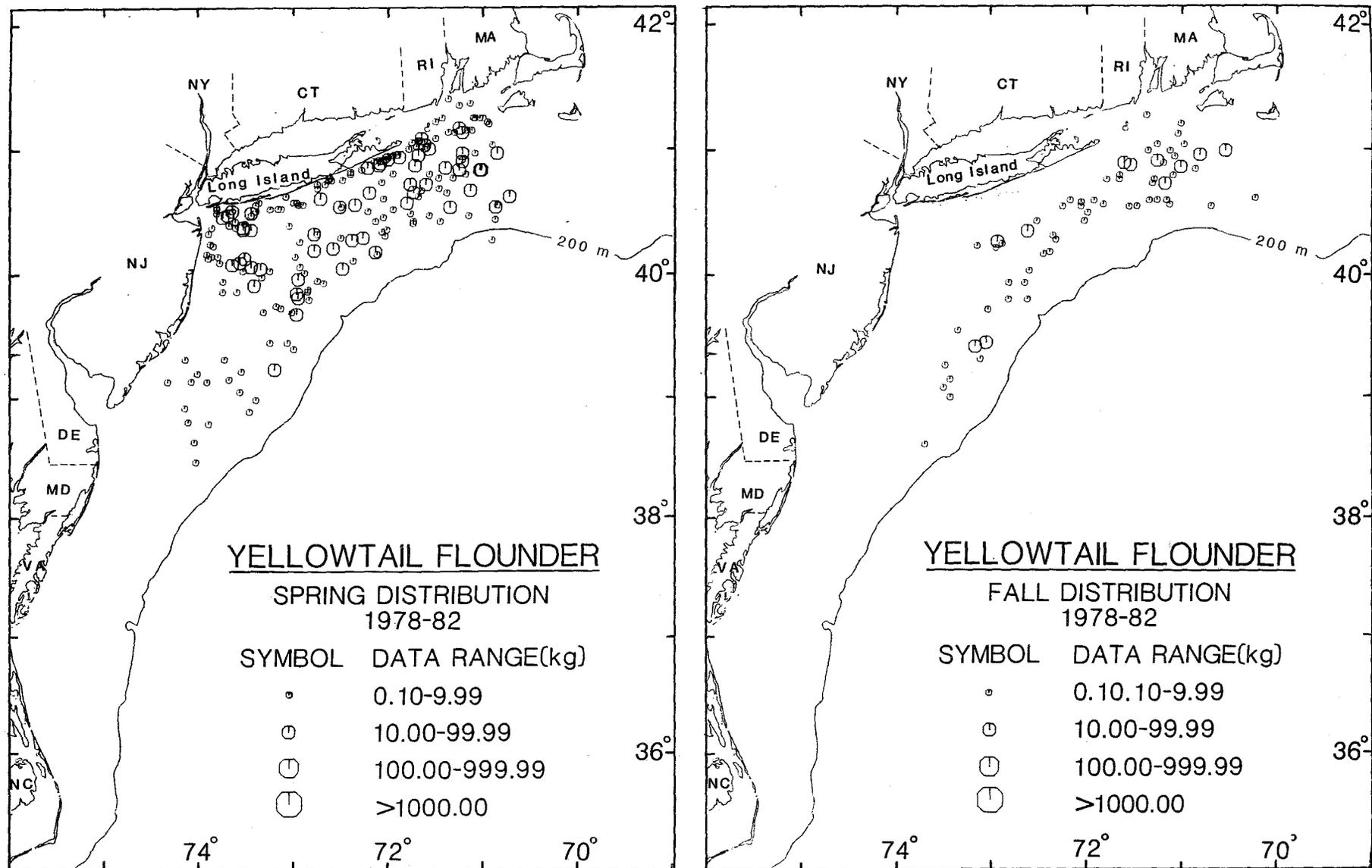


Figure 34. Yellowtail flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

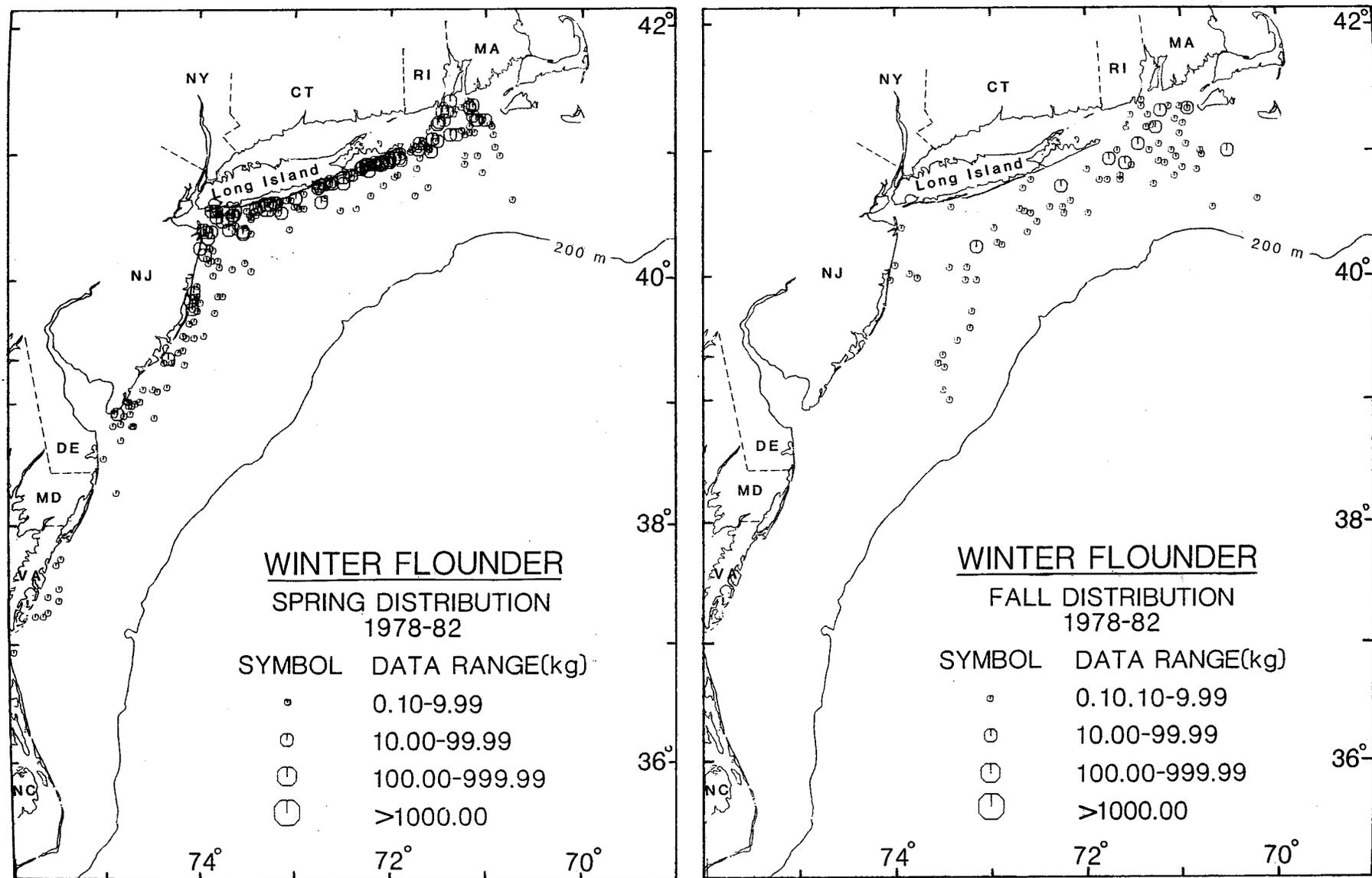


Figure 35. Winter flounder-spring and fall distribution from Northeast Fisheries Center resource cruises.

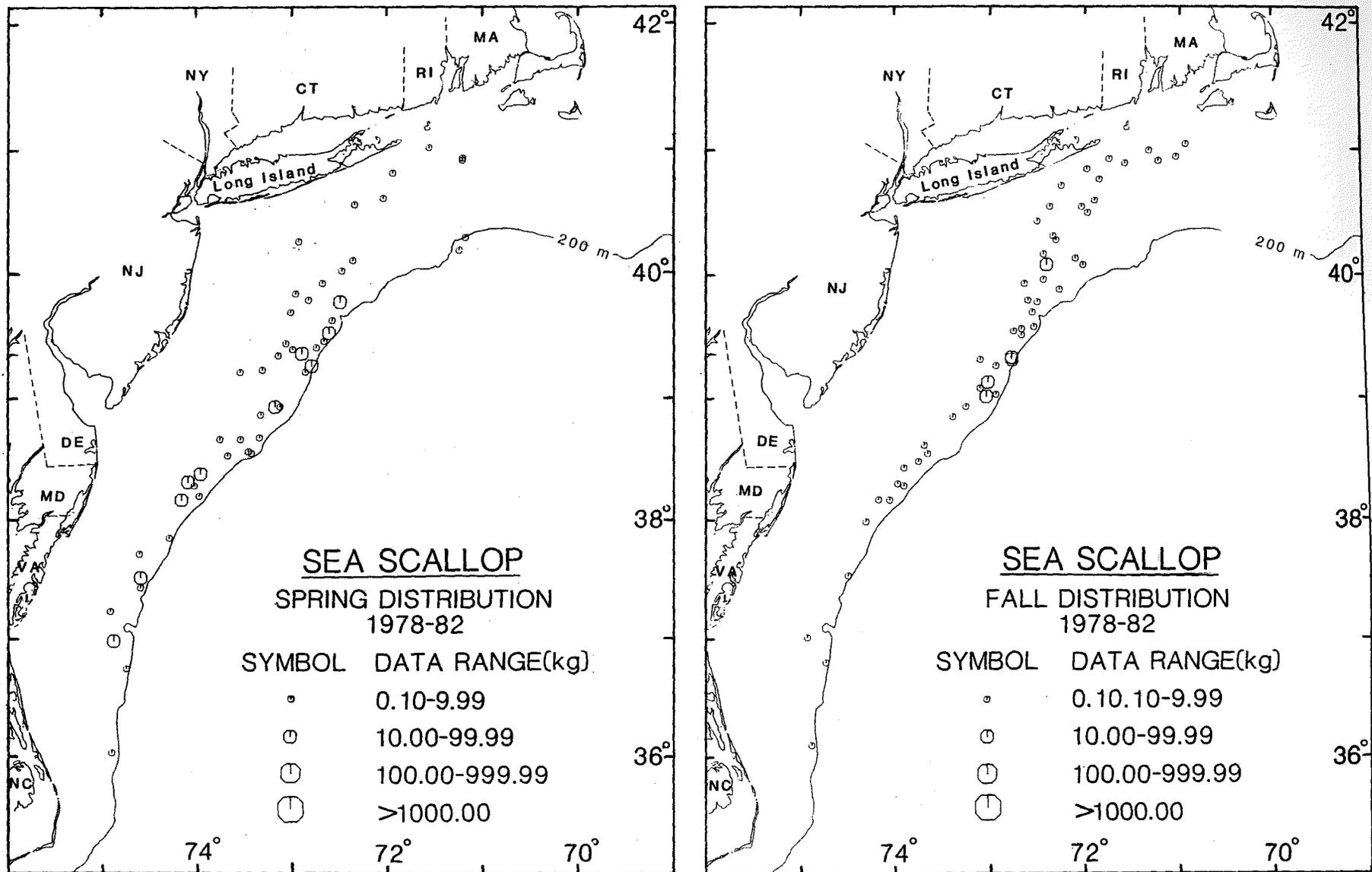


Figure 36. Sea scallop-spring and fall distribution from Northeast Fisheries Center resource cruises.

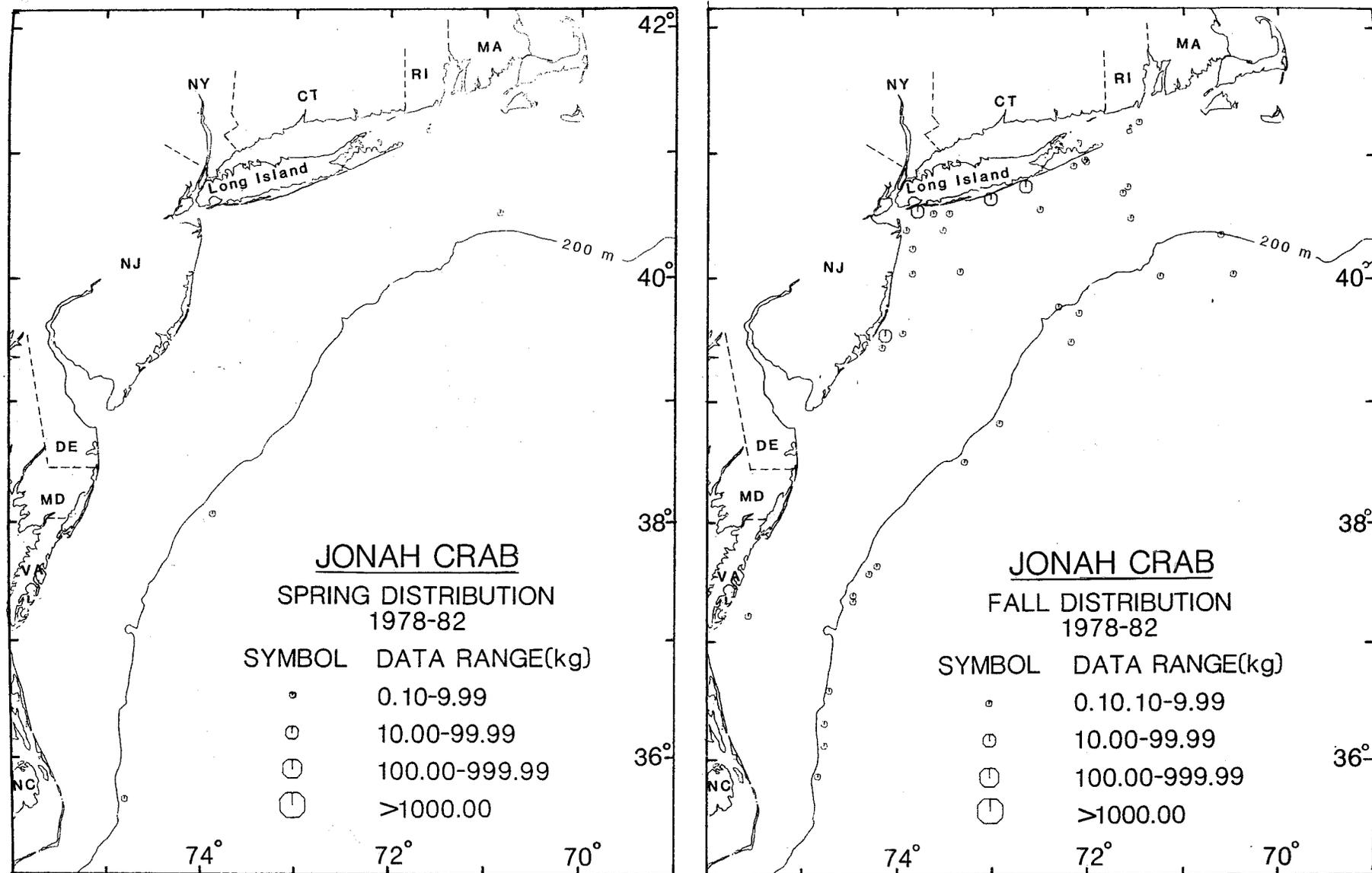


Figure 37. Jonah crab-spring and fall distribution from Northeast Fisheries Center resource cruises.

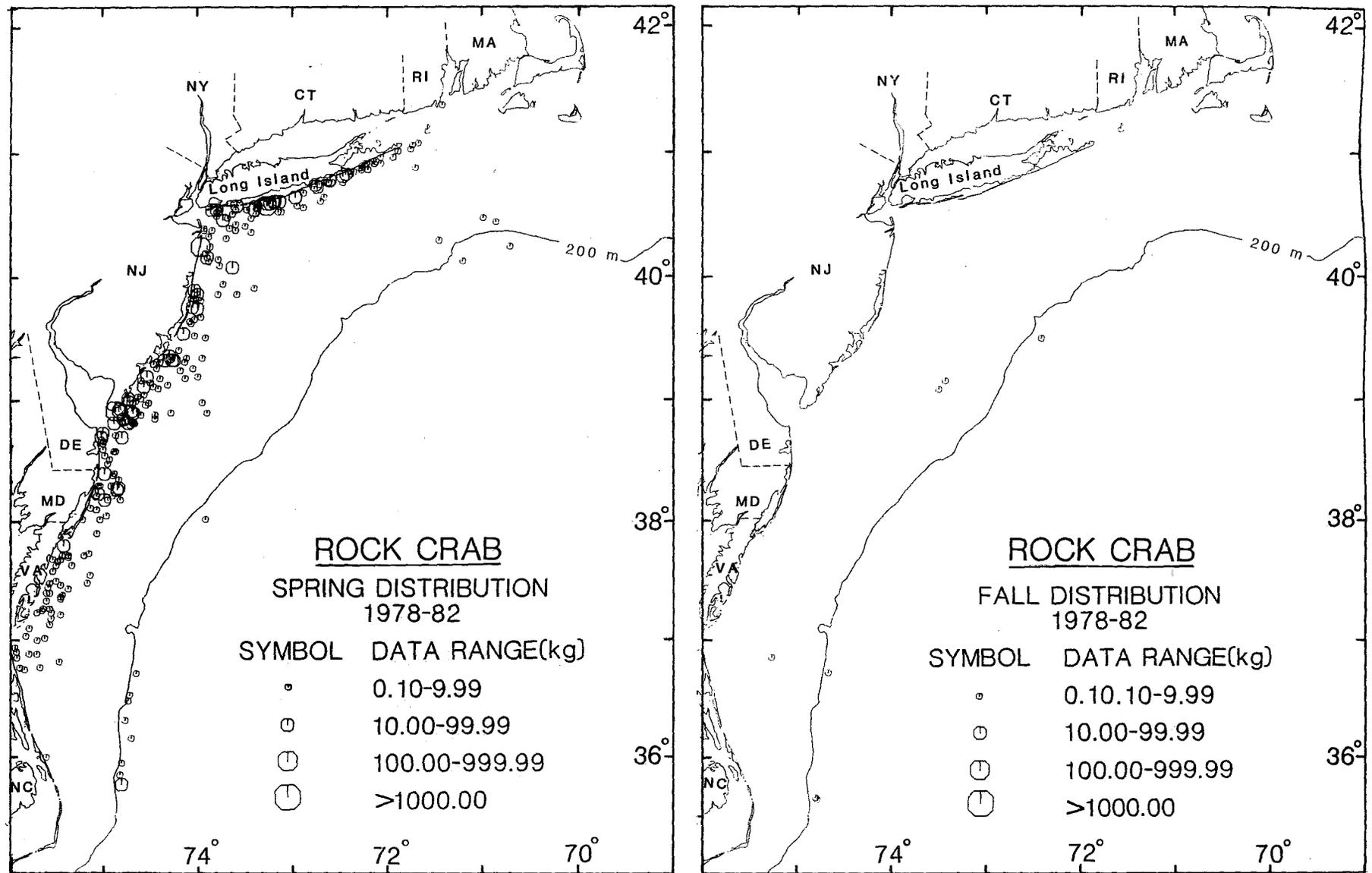


Figure 38. Rock crab-spring and fall distribution from Northeast Fisheries Center resource cruises.

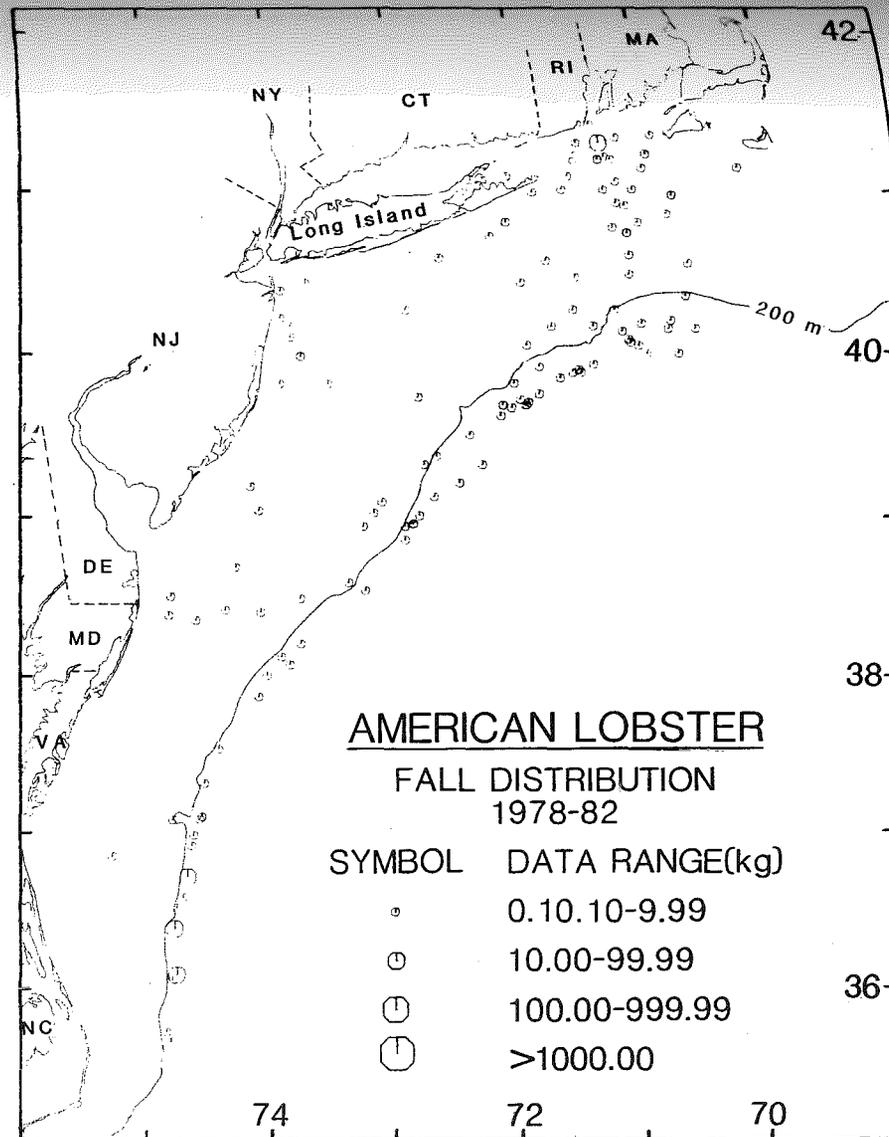
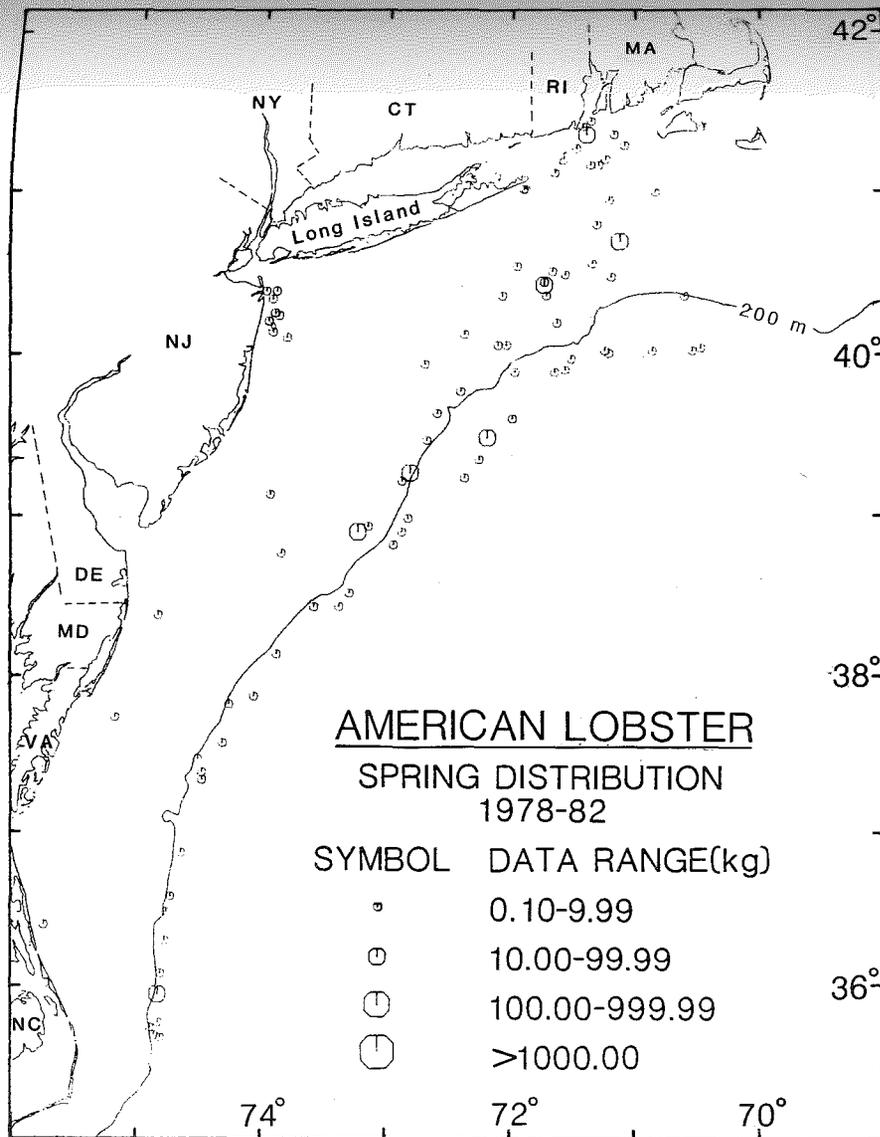


Figure 39. American lobster-spring and fall distribution from Northeast Fisheries Center resource cruises.

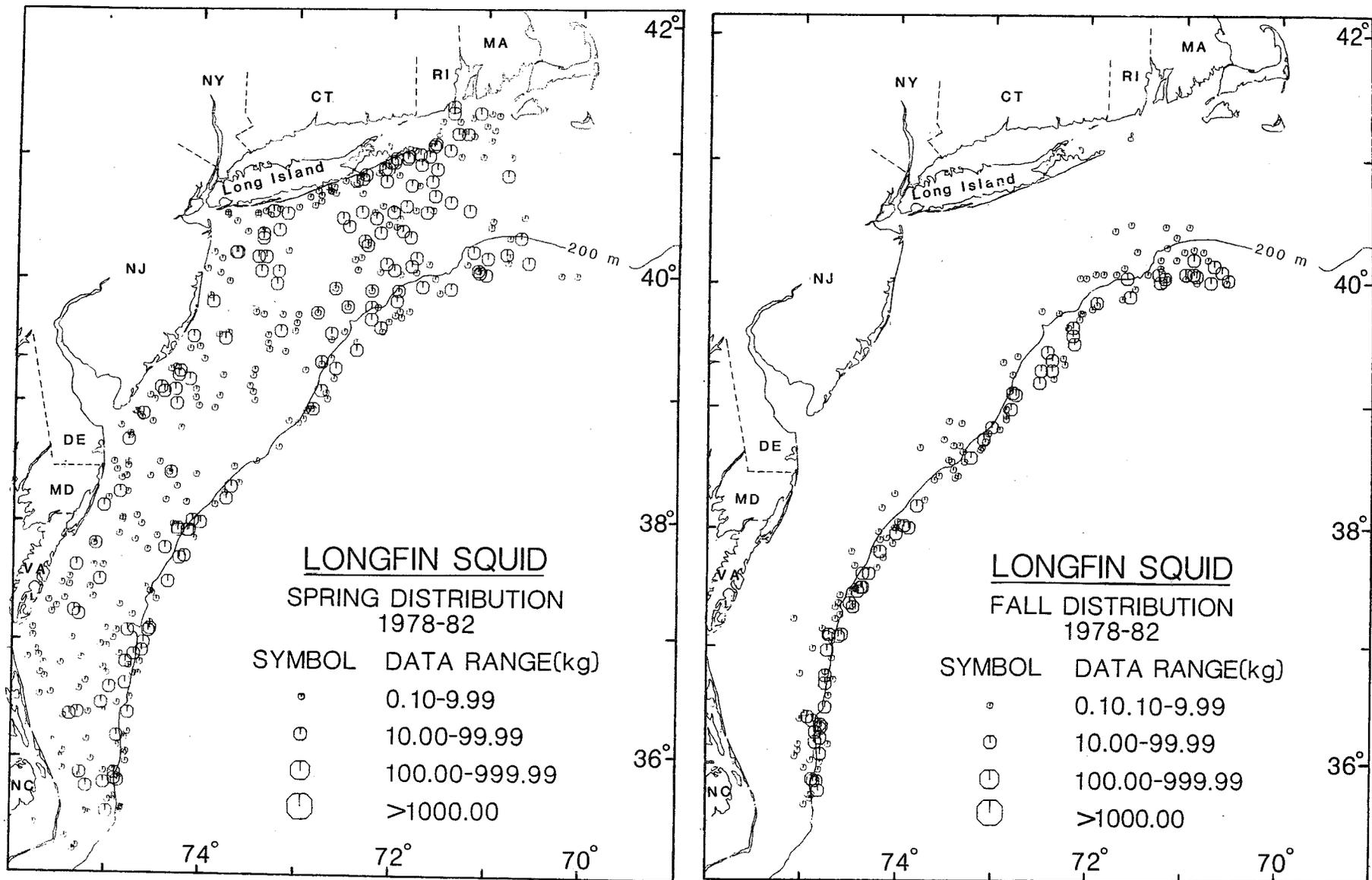


Figure 40. Longfin squid-spring and fall distribution from Northeast Fisheries Center resource cruises.

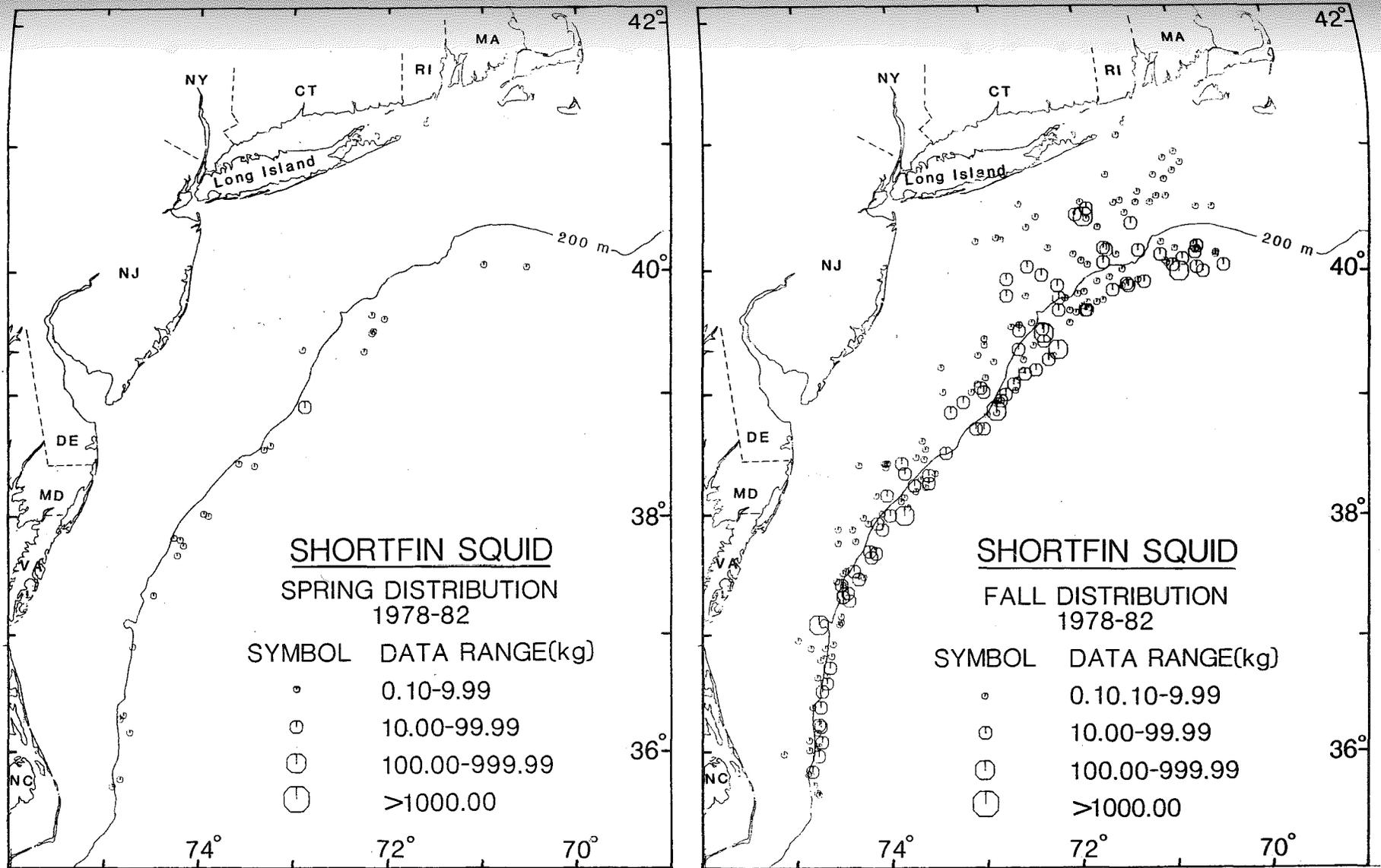


Figure 41. Shortfin squid-spring and fall distribution from Northeast Fisheries Center resource cruises.

## New Jersey Offshore Recreational Fishery

Although this survey deals only with the big-game fishery off New Jersey (Figure 8), it is representative of the fishery at least as far as Cape Hatteras to the south and Rhode Island to the north and east. Results of the 1981 survey include:

Participation - New Jersey's canyon fleet consisted of approximately 800 boats including 714 private, 82 charter, and four party boats; Effort - 5,473 trips were made during the 1981 season, with private boats accounting for 89% of the activity; Catch - total catch for all species was approximately 40,000 fish, with yellowtail tuna (*Thunnus albacares*) (18,200); albacore (*Thunnus alalunga*) (14,600); bigeye tuna (*Thunnus obesus*) (1,400); and white marlin (*Tetrapturus albidus*) (2,600) accounting for 92% of the total. The estimated weight of the aforementioned four species was just slightly less than two million pounds (907 mt); and Value - 800 boats made up the canyon fleet with an average length of 36 feet and a value of slightly greater than \$90 thousand. Therefore, value of the entire fleet was estimated at \$73 million. In addition, boat owners participating in this fishery spent approximately \$11.1 million during 1981 for the following: boats and boating equipment, \$4.6 million; boat maintenance, \$2.2 million; fishing equipment, \$0.7 million; mooring and storage, \$0.7 million; insurance, \$0.6 million; fuel, \$1.8 million; and bait, ice, and food, \$0.6 million. Table 6 summarizes the results of the offshore recreational fisheries for 1983 and includes catch statistics for 15 species by state from New York to Virginia.

The above facts and figures establish the magnitude and importance of this offshore recreational fishery and the economic impact any adverse change in distribution and/or abundance of tunas and billfishes would have on the fishery.

### Tilefish Fishery Catch and Effort

Table 7 gives tilefish (*Lopholatilus chamaeleonticeps*) catch and effort data for the years 1973 to 1981 based on information extracted from fishermen logbooks and governmental records of landings. Information given in this tabulation include: number of vessels actively fishing, the part of the year they fished, number of trips made per month, quantity of gear fished per trip, quantity of gear fished per year, and average catch-per-unit-of-gear. In addition, catch in weight (mt) is given on a yearly basis, for both the longline and total fishery.

It should be apparent from these data, that since 1978 this fishery has undergone dramatic changes as illustrated by an all but doubling of fishing effort (total "tubs"), a 50% decline in catch-per-unit-effort (CPUE), and a relatively constant harvest (longline landings). The combined simultaneous occurrence of increased effort, decreased CPUE, and stable yield over time are usually indicative of stock decline; therefore, it would be safe to assume that the tilefish stock is now under some type of stress (i.e., excessive fishing pressure).

Table 6. Species statistics from the offshore recreational fishery survey, 1983.

Species	NEW YORK				NEW JERSEY				DELAWARE				MARYLAND				VIRGINIA			
	# Caught	Avg. Catch Per Trip	Weight of* Total Catch	Avg. Weight	# Caught	Avg. Catch Per Trip	Weight of* Total Catch	Avg. Weight	# Caught	Avg. Catch Per Trip	Weight of* Total Catch	Avg. Weight	# Caught	Avg. Catch Per Trip	Weight of* Total Catch	Avg. Weight	# Caught	Avg. Catch Per Trip	Weight of* Total Catch	Avg. Weight
Yellowfin	5,675	0.07	305	53.7	3,861	0.70	195	50.5	1,318	1.14	61	46.3	1,488	0.74	69	46.4	3,755	0.81	151	40.2
Bigeye	2,806	0.04	450	160.4	1,514	0.28	257	169.8	76	0.07	13	171.1	19	0.009	4	210.5	78	0.02	4	51.3
Albacore	8,079	0.10	278	34.4	11,255	2.05	415	36.9	649	0.56	24	37.0	420	0.21	20	47.6	48	0.01	2	41.7
Bluefin	6,814	0.09	-	-	1,037	0.19	-	-	41	0.04	-	-	5	0.003	-	-	4,904	1.06	-	-
White marlin	693	0.009	33	47.6	1,605	0.3	78	48.6	301	0.26	15	49.8	693	0.34	33	47.6	1,839	0.40	87	47.3
Blue marlin	16	0.0002	6	375.0	116	0.02	50	431.0	6	0.005	2	333.3	15	0.007	8	533.3	123	0.03	32	260.2
Swordfish	63	0.0008	10	158.7	23	0.004	3	130.4	-	-	-	-	6	0.003	1	166.7	-	-	-	-
Skipjack	295	0.004	-	-	1,919	0.35	-	-	437	0.38	-	-	139	0.07	-	-	781	0.17	-	-
Dolphin	119	0.002	1	8.4	2,204	0.40	15	6.8	257	0.22	3	11.7	751	0.37	13	17.3	3,236	0.70	39	12.1
Mahoe	16	0.0002	<1	<62.5	100	0.02	3	30.0	56	0.05	2	35.7	109	0.05	5	45.9	919	0.20	29	31.6
King mackerel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,339	0.29	16	12.0
Mako	300	0.004	-	-	59	0.0007	-	-	23	0.02	-	-	48	0.02	-	-	15	0.003	-	-
Blue shark	122	0.002	-	-	86	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hammerhead	140	0.002	-	-	73	0.01	-	-	-	-	-	-	-	-	-	-	13	0.003	-	-
Other sharks	822	0.01	-	-	39	0.007	-	-	196	0.17	-	-	25	0.01	-	-	-	-	-	-

Table 7. Tilefish statistics -- New York and New Jersey (source: Turner, Grimes and Able)

	<u>Trips</u>		<u>Tubs</u>		<u>% of Total Tubs Fished by N.J. Vessels</u>	<u>Mean Number of Trips Per Month N.J.(N.Y.)</u>		<u>Mean Number of Tubs Per Trip N.J.(N.Y.)</u>	
	<u>Known</u>	<u>Total</u>	<u>Known</u>	<u>Total</u>					
1973	10	135	132	1,782	100	3.3		13.2	
1974	18	143	264	2,102	100	3.3		14.7	
1975	103	209	1,912	8,320	100	3.85		39.8	
1976	111	248	2,805	9,943	90	3.45		40.1	
1977	168	329	4,065	17,845	86	3.18		54.9	
1978	414	509	8,295	34,513	78	3.0 <sup>(1)</sup>	(1.89)	67.4	
1979	519	664	13,342	49,322	70	2.75 <sup>(1)</sup>	(2.7)	77.3(68.1)	
1980	557	630	10,740	59,365	68	1.9 <sup>(1)</sup>	(2.9)	98.4(85.1)	
1981	168	453	14,820	50,687	63	2.0(2.45)		116.1(107.4)	

(1) Number of trips was known for N.J. in 1978-1980 so mean number of trips per month for N.J. was not used.

	<u>Catch</u>	<u>Effort</u>	<u>Catch Rate</u>	<u>Trips</u>	<u>Tubs</u>
1973	319	1,782			
1974	376	2,102	143.6	12	144
1975	424	8,320	125.5	16	475
1976	922	9,943	114.9	50	1,600
1977	1,699	17,845	110.1	55	2,778
1978	3,065	34,513	110.9	56	3,209
1979	3,387	49,322	78.9	51	3,601
1980	3,481	59,365	59.5	58	3,463
1981	3,190	50,687	44.7	60	5,182

## New Jersey Fishing Grounds

This source of information was reduced to 16 charts (Figures 42-57) which delineate fishing grounds for 34 resource species or species groups based on a one-year survey of actively involved fishermen. In addition each chart gives the seasonality of each fishery, or fishery complex as well as its location in the MAB. The charts illustrate the ocean fishing grounds for the following: Atlantic mackerel, Atlantic cod, and pollock (Figure 42); tilefish (Figure 43); summer flounder (Figure 44); scup (Figure 45); black sea bass (Figure 46); butterfish and yellowtail flounder (Figure 47); silver and red hakes (Figure 48); yellowfin tuna, albacore, bigeye tuna, and bluefish (Figure 49); false albacore, bonito, and skipjack (Figure 50); white and blue marlin (Figure 51); swordfish (Figure 52); sharks and striped bass (Figure 53); ocean quahog and surf clam (Figure 54); American lobster and red crab (Figure 55); sea scallop (Figure 56); and shortfin and longfin squids (Figure 57).

If one extrapolates from the data presented in previous sections of this paper (e.g., commercial landings and value, recreational landings and value (big-game), and the distribution and abundance of important species), the information illustrated in the above 16 charts become quite relevant in terms of describing the fish and fishery resources of the MAB.

## Foreign Landings and Value

Results of our tabulations, although limited in scope (i.e., 1978-1983), are given in Table 8. Combined data for "fishing windows" 1-4 have been summarized in the aforementioned table and include: 1) individual species catch in thousands of pounds per "fishing window" per year, and 2) total species catch in thousands of pounds per year for silver hake (*Merluccius bilinearis*), red hake (*Urophycis chuss*), Atlantic mackerel (*Scomber scombrus*), butterfish (*Peprilus triacanthus*), longfin squid (*Loligo pealei*) and shortfin squid (*Illex illecebrosus*), and "other finfish." This tabulation demonstrates the amount of these species within the geographic limitation of the "fishing windows" associated with the MAB. As a point of interest, in 1979 these species totaled approximately 46.5 million pounds worth greater than 8.7 million dollars. It should be obvious from these data that primarily squids and secondarily silver hake dominated the catch while butterfish commanded the highest price in the market.

These somewhat dated data illustrate the volume and value of these resources. Such information coupled with recent (1980-87) joint U.S.-foreign ventures, indicate the growing importance of these species to U.S. commercial fishing interests. Therefore, the impact of any man-induced changes upon growth potential and possible socio-economic losses must be considered in light of this relatively new fisheries concept.

## Deep-Sea Fishes

The results of a literature search are presented as discussions of pelagic and demersal deep-sea fishes which are associated with the MAB. The primary sources of information describing pelagic deep-sea fish in the vicinity of the MAB are Krueger et al. (1975 and 1977). These two studies can be summarized for the MAB as follows: 1) the pelagic fish fauna is comprised mainly of mesopelagic species which generally drift with prevailing oceanic

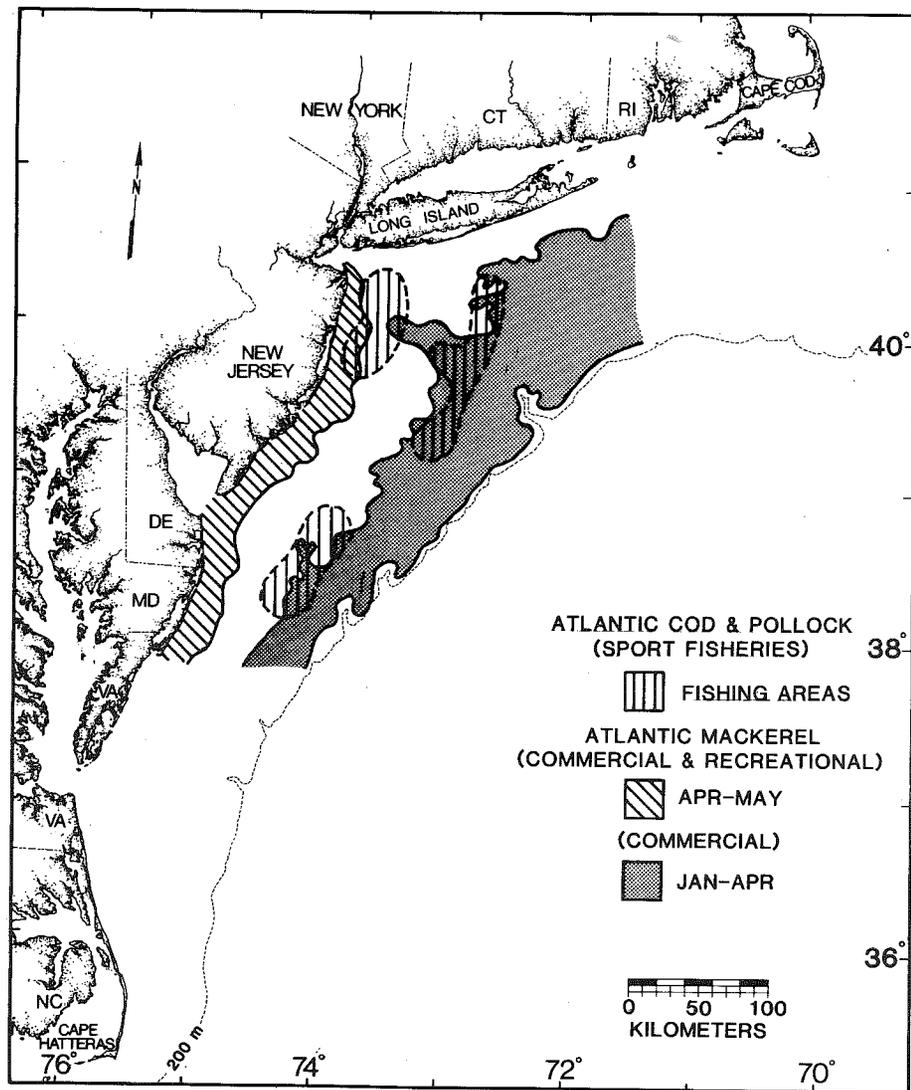


Figure 42. Fishing areas-Atlantic cod, pollock, Atlantic mackerel.

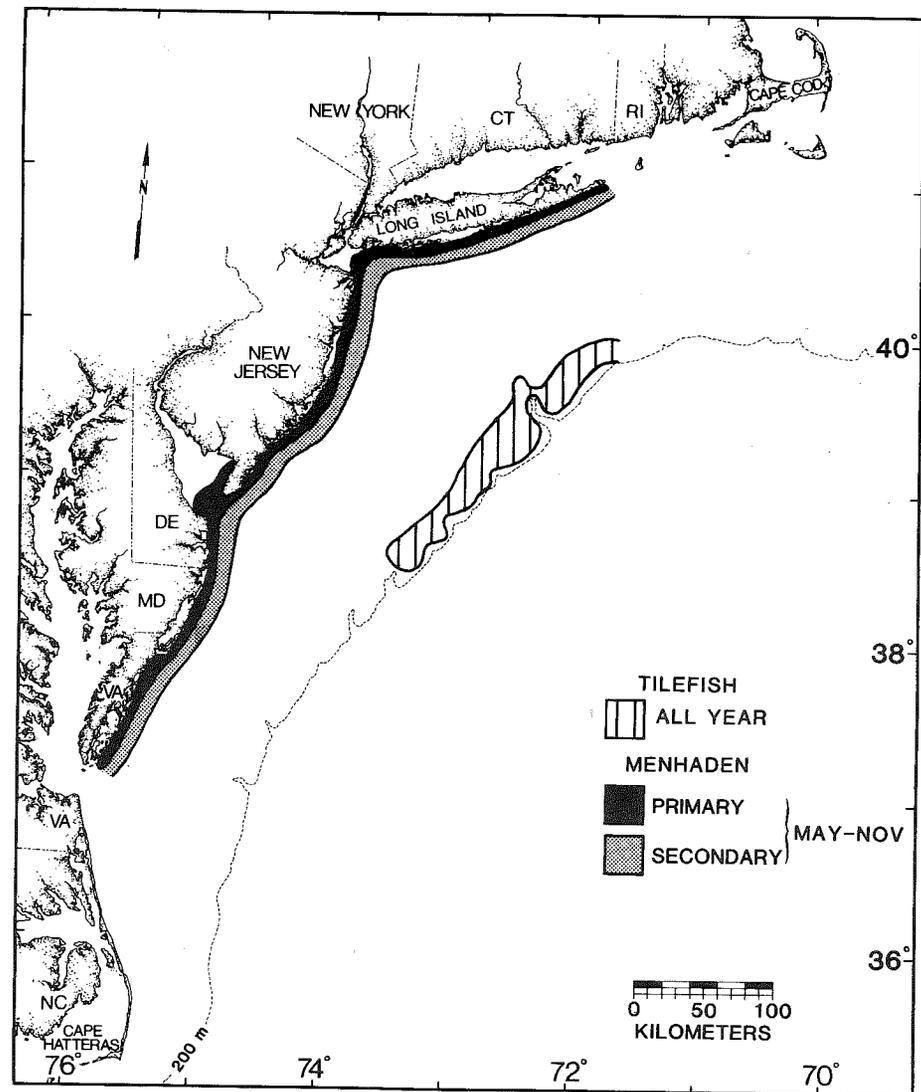


Figure 43. Fishing areas-tilefish, menhaden.

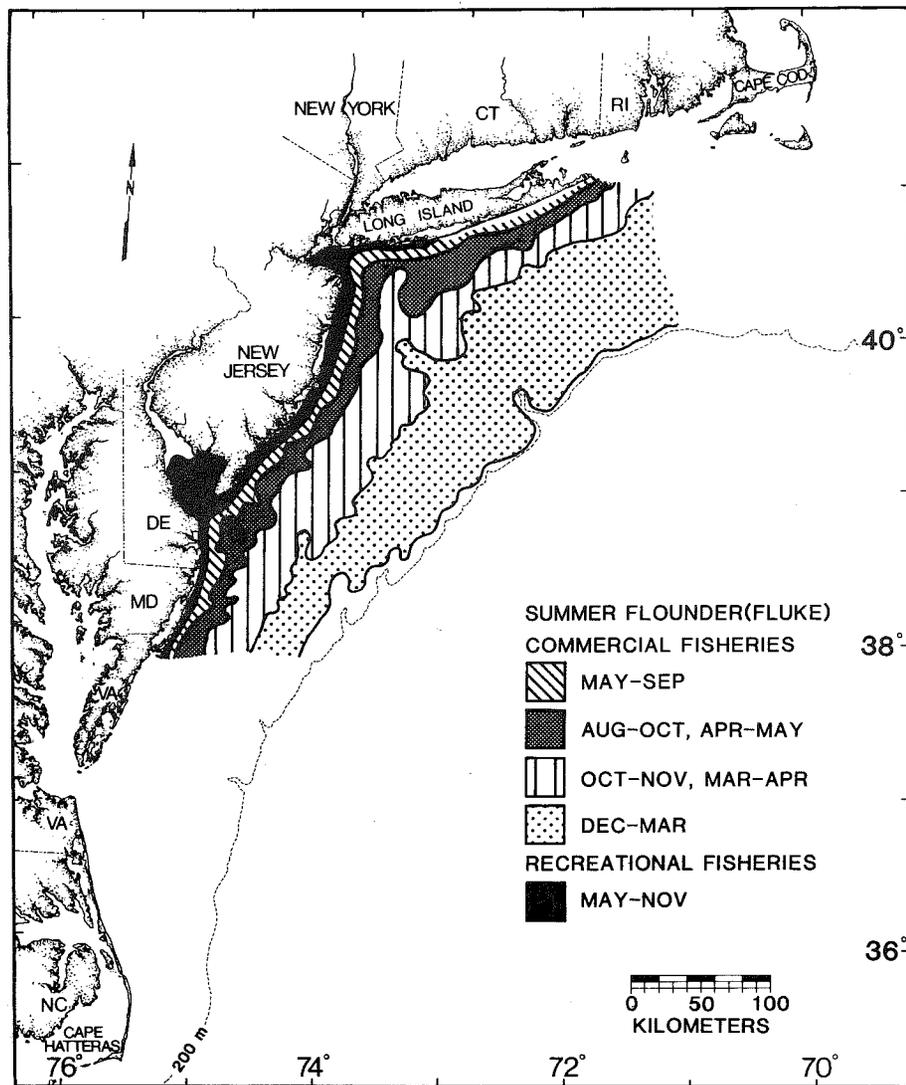


Figure 44. Fishing areas-summer flounder.

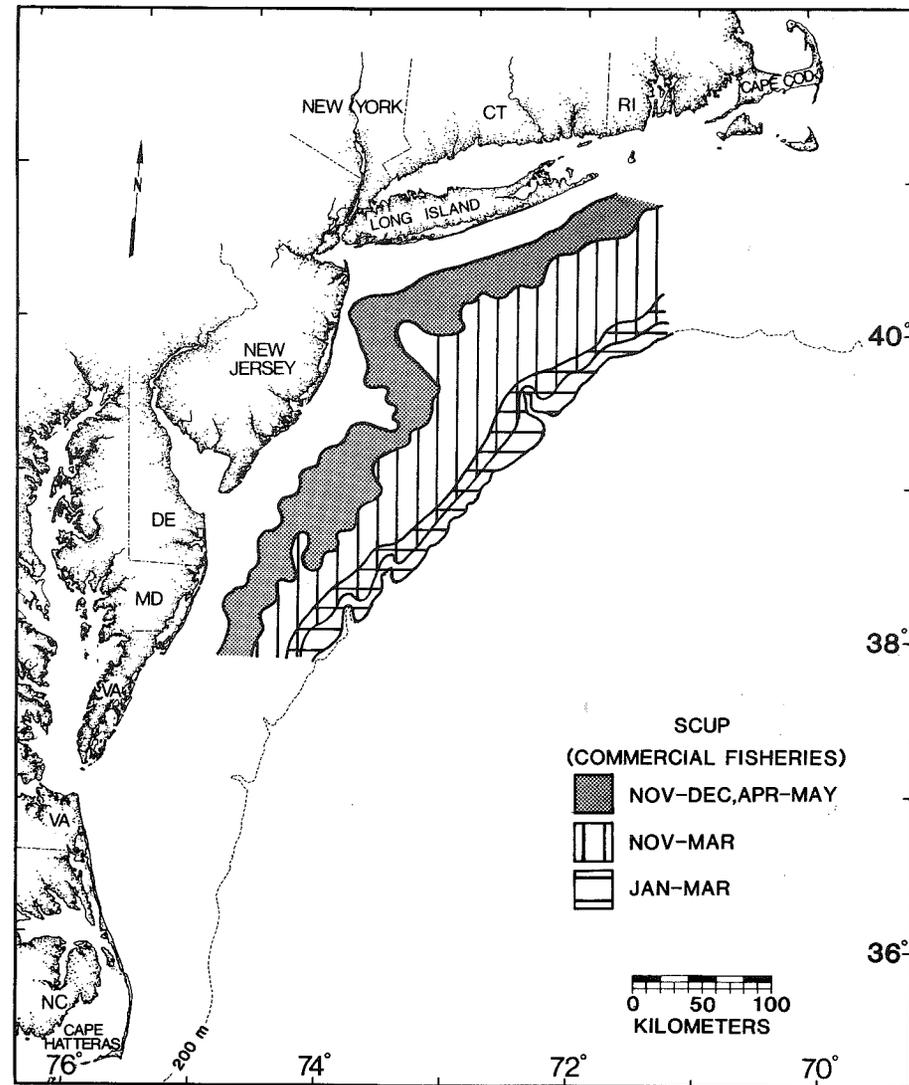


Figure 45. Fishing areas-scup.

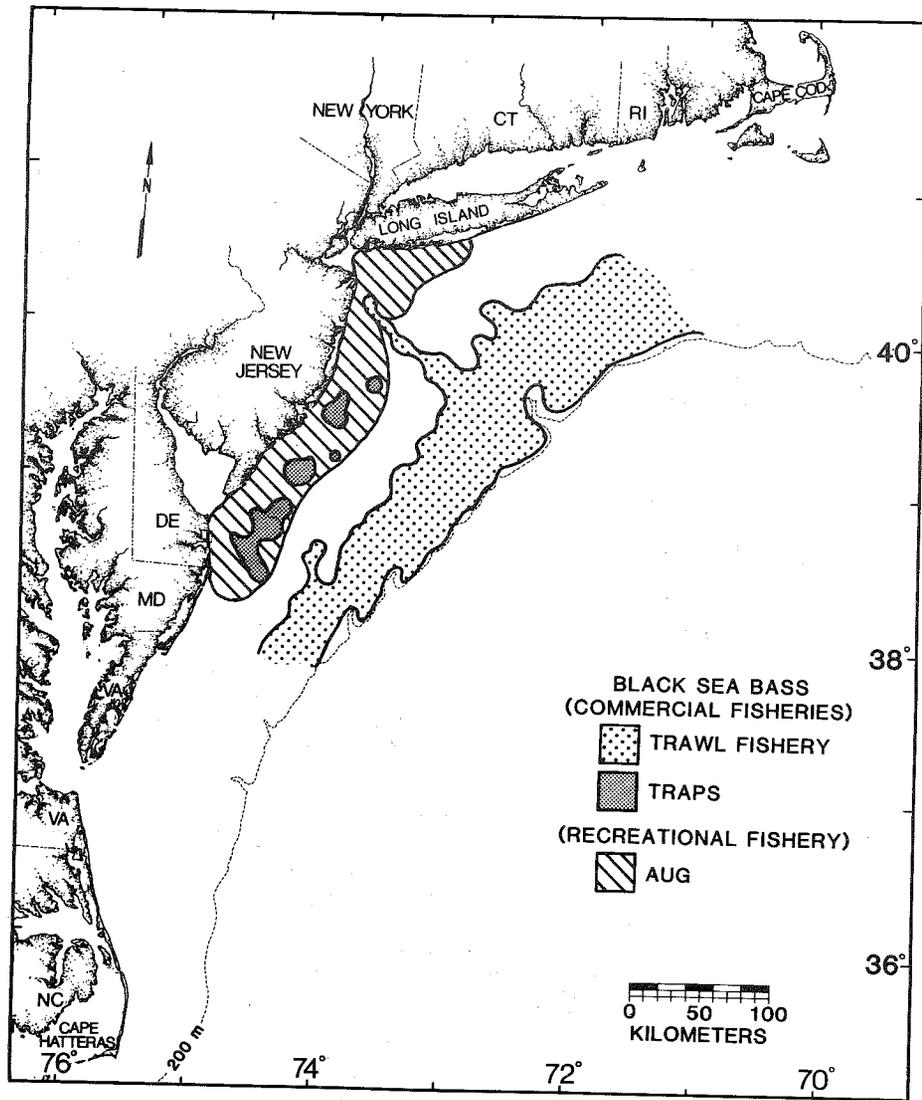


Figure 46. Fishing areas-black sea bass.

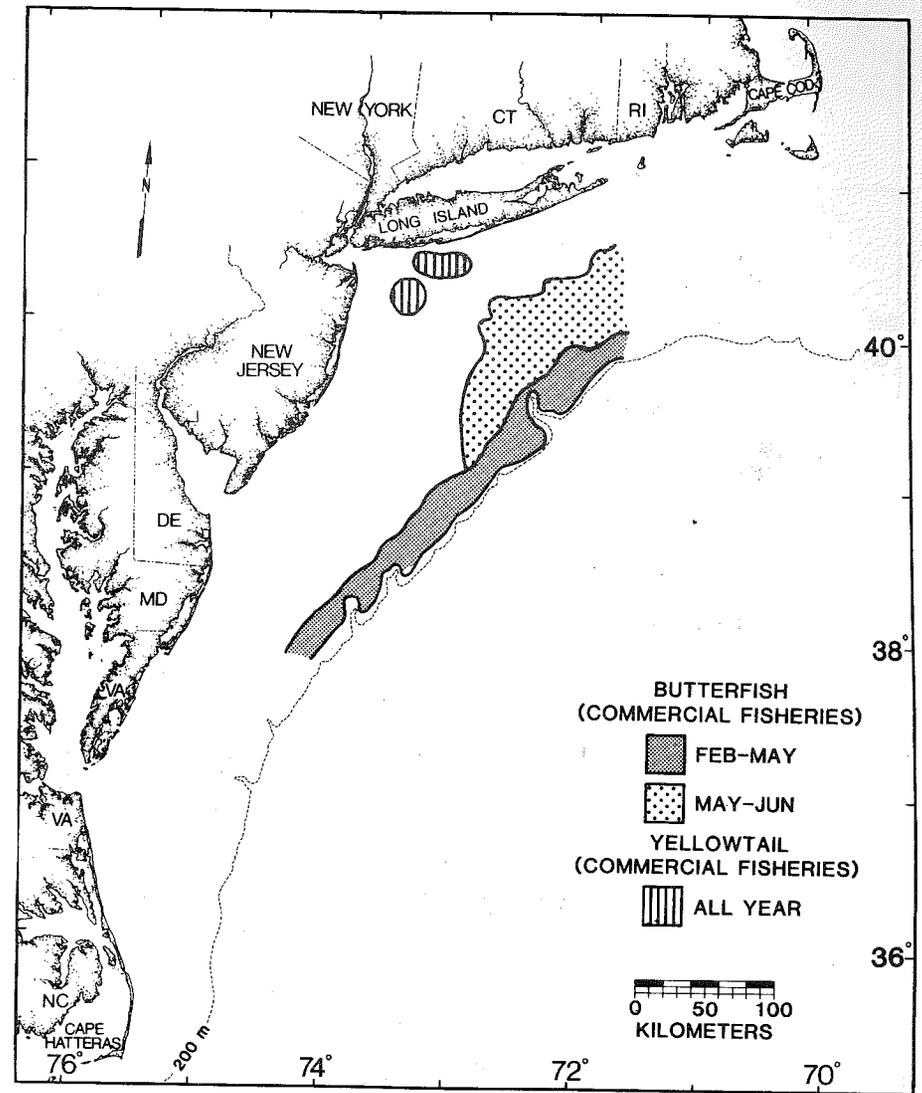


Figure 47. Fishing areas-butterfish and yellowtail flounder.

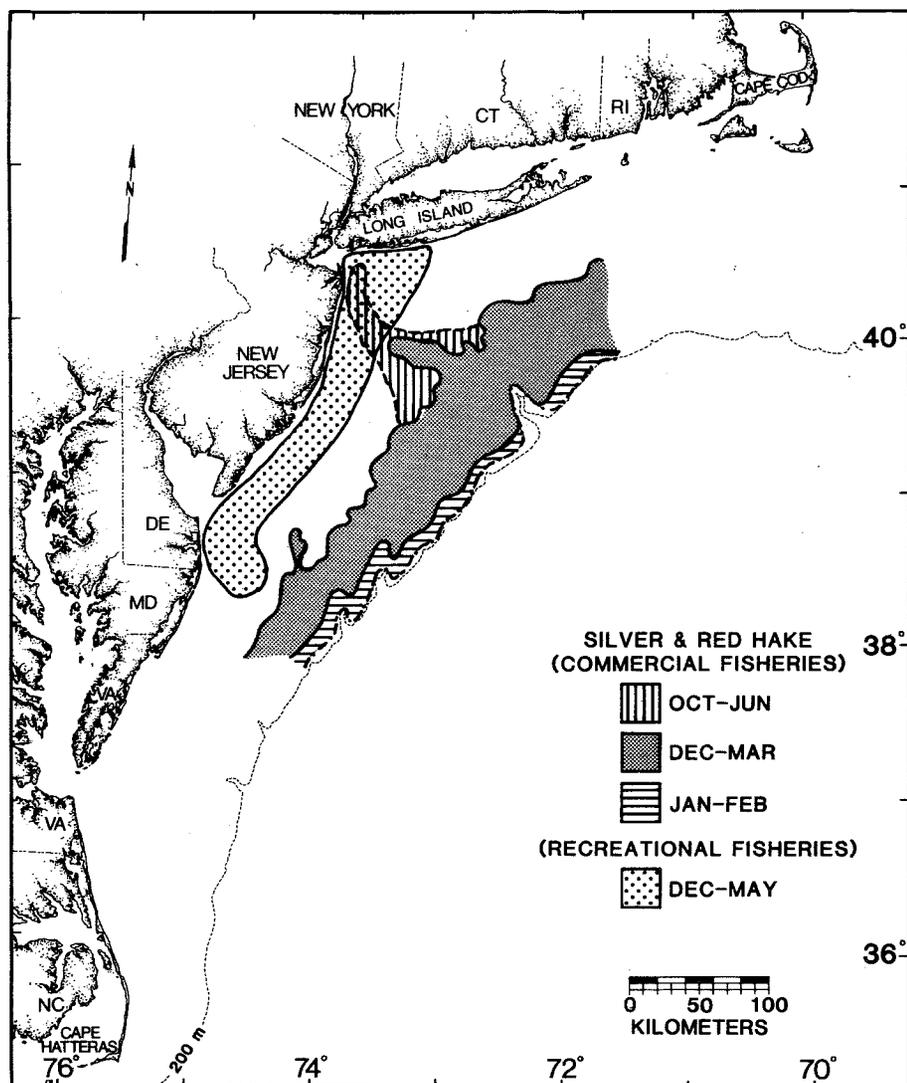


Figure 48. Fishing areas-silver and red hake.

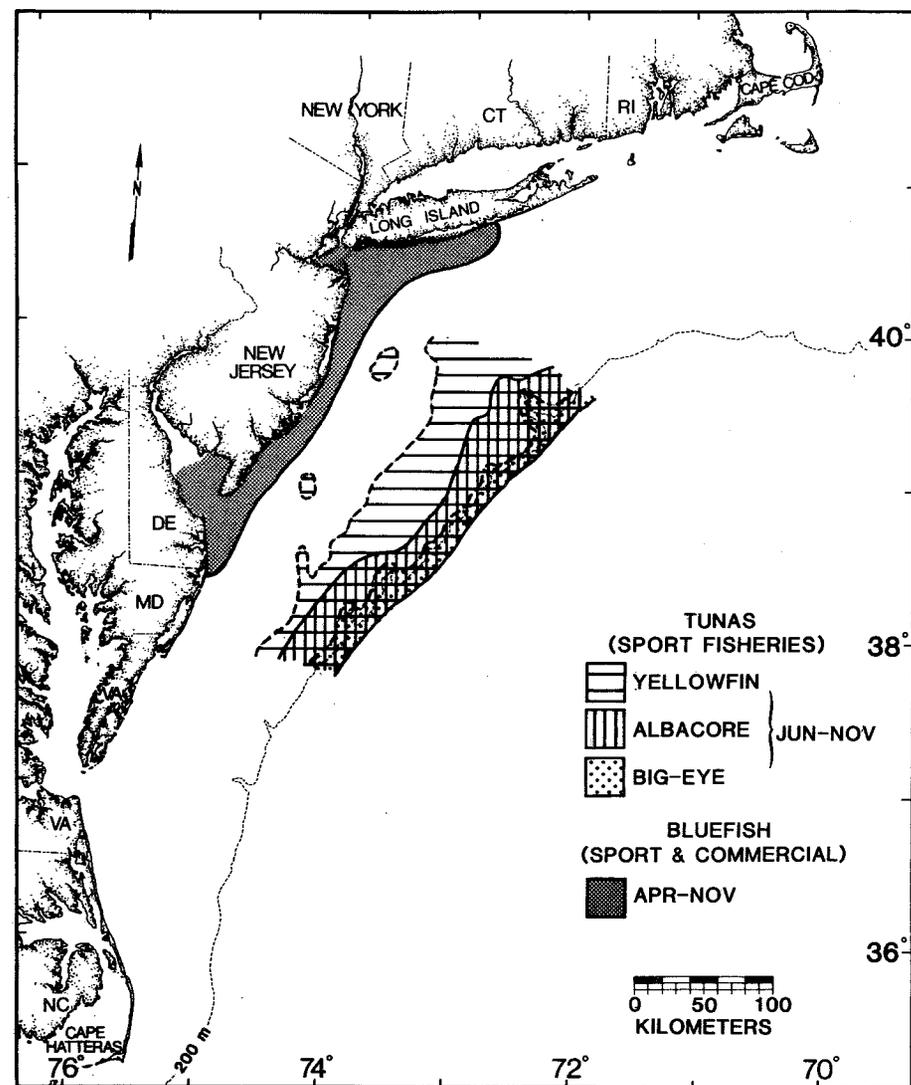


Figure 49. Fishing areas-tunas and bluefish.

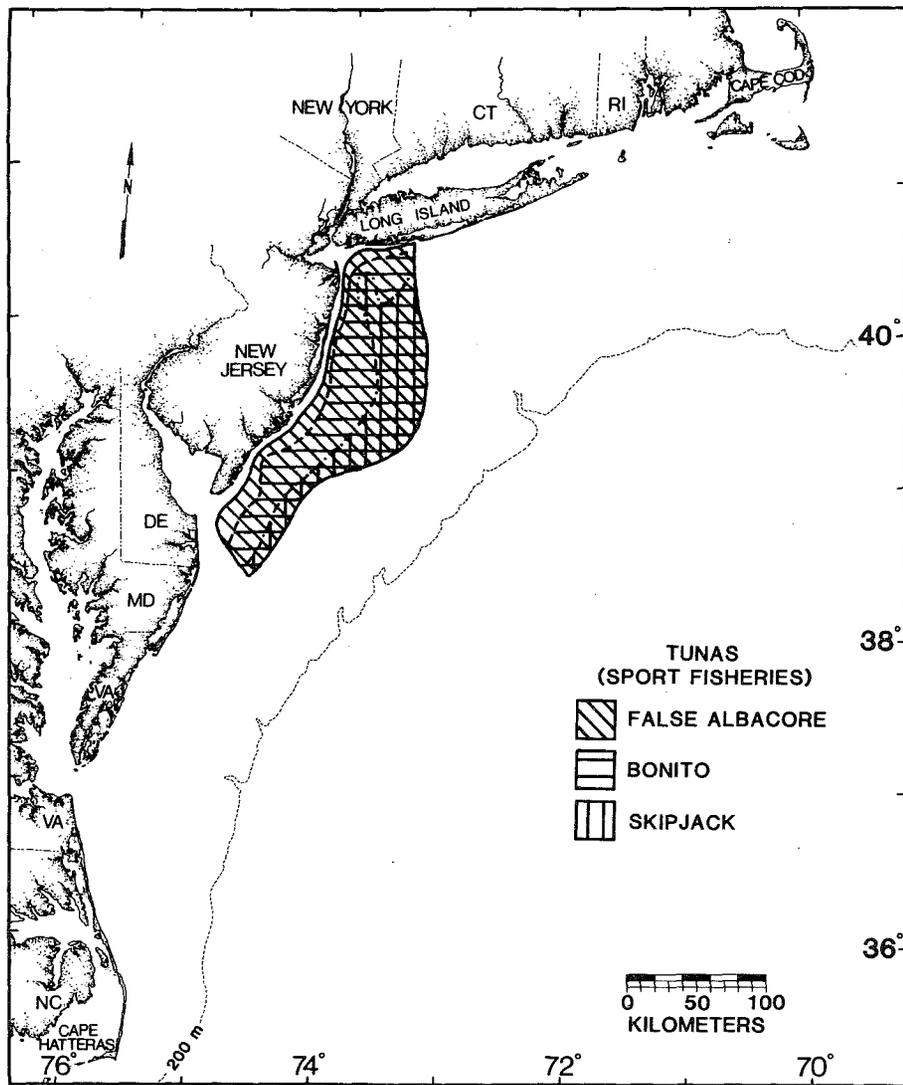


Figure 50. Fishing areas-tunas.

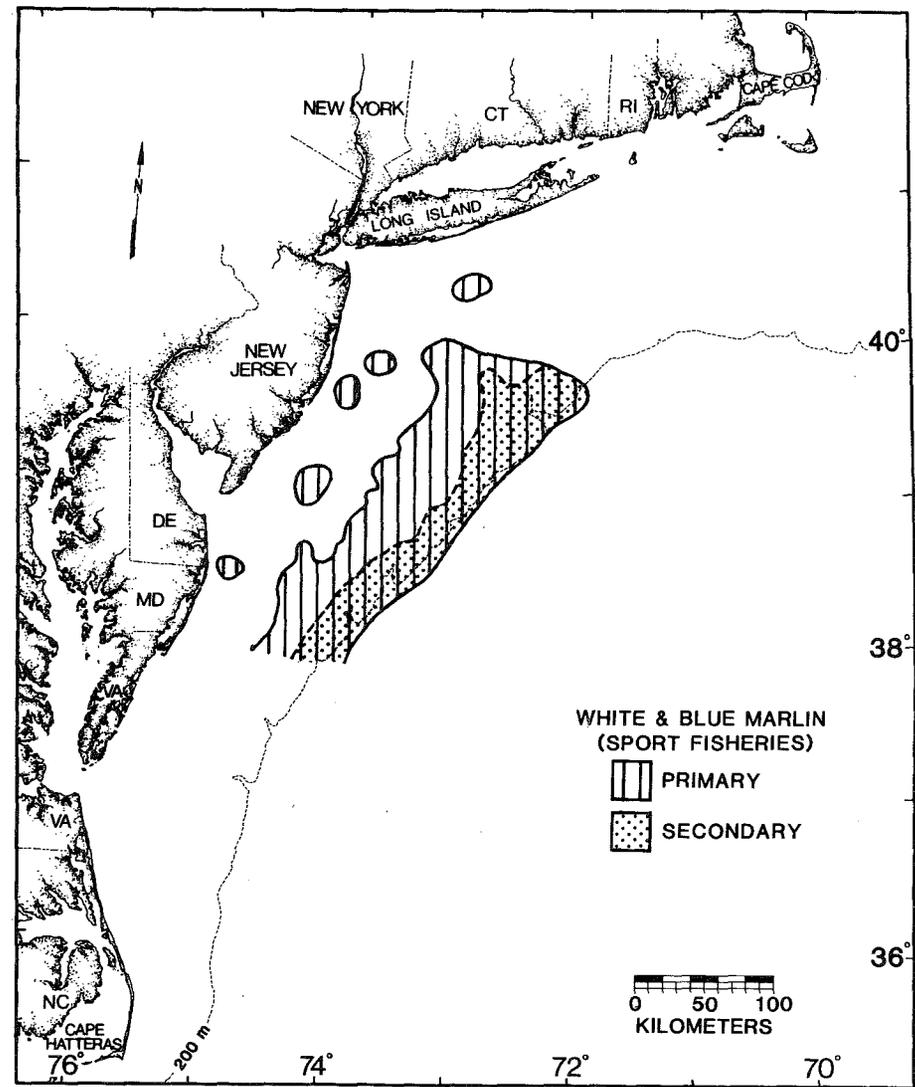


Figure 51. Fishing areas-white and blue marlin.

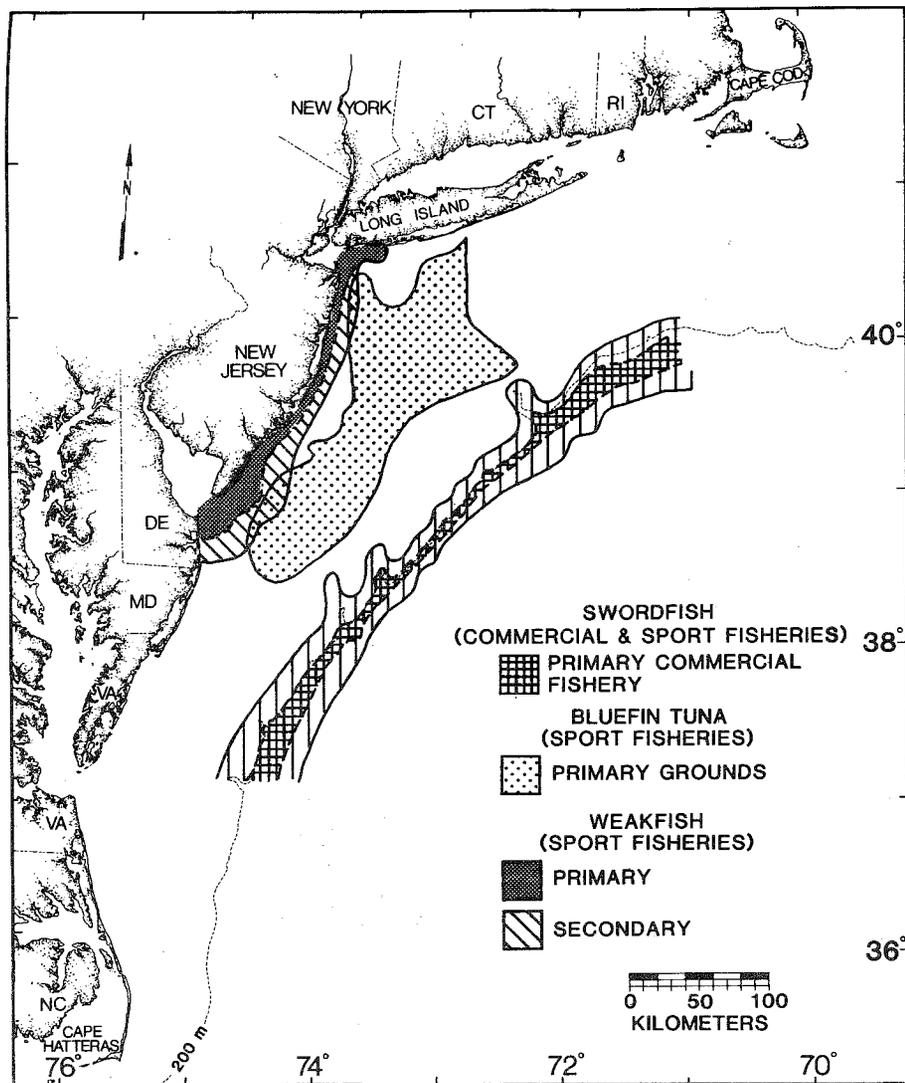


Figure 52. Fishing areas-swordfish, bluefin tuna and weakfish.

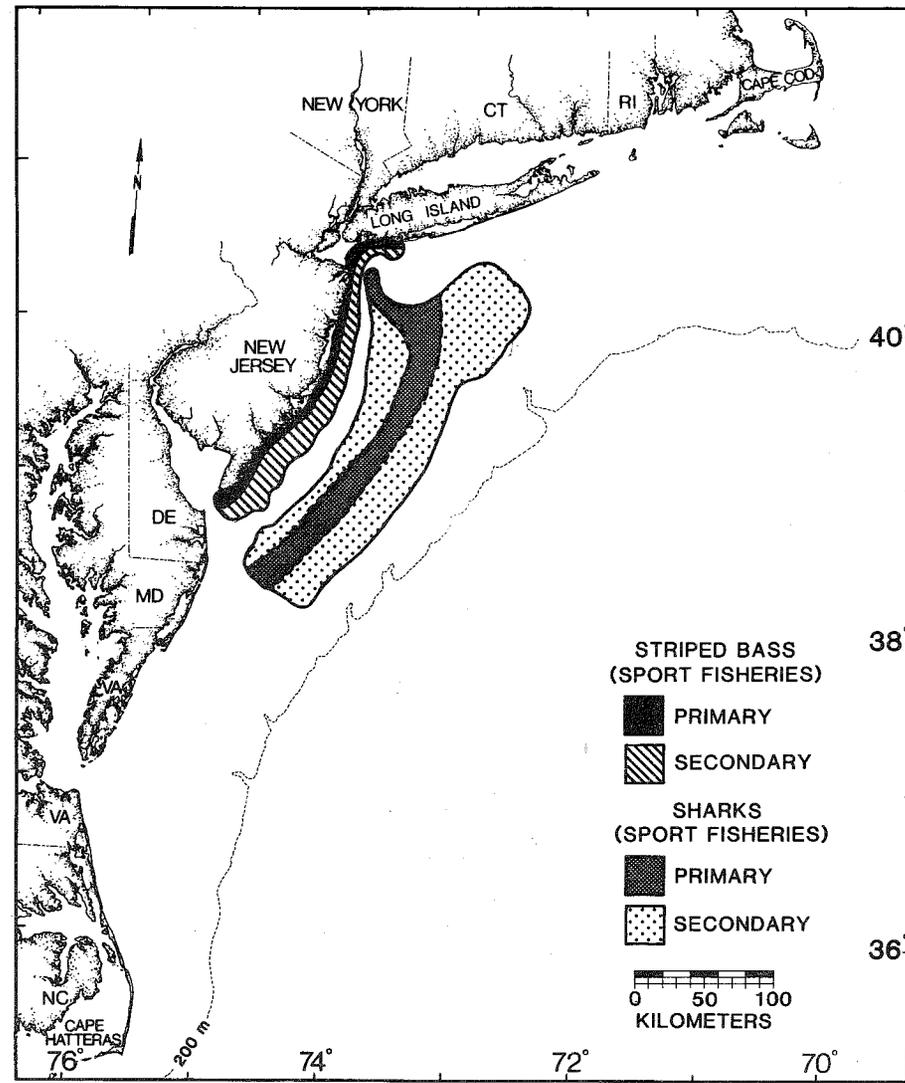


Figure 53. Fishing areas-striped bass and sharks.

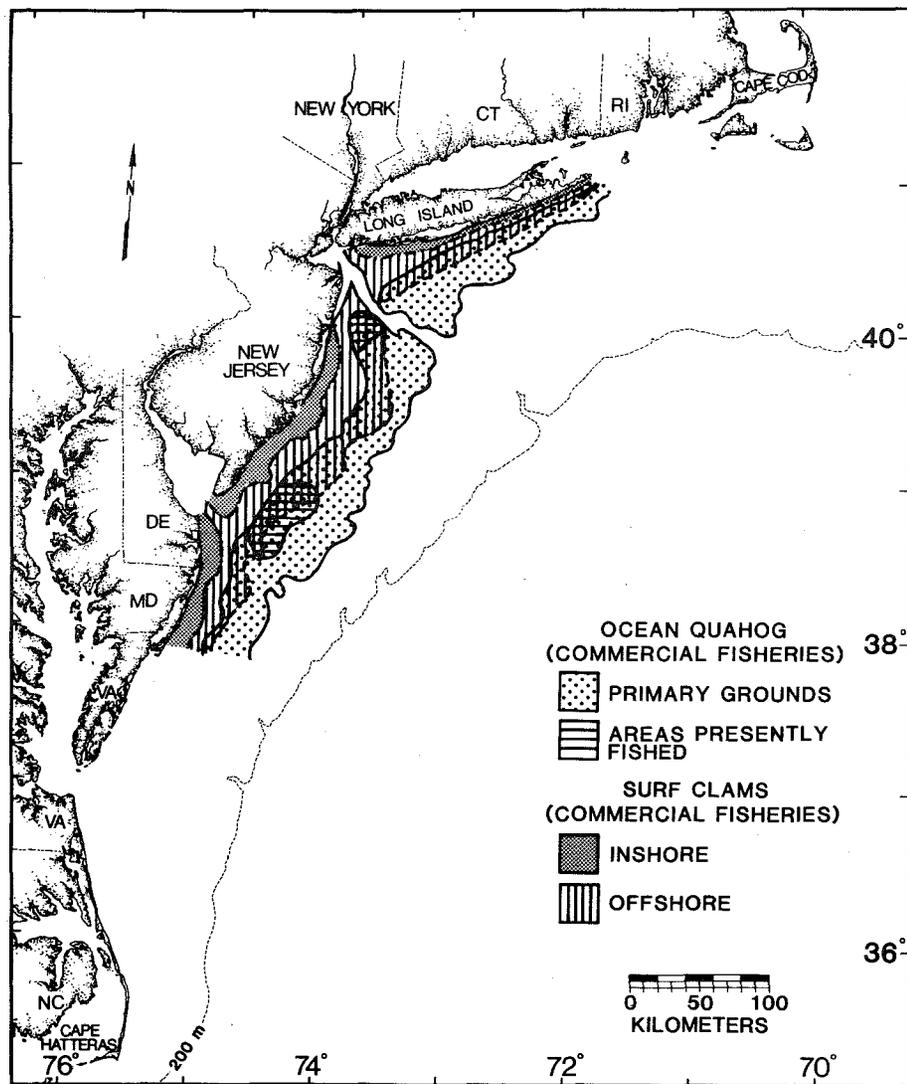


Figure 54. Fishing areas-ocean quahog and surf clams.

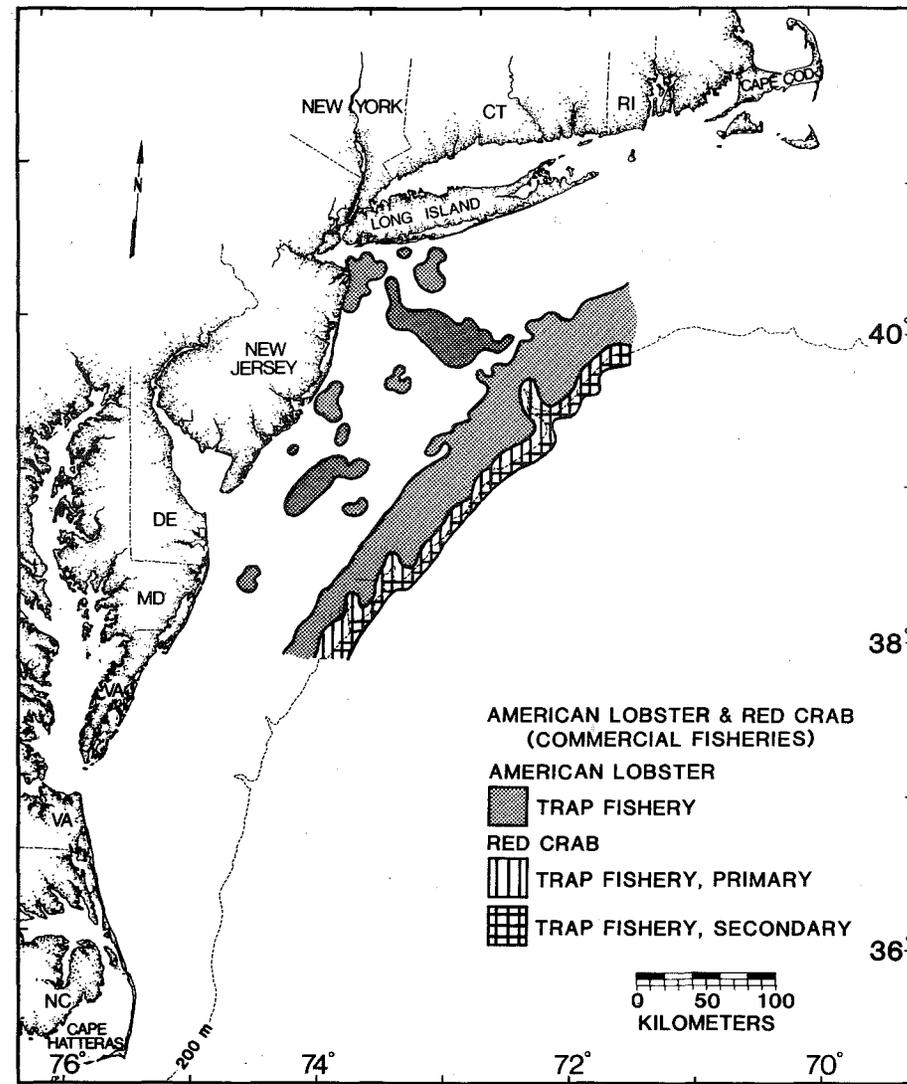


Figure 55. Fishing areas-American lobster and red crab.

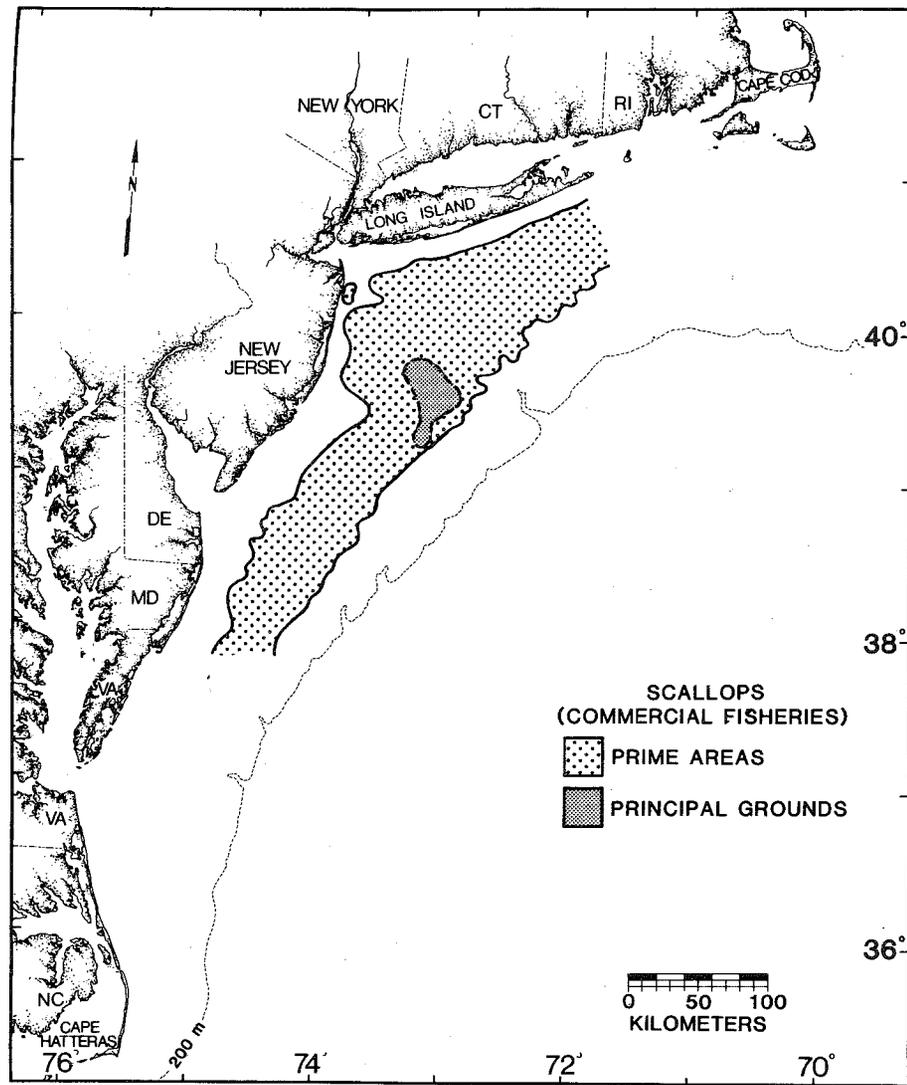


Figure 56. Fishing areas-scallops.

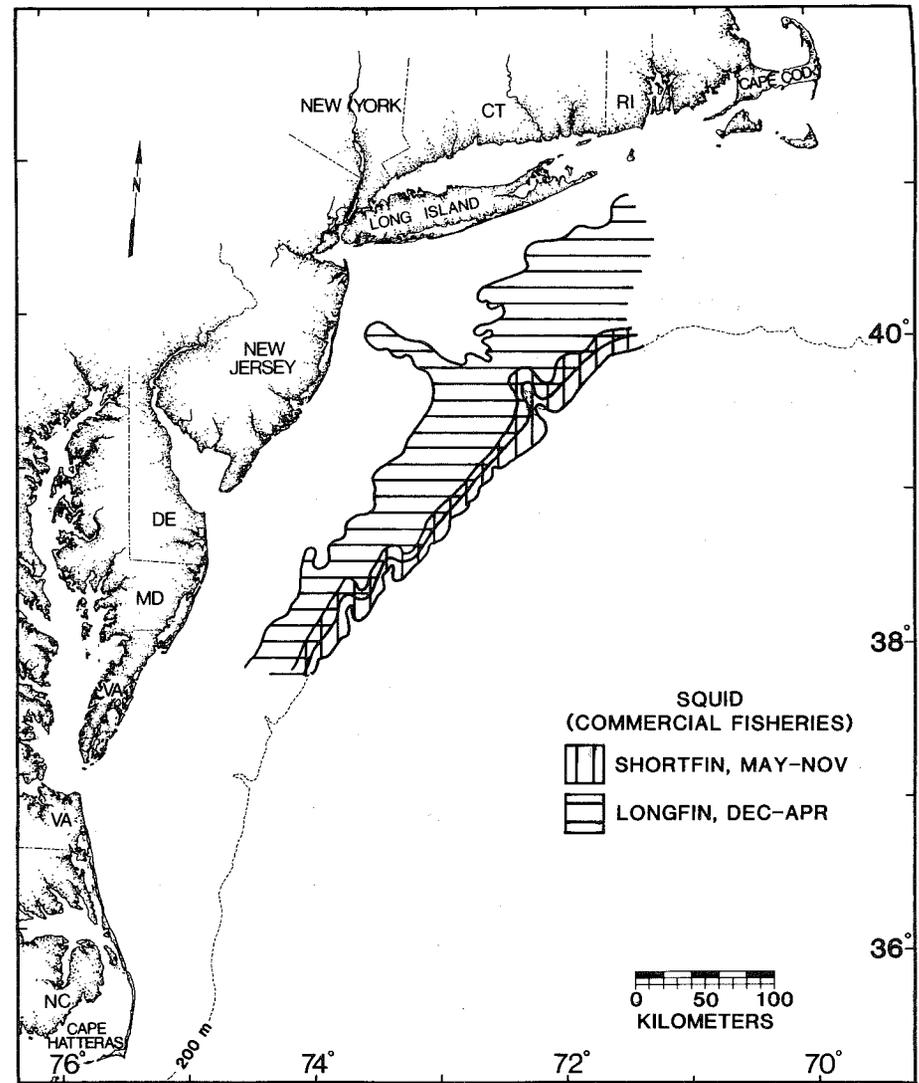


Figure 57. Fishing areas-squid.

Table 8. Foreign landings by statistical areas 1-4, 1978-1983.

Species	1978					1979					1980				
	1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total
Atlantic mackerel	3	121	107	11	243	*	8	82	39	130	-	9	70	635	714
Butterfish	213	117	269	2,300	2,900	505	65	514	734	1,817	3	34	301	1,532	1,869
Red Hake	7	35	71	2,876	4,988	1	24	522	1,578	4,808	3	12	138	76	3,478
Silver Hake	478	54	1,217	21,756	2,989	31	168	1,998	6,471	2,125	119	245	1,428	799	229
Shortfin squid	2,073	29,963	2,248	1,625	23,505	105	26,491	5,000	3,997	8,668	442	26,816	9,968	1,344	2,592
Longfin squid	3,348	1,886	3,454	11,130	35,909	1,066	3,368	12,217	11,017	35,593	58	3,446	13,591	17,774	38,570
Other finfish	386	95	692	3,815	19,818	546	259	2,053	1,950	27,668	60	175	2,439	803	34,869
TOTALS	6,509	32,271	8,217	44,539	90,351	2,254	30,382	22,219	25,787	80,809	685	30,737	27,935	22,964	82,320

Species	1981					1982					1983				
	1	2	3	4	TOTAL	1	2	3	4	TOTAL	1	2	3	4	TOTAL
Atlantic mackerel	-	96	79	11,505	11,680	15	1,178	3,399	410	5,00	9	209	20	381	619
Butterfish	51	115	368	1,400	1,934	165	94	590	888	1,737	292	151	404	519	1,366
Red Hake	2	25	95	66	6,175	22	68	116	159	5,927	6	4	47	97	2,419
Silver Hake	408	262	1,381	3,909	287	291	550	2,173	2,040	365	135	139	566	340	155
Shortfin squid	3,767	11,693	10,209	6,427	5,960	1,701	13,518	5,732	5,850	5,055	17	1,451	1,066	1,032	1,180
Longfin squid	445	4,144	10,880	18,590	32,097	3,295	4,069	12,101	11,745	26,801	3,295	2,891	12,977	5,983	3,567
Other finfish	928	614	2,172	2,461	34,059	657	936	2,270	2,064	31,210	278	231	1,470	440	25,147
TOTALS	5,601	16,949	25,185	44,458	92,192	6,143	20,414	26,381	23,154	76,096	2,551	5,076	16,550	8,793	34,452

currents; 2) 110 mesopelagic species were collected in adjacent to the MAB during baseline studies, with 108 of these species being collected in the upper 800 m; 3) Cyclothone spp. and Myctophids (lanternfish) make up 90% of the catch in the upper 200 m at night; 4) the species composition of these mesopelagic species depends on the movement of water masses in and out of the area, i.e., slope water, warm-core eddies, and even Sargasso Sea waters; 5) Cyclothone microdon and C. braveri were the first and third most abundant species; and 6) of the fifty species of lanternfish collected only Ceratoscopelus maderensis, Hygophum hygomi, Lobianchia dofleini, and Benthoosema glaciale were seasonally abundant. For additional details and discussions, Krueger et al. (1975 and 1977) should be carefully reviewed.

In terms of demersal deep-sea fishes, Musick et al. (1975) based on trawl collections, describe four groupings of demersal deep-sea fishes in the depth limits of the MAB; these are as follows: 1) "Middle slope" group (1,200-1,800 m) which is dominated by Antimora rostrata (blue hake), Synphobranchus kaupi, Coryphaenoides carapinus, Alepocephalus agassizzi, and Diarolene intronigra; 2) "lower slope" group (1,700-2,100 m) which is dominated by A. rostrata, C. carapinus, Halsauropsis macrochir, and S. kaupi; 3) "upper rise" group (2,100-2,900 m) which is dominated by C. armatus and A. rostrata, and 4) "lower rise" group (greater than 2,900 m) dominated by C. armatus. Additional detailed information relative to these demersal forms and their relationship to the MAB can be found in Meade et al. (1964), Haedrich et al. (1975), Musick (1976), Cohen and Pawson (1977), Haedrich and Rowe (1977), Sedberry and Musick (1978), Wenner (1978), Middletoan (1979), and Musick and Sulak (1979).

#### LITERATURE CITED

- Able, K. W., C. B. Grimes, R. A. Cooper and J. R. Uzman. 1981. Burrow construction and behavior of tilefish, Lopholatilus chamaeleonticeps, in the Hudson Submarine Canyon. Env. Biol. Fish. 7(3): 199-205.
- Azarovitz, T. R. 1981. A brief historical review of the Woods Hole Laboratory trawl survey time series. In: W. G. Doubleday and D. Rivard (eds.). Bottom trawl surveys/relevés au chalut de fond. Can. Spec. Publ. Fish. Aquat. Sci. Publ. 58.
- Clark, J. R. 1962. The 1960 salt-water angling survey. U. S. Fish Wildl. Serv., Circ. 153. 36 p.
- Cohen, D. M. and D. L. Pawson. 1977. Observations from SDRV ALVIN on populations of benthic fishes and selected larger invertebrates in and near Deepwater Dumpsite 106. Pages 423-450, in NOAA, Baseline Report of Environmental Conditions in Deepwater Dumpsite 106. Volume II: Biological Characteristics. NOAA Dumpsite Evaluation Report 77-1. Rockville, MD. 485 p.
- Figley, W. and D. Long. 1982. New Jersey's offshore recreational big game fishery. N.J. Dep. Environ. Protect., Div. Fish, Game and Wildl., Mar. Fish. Admin., Tech. Ser. 82-1. 34 p.
- Freeman, B. L. and S. C. Turner. 1977. Biological and fisheries data on tilefish, Lopholatilus chamaeleonticeps Goode and Bean. NOAA, NMFS, NEFC, Sandy Hook Lab., Tech. Ser. 5. 41 p.

- Grimes, C. B., K. W. Able, and S. C. Turner. 1980a. A preliminary and population dynamics of tilefish in Atlantic and Gulf waters. *Coastal Oceanography and Climatic News* 2(3): 30-31.
- Grimes, C. B., S. C. Turner, K. W. Able, and S. J. Katz. 1980b. Life history and population dynamics of tilefish in Atlantic and Gulf waters. *Coastal Oceanography and Climatic News* 2(3): 30-31.
- Grosslein, M. D. 1969. Groundfish survey program of BCF, Woods Hole. *Commer. Fish. Rev.* 31(8-9): 22-35.
- Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, MA. *ICNAF Res. Doc.* 74/96.
- Grosslein, M. D. and T. R. Azarovitz. 1982. Fish distribution. *MESA New York Bight Atlas Monograph* 15. New York Sea Grant Inst., Albany, N.Y. 182p.
- Haedrich, R. L. and G. T. Rowe. 1977. Megafaunal Biomass in the Deep-Sea. *Nature*, 269(5624): 141-142.
- Krueger, W. H., R. H. Gibbs, Jr., R. C. Kleckner, A. A. Keller, and M. J. Keene. 1977. Distribution and abundance of mesopelagic fishes on Cruises 2 and 3 at Deepwater Dumpsite 106. Pages 377-422 in NOAA Baseline Report of Environmental Conditions in Deepwater Dumpsite 106. Volume II: Biological Characteristics. NOAA Dumpsite Evaluation Report 77-1. Rockville, MD. 485 p.
- Krueger, W. H., M. J. Keene, and A. A. Keller. 1975. Systematic analysis of midwater fishes obtained at Deepwater Dumpsite 106. Pages 359-388 in NOAA, May 1974 Baseline Investigation of Deepwater Dumpsite 106. NOAA Dumpsite Evaluation Report 75-1. Rockville, MD. 388 p.
- Long, D. and W. Figley. 1981. New Jersey's recreational and commercial ocean fishing grounds. N.J. Div. Environ. Protect., Div. Fish, Game and Wildl., Mar. Fish. Admin., Tech. Ser. 81-1. 86 p.
- Meade, G. W., E. Bertelsen, and D. M. Cohen. 1964. Reproduction among deep-sea fishes. *Deep-Sea Res.* 11: 569-596.
- Middleton, R. W. 1979. Distribution and abundance of macrourids in Norfolk Canyon and on the adjacent slope. MS Thesis, College of William and Mary, Williamsburg, VA.
- Musick, J. A. 1976. Community structure of fishes on the continental slope and rise off the Middle Atlantic Coast of the U.S., Proceedings of the Joint International Oceanographic Assembly, Edinburgh, Scotland (available from F.A.O., Rome).
- Musick, J. A. and K. J. Sulak. 1979. Characterization of the demersal fish community of a deep-sea radioactive dumpsite, Contract Rep. Submitted to U.S. EPA by VIMS. 61 p.

Musick, J. A., C. A. Wenner, and G. R. Sedberry. 1975. Archibenthic and abyssobenthic fishes of Deepwater Dumpsite 106 and the adjacent area. Pages 229-269 in NOAA, May 1974 Baseline Investigation of Deepwater Dumpsite 106. NOAA Dumpsite Evaluation Report 75-1. Rockville, MD. 388 p.

Sedberry, G. s. and J. A. Musick. 1978. Feeding strategies of some demersal fishes of the continental slope and rise off the Mid-Atlantic coast of U.S.A. Marine Biology 44: 357-375.

Thompson, P. A., Jr. 1982. Japanese longline fishing: Comparison between observed data and Japanese quarterly reports for 1979 in the Atlantic and Gulf of Mexico. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SEFC-64. 38 p.

Turner, S. C., E. D. Anderson, and S. J. Wilk. 1981. A preliminary analysis of the status of the tilefish population in the southern New England-Middle Atlantic region. NOAA, NMFS, NEFC, Sandy Hook Lab., Rep. No. SHL 81-03. 18 p.

U.S. Department of Commerce. 1977a. Physical characteristics. In: Baseline report of environmental conditions in Deepwater Dumpsite 106. U.S. Dep. Comm., NOAA, NOS, NOAA Dumpsite Evaluation Rep. 77-1, Vol. I. 218 p.

U.S. Department of Commerce. 1977b. Biological characteristics. In: Baseline report of environmental conditions in Deepwater Dumpsite 106. U.S. Dep. Commer., NOAA, NOS, NOAA Dumpsite Evaluation Rep. 77-1, Vol. II. 266 p.

U.S. Department of Commerce. 1984. Marine recreational fishery statistics survey, Atlantic and Gulf coasts, 1979 (revised)-1980. U.S. Dep. Commer., NOAA, NMFS, Current Fishery Statistics No. 8322. 239 p.

U.S. Department of Commerce. 1985a. Marine recreational fishery statistics survey, Atlantic and Gulf coasts, 1981-1982. U.S. Dep. Commer., NOAA, NMFS, Current Fishery Statistics No. 8324. 213 p.

U.S. Department of Commerce. 1985b. Marine recreational fishery statistics survey, Atlantic and Gulf coasts, 1983-1984. U.S. Dep. Commer., NOAA, NMFS, Current Fishery Statistics No. 8326. 222 p.

U.S. Department of Commerce. 1986. Marine recreational fishery statistics survey, Atlantic and Gulf coasts, 1985. U.S. Dep. Commer., NOAA, NMFS, Current Fishery statistics No. 8327. 130 p.

Wenner, C. A. and J. A. Musick. 1977. Biology of the morid fish Antimora rostrata in the western Atlantic. J. Fish. Res. Bd. Can. 34: 2362-2368.

Wenner, C. A. 1978. Making a living on the continental slope and in the deep-sea: Life history of some dominant species of the Norfolk Canyon area. Ph.D. Dissertation, College of William and Mary in Williamsburg, Virginia. April 14, 1978. 294 p.

Cetaceans, Sea Turtles, and Pinnipeds of the  
Mid-Atlantic Water Management Unit

by

Tracey P. McKenzie<sup>1</sup> and John R. Nicolas<sup>2</sup>

INTRODUCTION

Research efforts in the past decade on protected species in the U.S. western North Atlantic ocean have enhanced our understanding of the distribution, abundance, and general life history of these species. Surveys conducted by the University of Rhode Island's (URI) Cetacean and Turtle Assessment Program (CETAP) provide a comprehensive baseline characterization of cetaceans and turtles in shelf and slope waters from Cape Hatteras, NC to Cape Sable, Nova Scotia, Canada. Several academic and private institutions study the ecology of these species. Manomet Bird Observatory (MBO) provides valuable time series data on whale and turtle abundance from Maine to Virginia. The University of Maine (UMO) and the New England Aquarium (NEA) conduct studies on pinniped and mammal distribution and food habits. The Virginia Institute of Marine Sciences (VIMS) conducts research on the distribution, abundance, food habits, and mortality of sea turtles within the Chesapeake Bay and Virginia waters. The Northeast Marine Mammal Stranding Network and Sea Turtle Stranding and Salvage Network collect meristic, reproductive, and population data on all cetaceans, turtles, and pinnipeds. Fisheries Compliance Inspectors with the National Marine Fisheries Service (NMFS), Northeast Region (NER) collect sighting data on cetaceans as well as reproductive, food habits, and population data from toothed whales taken incidentally during the course of commercial fishing operations.

From these sources and numerous government contract reports and manuscripts, this section summarizes and describes the spatial and temporal distribution and general life history of protected species within the Mid-Atlantic Water Management Unit area (MAWMU); discusses activities that may adversely affect these animals; identifies ongoing research as well as data gaps, and identifies sources that have specific information. It is our intent to provide this summary in a format that will be useful to resource managers who must assess the potential impacts of various activities on living marine resources that occur within the WMU area. Descriptions of mammals and turtles are arranged by species. Specifics on social structure, reproduction, and

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general life history is uneven and better known for some species than others. The apparent incompleteness of information for some species descriptions reflects the lack of information.

Our figures depict the spatial and temporal distribution for species that may occur within the WMU area. These figures reflect trends in seasonal distributions based on sighting data out to the 2000 m depth contour; however, many species' distributions extend beyond the 2000 m contour. Two distributional gradients are shown: the general distributions of seasonal occurrence derived from opportunistic sightings and dedicated surveys (from CETAP and MBO) and significantly higher densities that are taken from CetAP and are adjusted for sighting effort.

Cetacean and turtle abundance and estimates are intentionally omitted. Recently acquired data from CetAP and MBO are being compiled and archived onto tape at the NMFS Northeast Fisheries Center. When completed, regional and seasonal abundance and density estimates can be calculated and plotted. These data should be invaluable to federal agencies proposing activities that may impact protected species and resource managers in decision making roles.

Marine mammals and endangered species are protected by the federal Marine Mammal Protection Act (MMPA) of 1972 and the Endangered Species Act (ESA) of 1973. Of the nineteen species described here, eight are classified as endangered or threatened under the ESA; the remainder are protected under the MMPA. These laws prohibit the taking (i.e., harm, harass, kill, etc.) of protected species. Any action (i.e., ocean dumping, incineration, oil and gas development, coastal development and construction, dredge and fill, etc.) by federal and state agencies must take into account the potential effects of these activities these species, pursuant to Section 7 of the ESA.

Protected species use the WMU area for such life functions as feeding, reproduction, nursing, and migration. Some species occupy the area yearround while others use the area seasonally or move intermittently inshore and offshore. Because marine mammals are known to be major consumers of commercially important marine resources and their prey, they play a major role in the dynamics of the western North Atlantic ecosystem. Changes in distributions, abundance, or in prey species' biomass as a result of natural variability and man's activities may impair reproductive fitness, recovery to maximum sustainable levels, and the survivability of some species.

#### LIST OF ENDANGERED AND THREATENED SPECIES

Right Whale - Eubalaena glacialis

Humpback Whale - Megaptera novaeangliae

Fin Whale - Balaenoptera physalus

Sei Whale - Balaenoptera borealis

Sperm Whale - Physeter macrocephalus

Loggerhead Sea Turtle - Caretta caretta

Leatherback Sea Turtle - Dermochelys coriacea

Kemp's ridley Sea Turtle - Lepidochelys kempii

#### DESCRIPTION OF SPECIES

##### RIGHT WHALE

Right whales are the most severely depleted large whales ocean wide. They occur in temperate waters of the North Atlantic. The occurrence of the 200-500 whales that live within this area ranges from the Bay of Fundy to Florida (Kraus, 1985). In the WMU area their occurrence is limited to a few sightings (Fig. 1). Most right whale sightings occur in spring when aggregations are observed in the Great South Channel area and along the northern edge of Georges Bank in response to dense concentrations of copepods, Calanus finmarchicus (Kenney and Winn, 1987). Winn et al. (1986) indicate that right whales occur there for periods of up to 24 days, with peak numbers in May. A few sightings have been made off Long Island and Virginia. In summer, right whales are mostly absent from the WMU area; they occur in the Bay of Fundy and Scotian shelf waters. Fall and winter sighting data indicate occurrences off Cape Ann and Cape Cod, Massachusetts with occasional sightings along the coast from New Jersey to North Carolina.

The migrational pathways of right whales are not well understood. During late summer and fall, they migrate south from the Gulf of Maine and the Nova Scotia shelf (Winn et al., 1981). Winn et al. (1986) hypothesize that some individuals (cow/calf pairs) migrate north and south along the shore and others migrate through offshore waters. Photographically matched identifications indicate that cows with newborn calves frequent Florida/Georgia nearshore waters in winter (Kraus, 1985).

Reproductive data are generally not available for right whales. Mating and calving may occur both north and south of the MAWMU area. Recent reports indicate that calving activity may be centered off Georgia and Florida (Kraus, 1985). Watkins and Schevill (1979) suggest that some calving may occur near Cape Cod during the winter. Close contact behavior, possibly related to reproduction, has been observed in Cape Cod Bay, the Great South Channel area, and the Browns Bank area of the Bay of Fundy (Kraus and Prescott, 1982; C. Mayo, personal communication). Kraus et al. (1984) estimate that approximately 8 calves are born each year, females mature between 5-7 years of age, and suggest that cows bear calves every three years. This reproductive interval is consistent with Roger Payne's observations of South Atlantic right whales.

##### HUMPBACK WHALE

Endangered humpback whales occur in the northwest Atlantic from winter breeding grounds in the Caribbean to summer feeding grounds from Cape Cod to Iceland (Katona et al., 1980).

Sightings of humpback whales are relatively constant each year over the shelf waters from spring through fall. Between April and October, they occur in southern New England waters, over Georges Bank, and north over the Gulf of Maine (Figure 2). Summer concentrations primarily occur off the coast of New

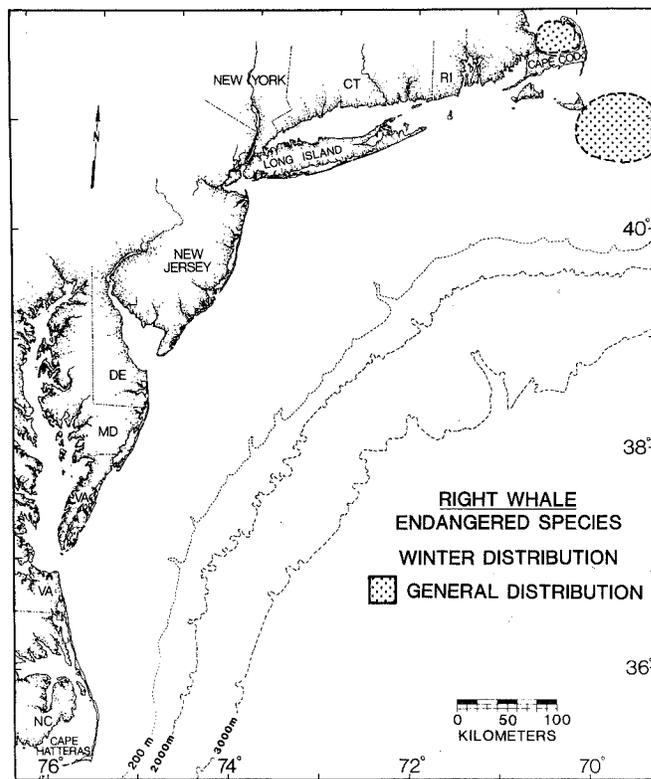
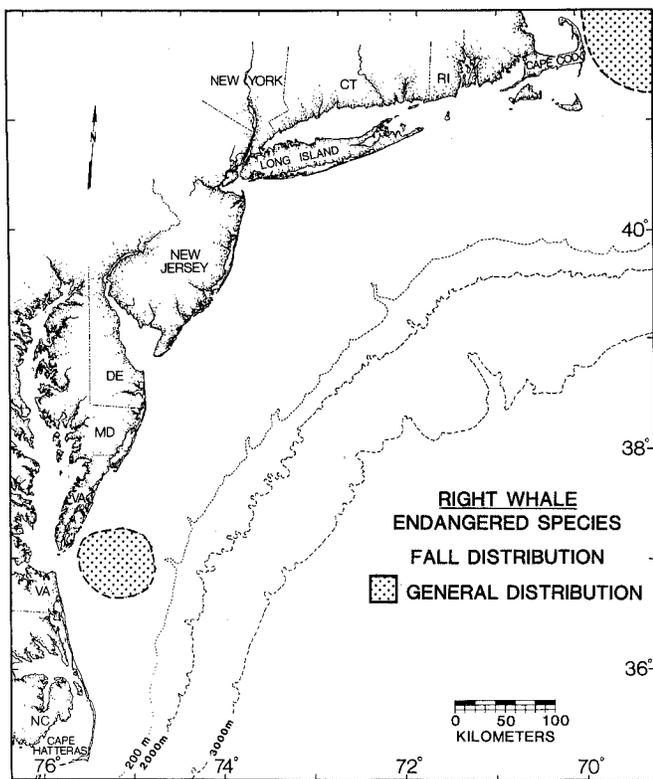
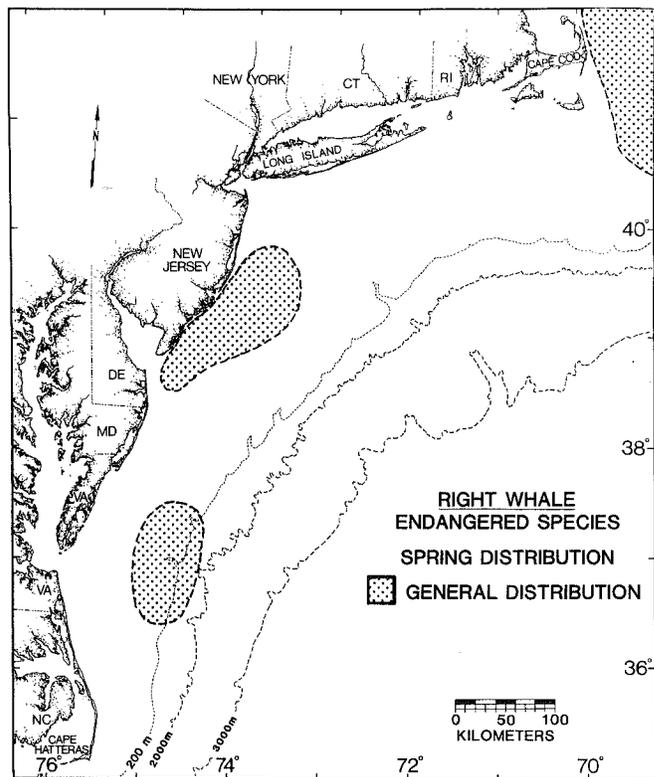
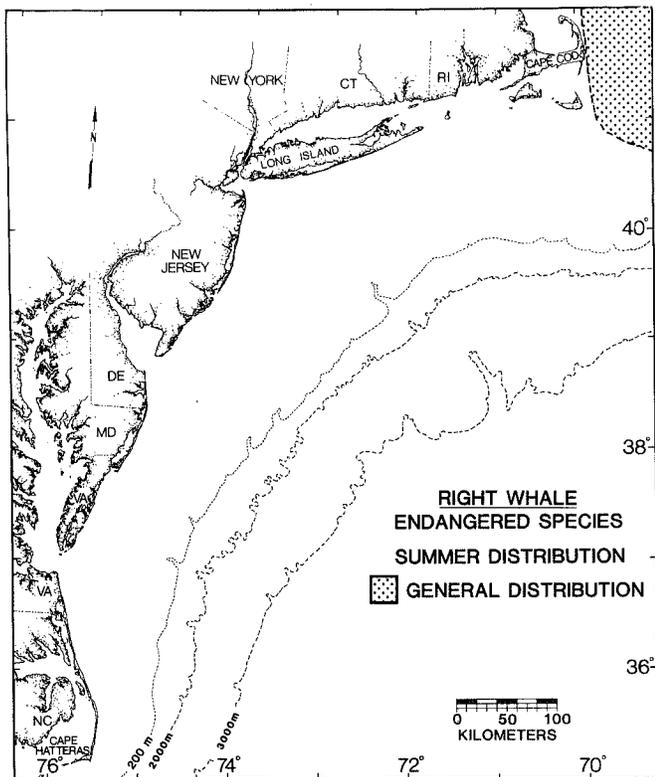


Figure 1. Seasonal distribution, Right whale.

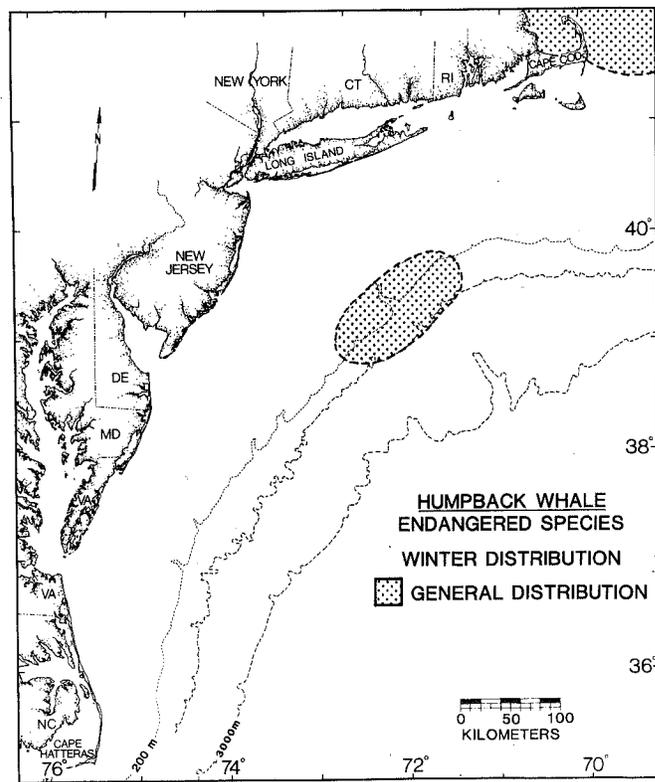
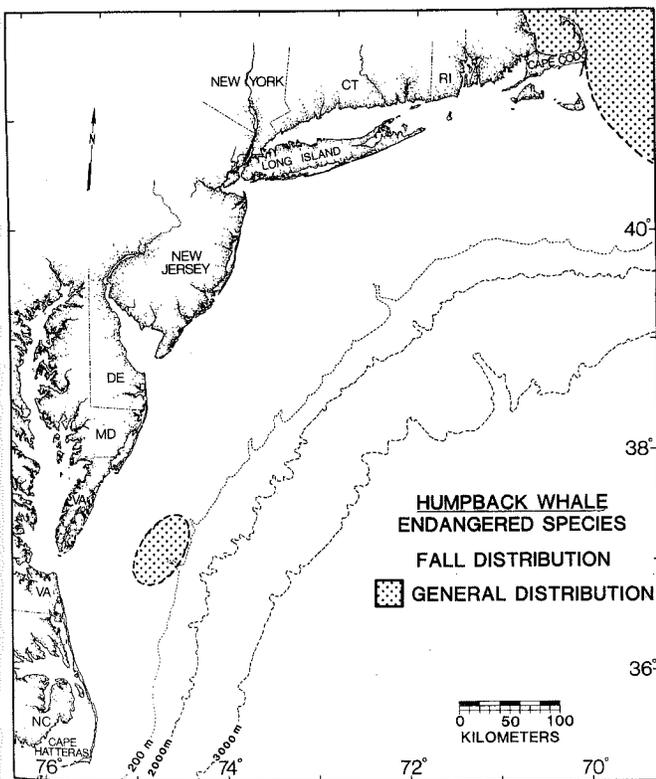
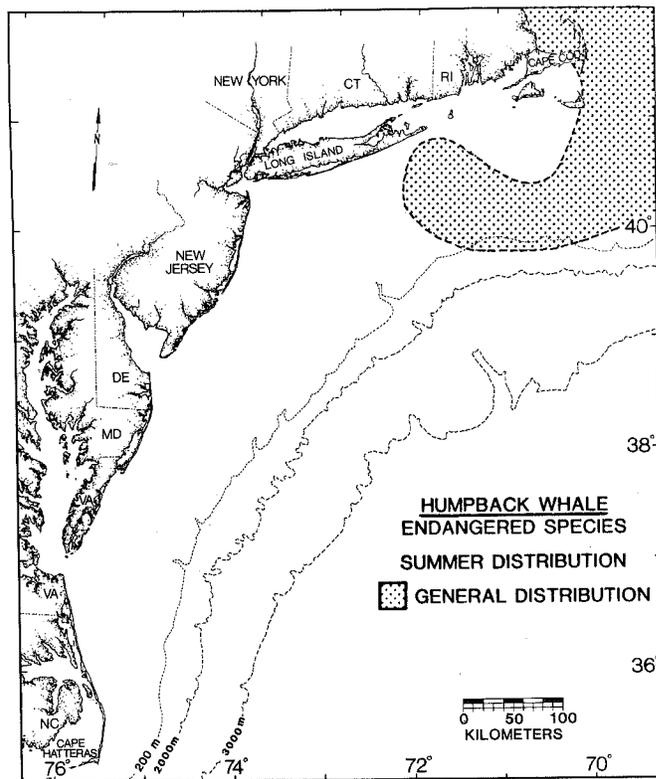
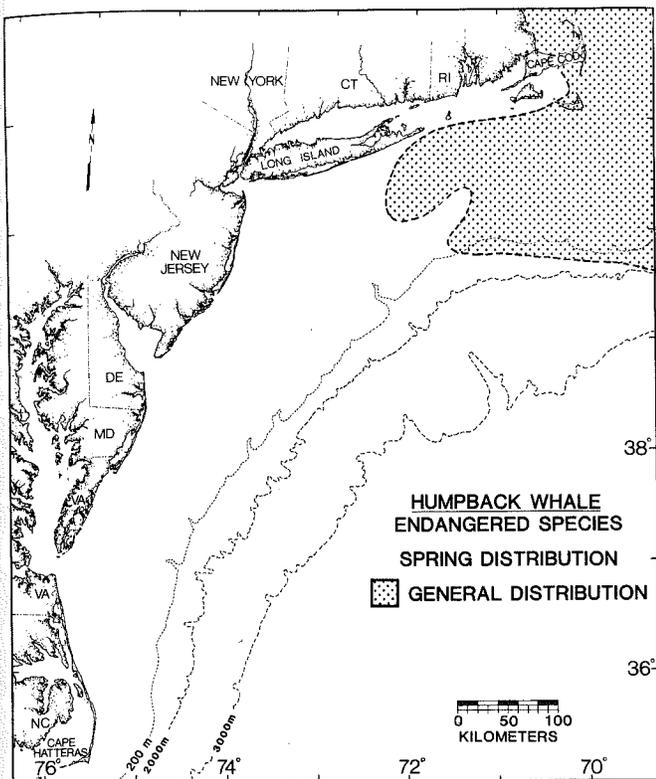


Figure 2. Seasonal distribution, Humpback whale.

England in Gulf of Maine waters. In winter, humpbacks pass through the MAWMU area during their winter migration to the Caribbean. Kenney et al. (1982) suggest that the Great South Channel is a major exit and entry point between Gulf of Maine feeding areas and deeper water migration routes. Of the over 10,000 humpbacks occurring worldwide, about 5,700 occur in the western North Atlantic. Over 300 individually identified animals frequent Gulf of Maine waters in spring, summer, and fall.

Major summer feeding areas in the MAWMU and areas north are along the 100 m contour from the northern portion of the great South Channel eastward to Nantucket Shoals and north to Jeffreys Ledge. An area east of Montauk has also been described as a humpback whale feeding area (URI, CeTAP, 1982). Opportunistic feeding is likely to occur all along the Mid-Atlantic shelf. A particularly important food item for humpbacks in the western North Atlantic is the sand lance, *Ammodytes* sp., Payne et al. (1986) recognize an important relationship between sand lance and humpback whales. They hypothesize that behavior and bottom topography are critical factors in the foraging strategies of humpback whales and, hence the present distribution of this species. Other prey of humpback whales include herring, mackerel, and gadoids (Kenney et al., 1983).

Humpback whales mate and bear calves during winter in Caribbean waters. Gestation lasts for 11 to 12 months and the calving interval is thought to be 2 to 3 years (NMFS, 1984).

#### FIN WHALE

Endangered fin whales are the most abundant large whales in the MAWMU area. They are widely distributed throughout shelf waters of the Mid- and North Atlantic on a year-round basis (Figure 3). This species tends to occupy the shelf proper rather than the shelf edge (URI, CeTAP, 1982). The area east of the Delaware Bay and the Delmarva Peninsula also appears to be an important winter and spring habitat. In spring, fin whale distribution shifts northward and offshore with a subsequent southward return in the fall. Of the estimated 120,500 fin whales occurring worldwide, about 7,200 occur in the western North Atlantic. About 1,000-3,000 fin whales occur between the Gulf of Maine and Virginia.

Fin whales feed on euphausiids, copepods, and schooling fishes, depending on prey availability (Mitchell, 1974). Feeding activity occurs from the Bay of Fundy to waters east of the Delmarva Peninsula.

Fin whales are probably born during the winter in the western North Atlantic (Mitchell, 1974); however, their mating and calving grounds are unknown. The high number of calf and juvenile sightings in spring in shelf waters may be due to the birth of calves just prior to that time (URI, CeTAP, 1982).

#### SEI WHALE

Endangered sei whales occur in the northern portion of the MAWMU area from southern New England and north past Cape Cod to Nova Scotia in spring and summer (Figure 4) (Mitchell and Chapman, 1977). In spring, sei whales are concentrated at the head of Hydrographer's Canyon to the northeast peak of

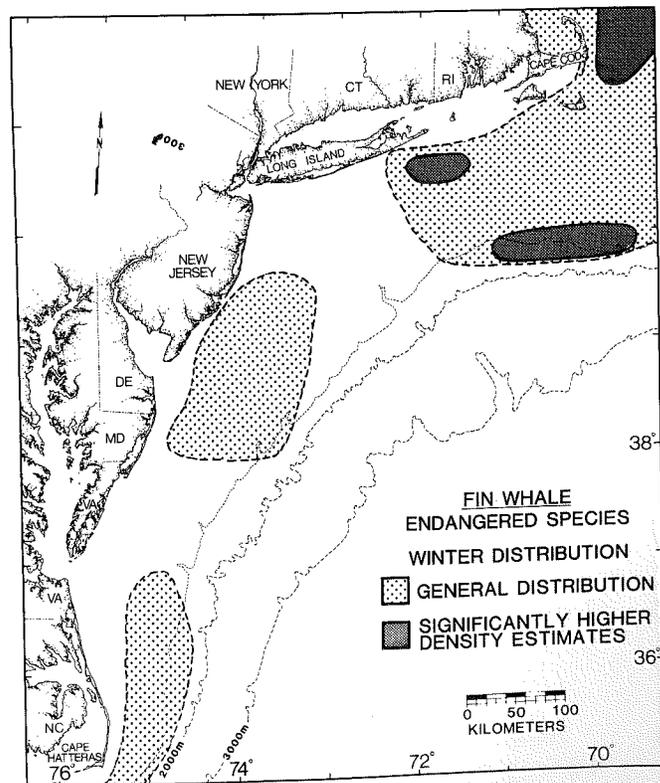
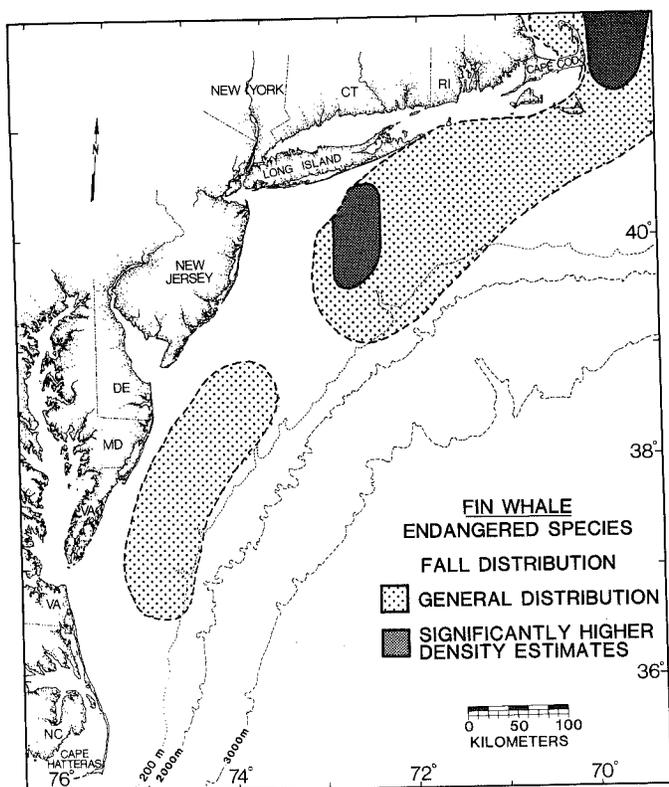
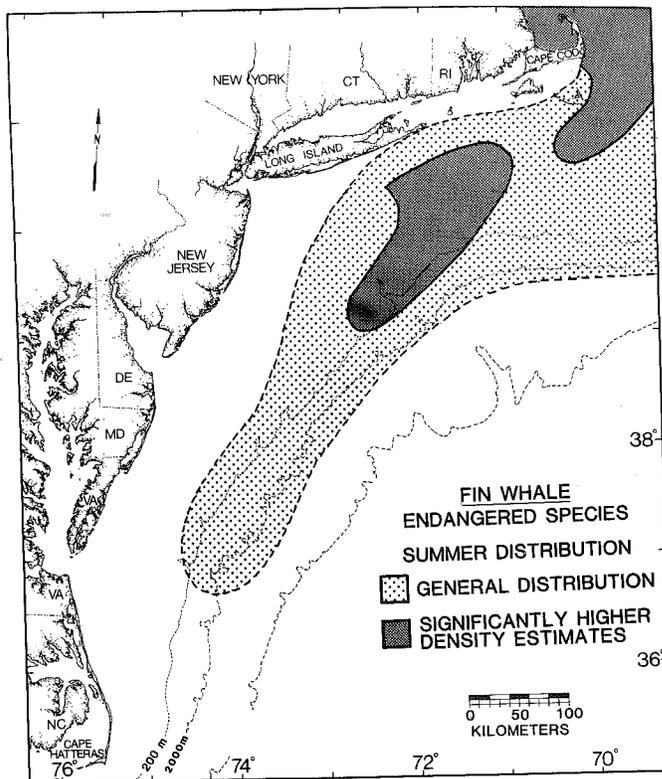
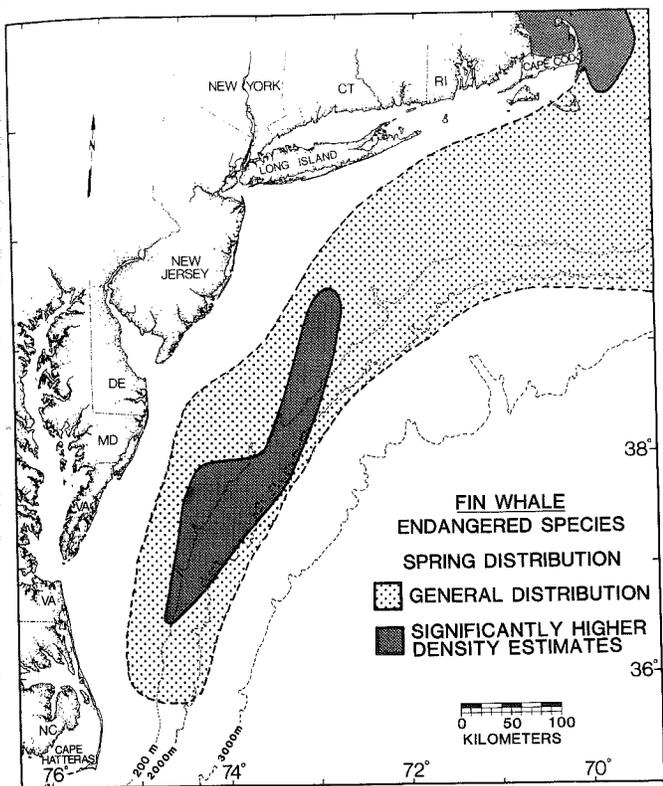


Figure 3. Seasonal distribution, Fin whale.

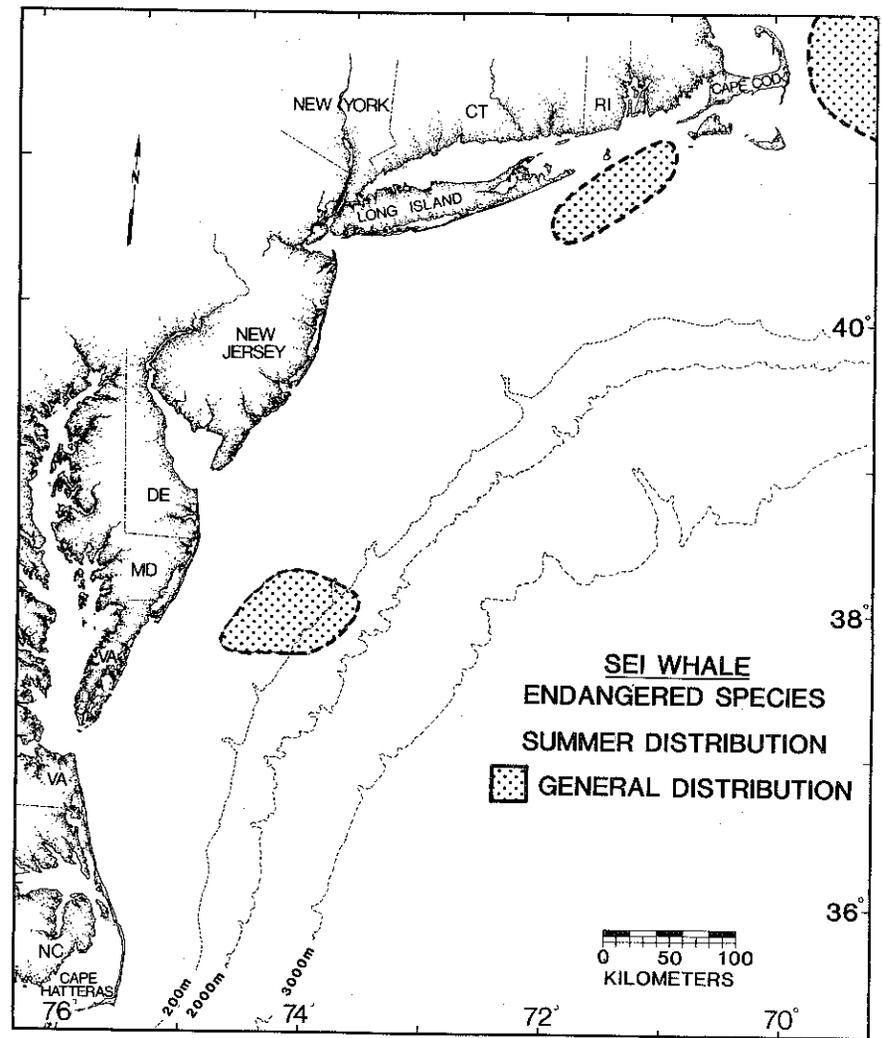
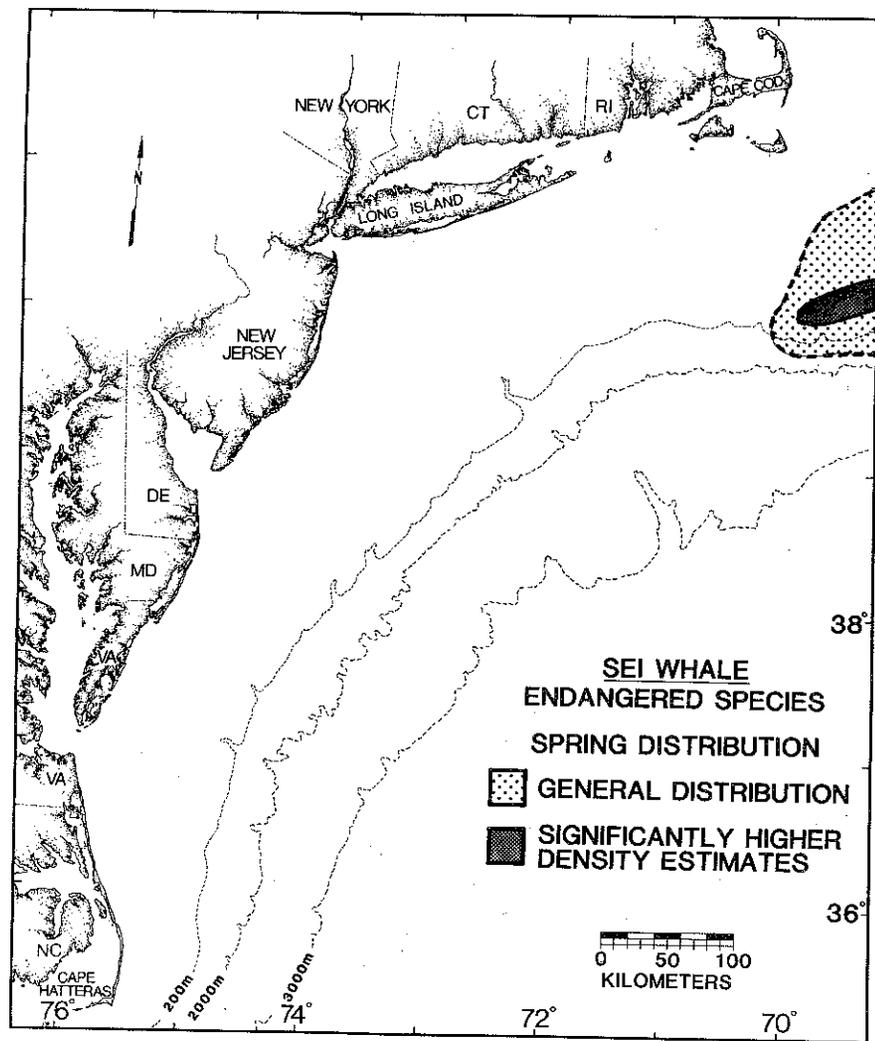


Figure 4. Seasonal distribution, Sei whale.

Georges Bank and continue north along the Scotian shelf edge. Summer sightings of sei whales are fewer and scattered over the eastern portion of Georges Bank. In fall and winter, sei whales are rarely seen in the Mid-Atlantic shelf and slope waters.

Sei whales feed primarily on copepods and euphausiids (Kenney et al., 1983). Sei whale distributions along the edge of Georges Bank and at the head of Hydrographer's Canyon may reflect copepod distribution.

The location, if any, of sei whale mating and/or calving grounds is unknown (Katona et al., 1977). Calves and juveniles have been observed with adults in spring and summer.

#### MINKE WHALE

Minke whales occur in shelf waters from Virginia to Baffin Island (Katona et al., 1977), but sightings south of Nova Scotia are predominately concentrated in southwestern Gulf of Maine waters and Georges Bank (Figure 5). In spring and summer, minke whales are widely distributed in the Mid-Atlantic region eastward from Montauk Point to southeast of the Nantucket Shoals and over Georges Bank through the Great South Channel. The fall distribution of minke whales is generally southward and in winter these animals are almost completely absent from the MAWMU area.

In the western North Atlantic, minke whales feed primarily on schooling fish such as sand lance, capelin, herring, and mackerel (Kenney et al., 1983).

Minke whale calving may take place during the winter (Mitchell and Koziacki, 1975) and Mead (1975) suggests that a calving area may be located in the Mid-Atlantic region. However, no areas have yet been identified.

#### SPERM WHALE

Endangered sperm whales are widely distributed throughout deep waters of the North Atlantic (Brown, 1958). In the MAWMU area, sperm whales are concentrated along the 1000 m contour although their distribution extends well beyond the shelf edge into deeper water (Brown, 1958; Slijper et al., 1964) (Figure 6). In spring and summer, they are abundant throughout the central portion of the Mid-Atlantic shelf-edge region and slope waters. Sperm whales are also relatively abundant south of New England on the continental shelf edge and east and north of Georges Bank into the Northeast Channel region in summer (URI, CeTAP, 1982; Hain et al., 1985). They are concentrated south of New England in fall and in winter the distribution shifts east and northeast of Cape Hatteras. These seasonal north-south migrations are characterized by sexual segregation and social groupings. The northern limit of mixed schools of females and juveniles is about 40°N latitude while medium and large males migrate further and to higher latitudes (Slijper et al., 1964; Best, 1979).

Sperm whales are deep-diving animals that feed predominately on squid (Caldwell et al., 1966; Gambell, 1977). They also feed on deep-water fishes such as sharks, rays, anglers, lumpfish, and rockfish (Kenney et al., 1983).

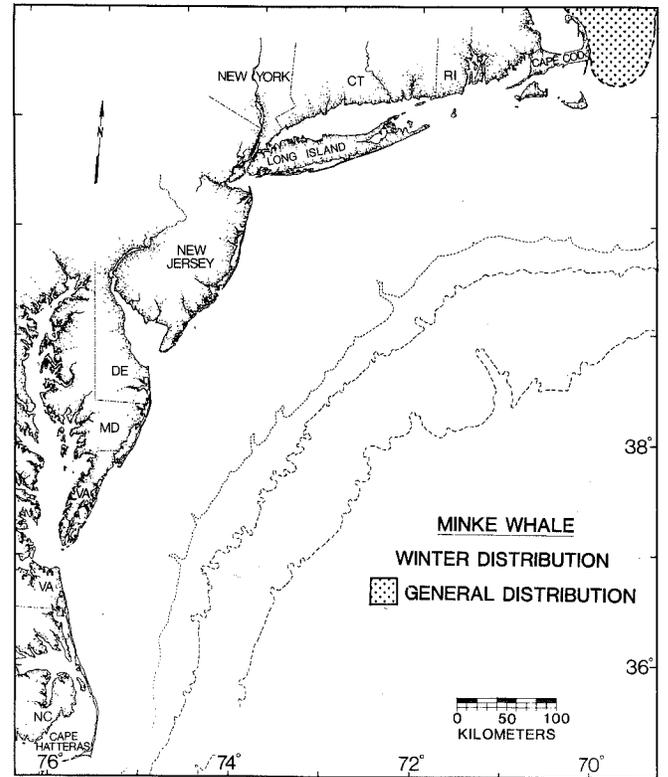
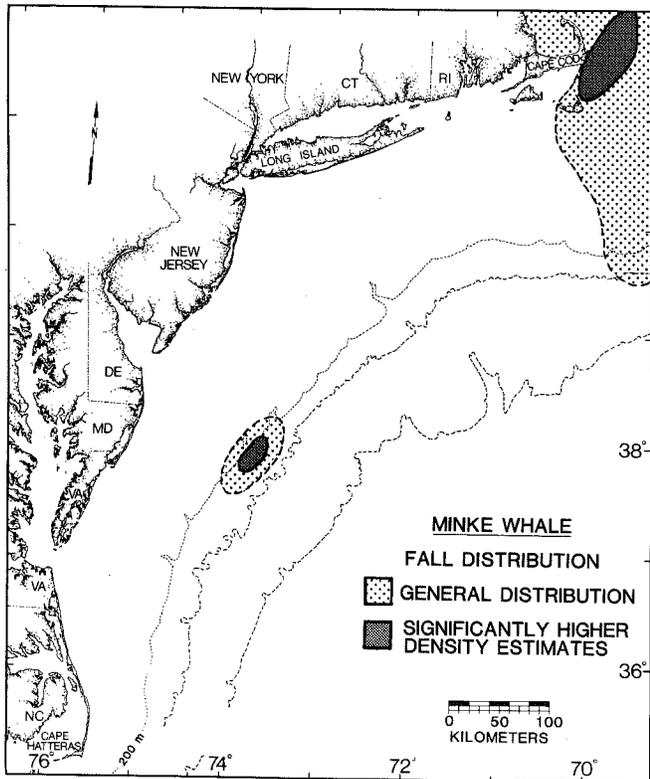
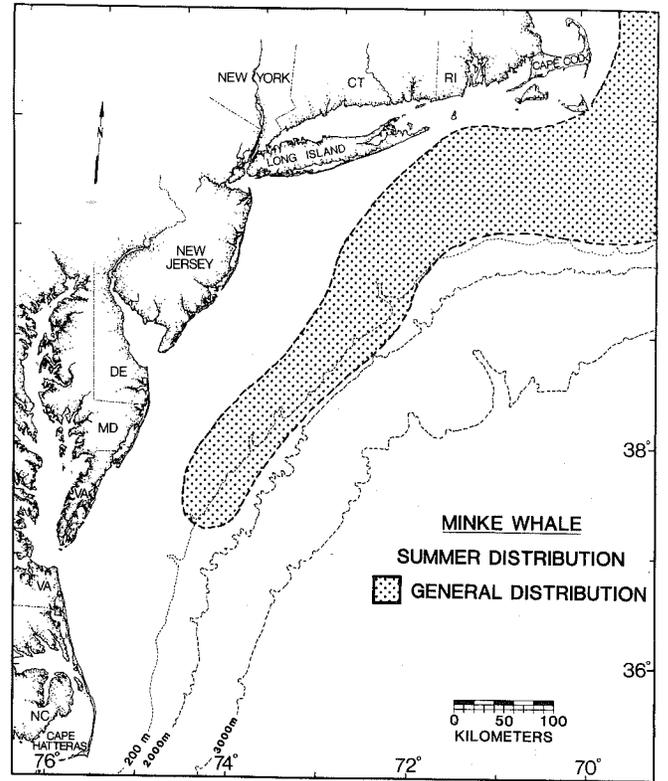
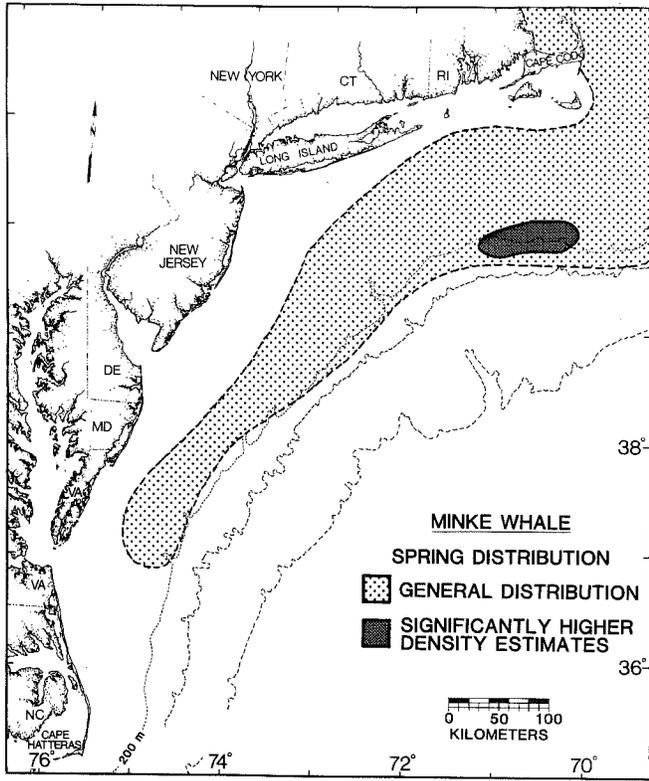


Figure 5. Seasonal distribution, Minke whale.

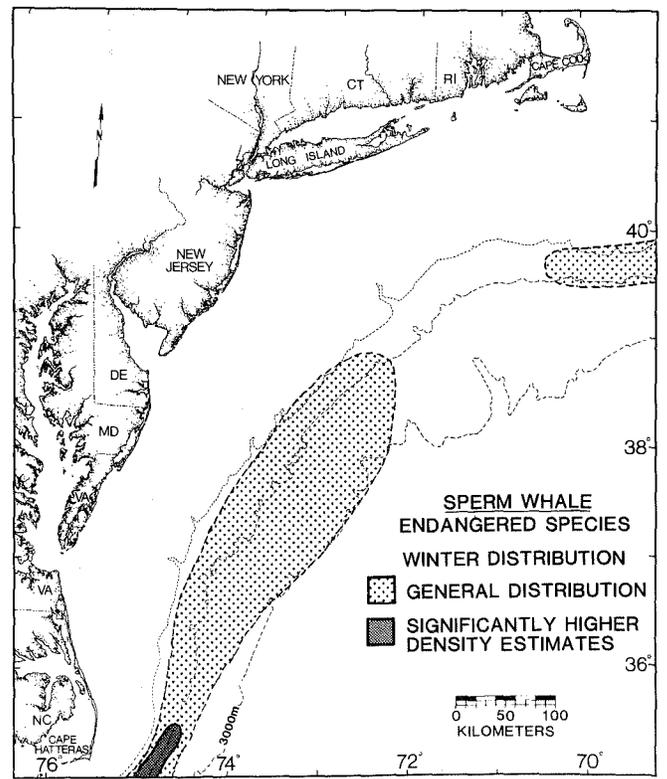
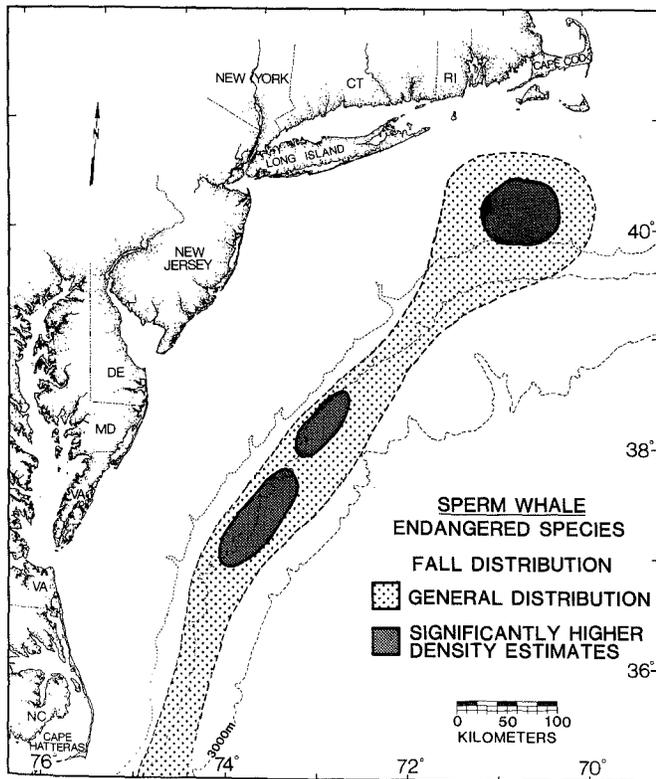
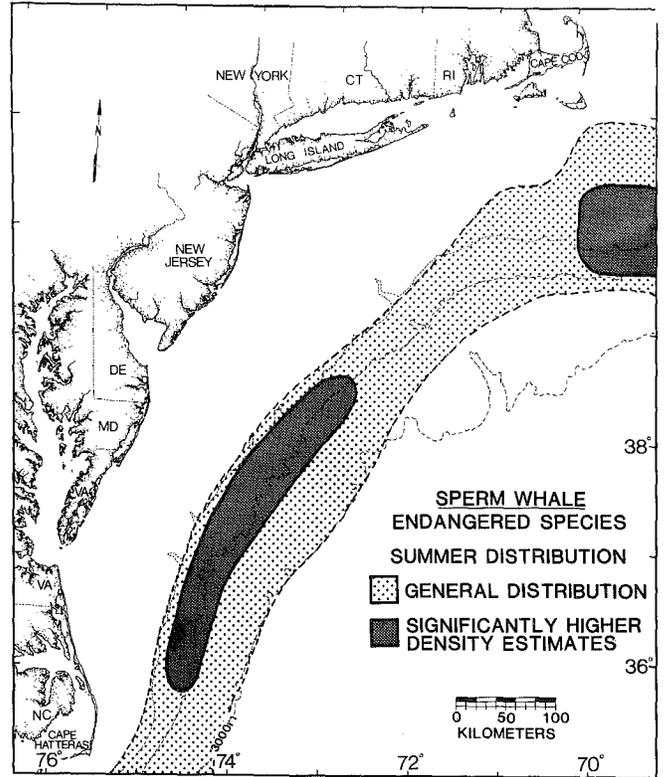
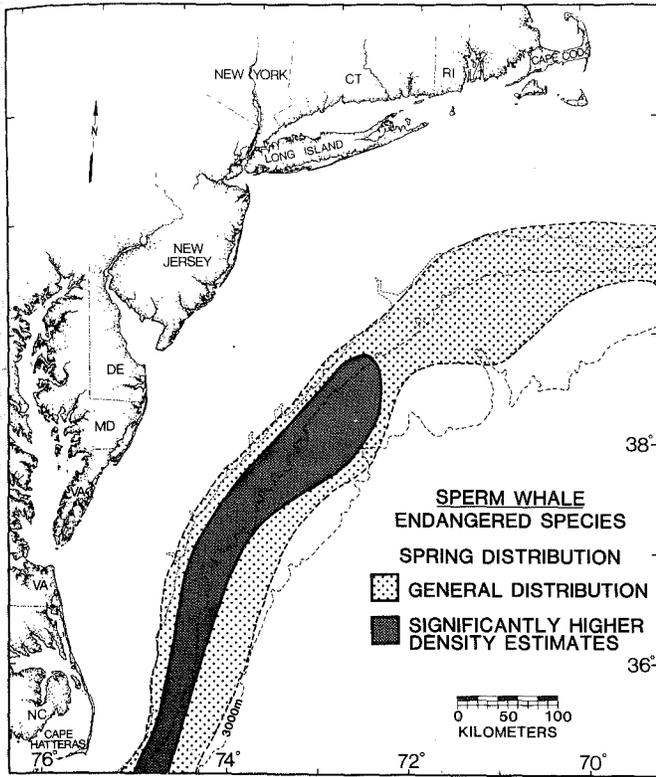


Figure 6. Seasonal distribution, Sperm whale.

Mating occurs during the northward spring migration and gestation is thought to be 14-16 months (Katona et al., 1977). The distribution of calves and juveniles parallels that of the adults (URI, CeTAP, 1982). Given the moderate to high sighting frequency, feeding habits, cow/calf sightings, and conservative abundance estimates, the MAWMU area and surrounding waters may be of particular importance to sperm whales.

#### ATLANTIC WHITESIDED DOLPHIN

Atlantic whitesided dolphins occur primarily inshore of the 100-m depth contour in the MAWMU area. They range from the Gulf of Maine south to the Chesapeake Bight (Testaverde and Head, 1980).

The dolphins are primarily found in Gulf of Maine waters east and southeast of Cape Cod, and on Georges Bank in spring, summer, and fall (URI, CeTAP, 1982) (Figure 7). In winter, abundance is reduced throughout their range except in areas around Cape Cod and the Gulf of Maine. Lower winter densities generally suggest an offshore or southward movement. Calves and juveniles occur from the Gulf of Maine south to the Great South Channel. No calves or juveniles were sighted in the southern portion of the adult range (URI, CeTAP, 1982).

The general distribution and feeding habits of Atlantic whitesided dolphins suggest certain areas of importance, especially on shallow fishing banks around Cape Cod and on the northwest edge of Georges Bank in an area defined as the Great South Channel-Jeffreys Ledge corridor (CeTAP, 1982; Kenney and Winn, 1987). These areas are outside of the MAWMU area. Atlantic whitesided dolphins feed on pelagic and benthopelagic fishes such as capelin, herring, hakes, sand lance, smelt, and cod (Kenney et al., 1983), although squid, crustaceans, and molluscs make up part of their diet (NMFS, 1984).

Little information is available to indicate specific breeding or calving grounds or seasons for Atlantic whitesided dolphins. The gestation period is about 10 months and calves are probably born between May and August in the western North Atlantic (Sergeant et al., 1980).

#### PILOT WHALE

Two species of pilot whales are considered jointly here since they are virtually inseparable in the field. Long finned pilot whales, Globicephala melaena, are the more northern species and occur from North Carolina (Leatherwood et al., 1976) to Greenland (Mercer, 1975). Short finned pilot whales, G. macrorhynchus, the southern species, occur from North Carolina (Schmidtley, 1981) to the Gulf of Mexico (Fritz and Reynolds, 1981). In the MAWMU area, the ranges of the two species extend north from the Mid-Atlantic region to New England, over Georges Bank and into the Gulf of Maine (Figure 8) and may overlap between Virginia and North Carolina. Pilot whales occur along the 100 m depth contour seasonally. They are found offshore over deep water as well.

Pilot whales are widely distributed in the MAWMU area in spring with no specific areas of concentration. In summer, they concentrate along the 2000 m contour from the Delmarva Peninsula south to Cape Hatteras and another inshore area northeast of Cape Cod. In winter, sightings have been made southeast of

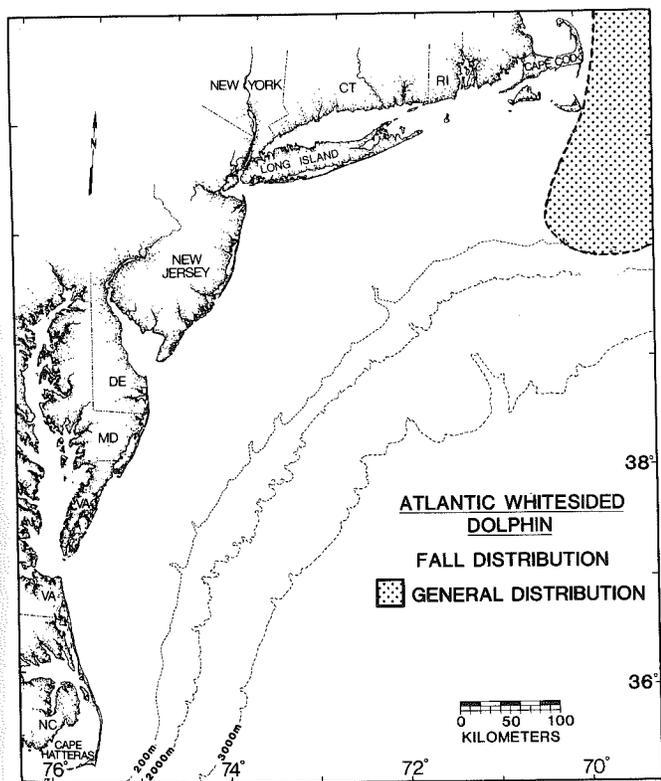
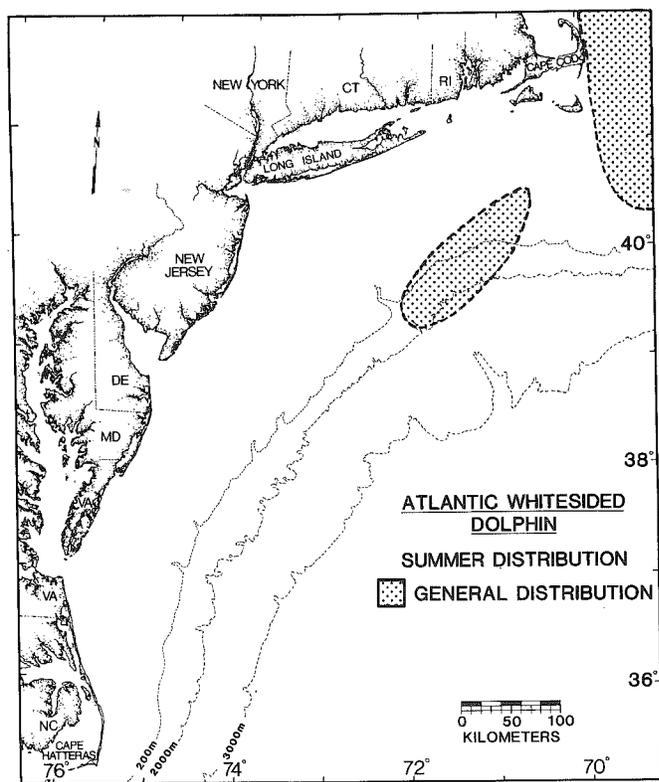
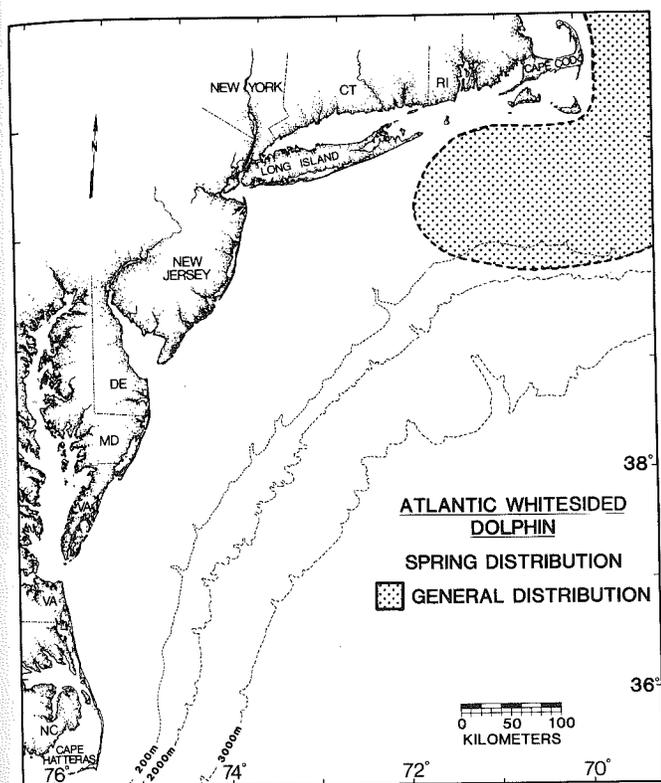


Figure 7. Seasonal distribution, Atlantic whitesided dolphin.

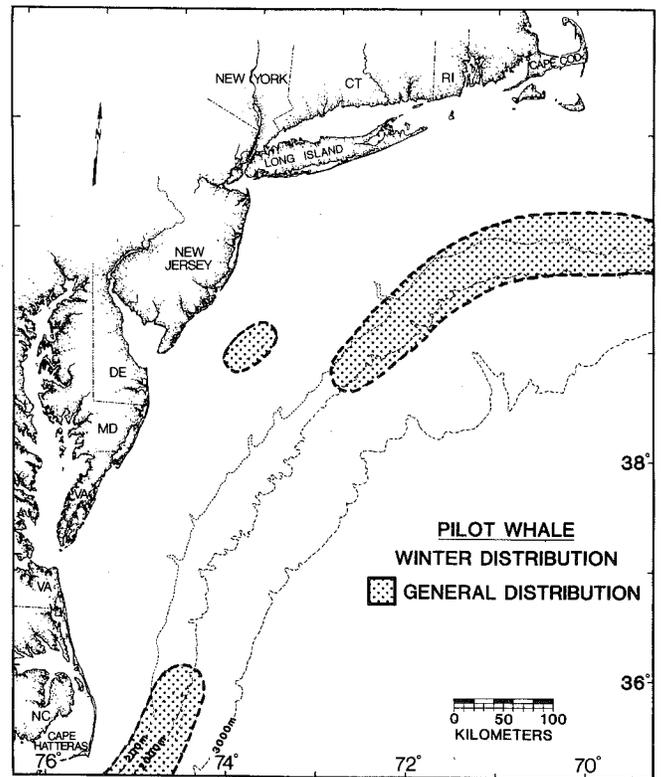
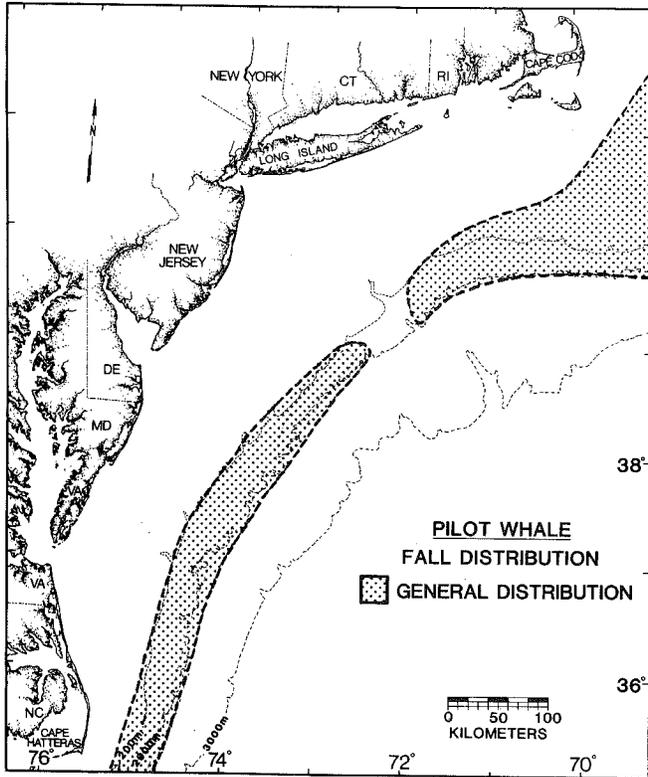
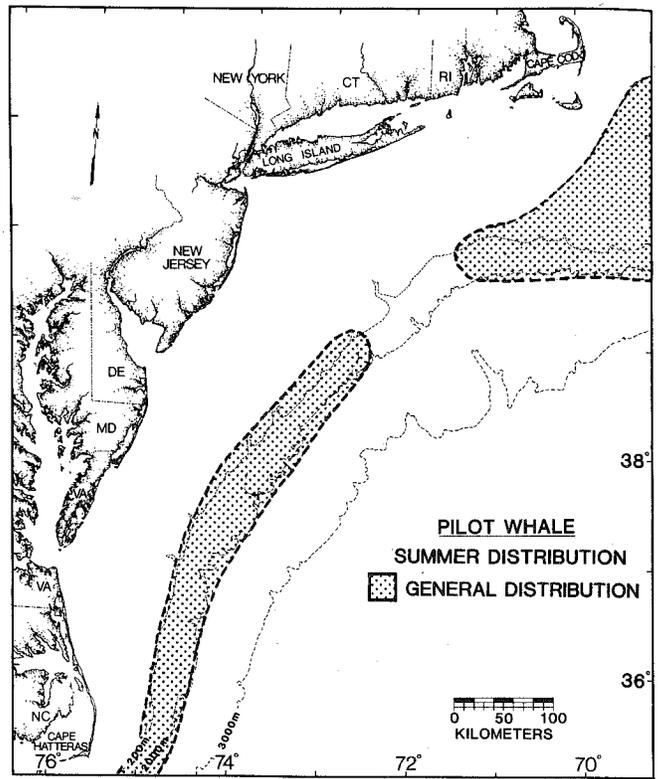
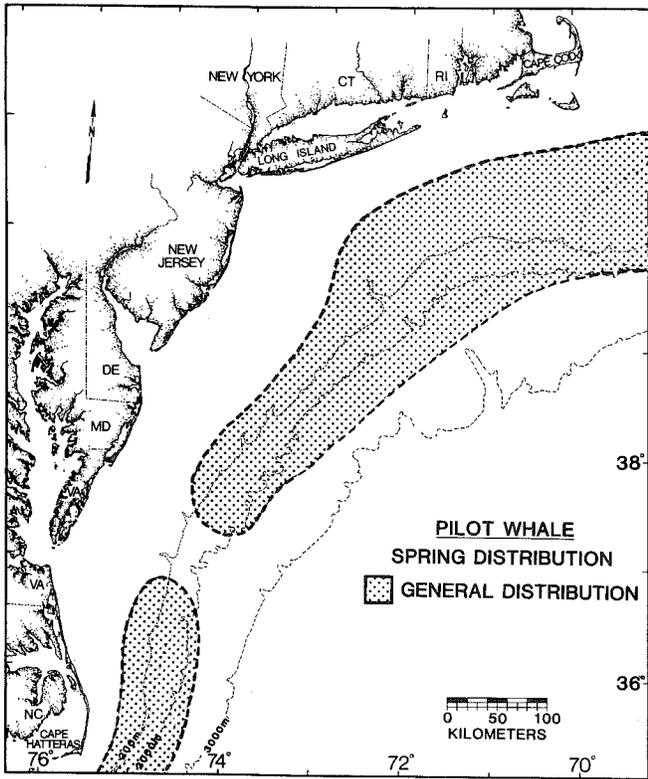


Figure 8. Seasonal distribution, Pilot whale.

Long Island (CeTAP, 1982), although some may move offshore and/or southward then. These areas of concentration may reflect distributional differences in the range of the two species (URI, CeTAP, 1982).

Pilot whales are social and generally travel in large schools composed of smaller social units or pods. Schools scatter when they are in a feeding area. They are capable of relatively deep dives and feed almost exclusively on squid (Kenney et al., 1983) although hakes, haddock, herring, and other schooling fish make up part of their diet. Nicolas (1984) suggests that butterfish and mackerel may be prey for pilot whales in winter and spring due to their overlapping distributions and behavioral traits.

Pilot whales are thought to be polygynous. Cows may bear one calf every three years. The gestation period is about 16 months and lactation can occur for two years (NMFS, 1984). There is no information available to indicate a specific breeding area or season for pilot whales in the western North Atlantic.

The general distribution of pilot whales may reflect prey distribution. In the MAWMU area, pilot whales are often seen in close association with bottlenose dolphins, (URI, CeTAP, 1982). These associations may be related to their similar prey species and/or to relative advantages of associating with another species presumed to be more efficient at locating certain prey (URI, CeTAP, 1982).

#### GRAMPUS WHALE OR RISSO DOLPHIN

Grampus whales occur from Cape Hatteras to the eastern edge of Georges Bank, with many sightings occurring in the MAWMU area along the shelf edge throughout the year (Figure 9). Grampus whales are usually found between the 100 m and 2000 m contour (Powers et al., 1982). Sightings seaward of the 2000 m contour in spring, summer, and winter and shoreward of the 100 m contour in spring, summer, and fall have been observed (URI, CeTAP, 1982).

Grampus whales feed almost exclusively on squid (Nishiwaki, 1972; Kenney et al., 1983) and are thought to feed at depth.

No information is available on the reproductive behavior of grampus whales.

#### SADDLEBACK OR COMMON DOLPHIN

Saddleback or common dolphins occur along the shelf edge near the 100 m or 200 m depth contour from Cape Hatteras to Georges Bank. They are known to move inshore of the 100 m depth contour seasonally, and are found offshore over deep water during spring, summer, and winter (URI, CeTAP, 1982).

Seasonal variation in the observed densities along the shelf in the MAWMU area is notably opposite that of other cetaceans (Figure 10). Common dolphins are widely distributed in spring throughout the WMU area. In summer, the abundance is low compared to spring, fall, and winter, suggesting a general emigration from the area then. The fall distribution shifts northward over the shelf to Block Canyon and southern Georges Bank. In winter, common dolphins are abundant and distributed widely in the WMU area.

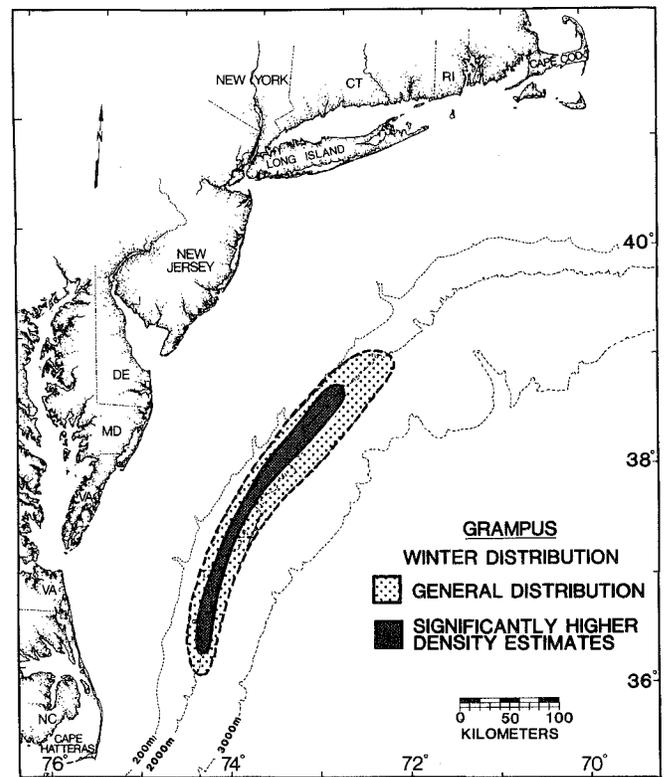
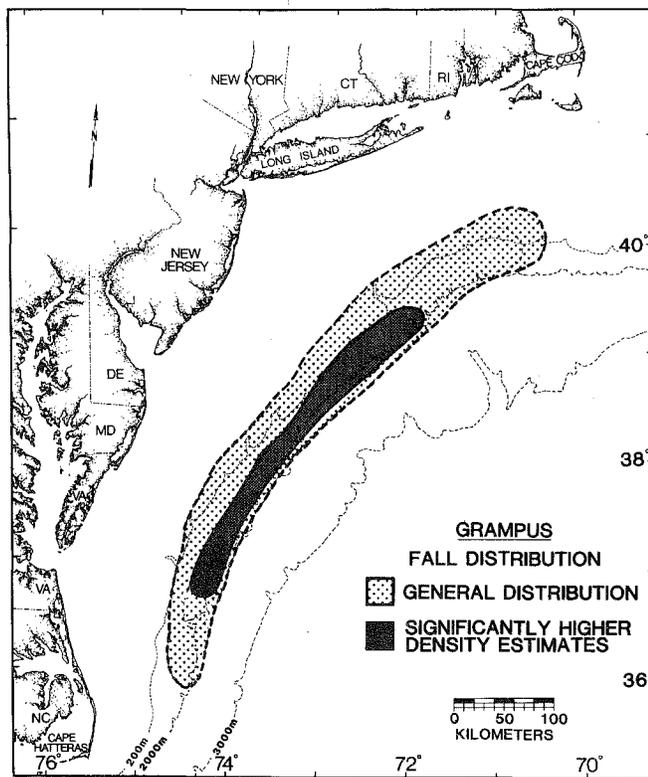
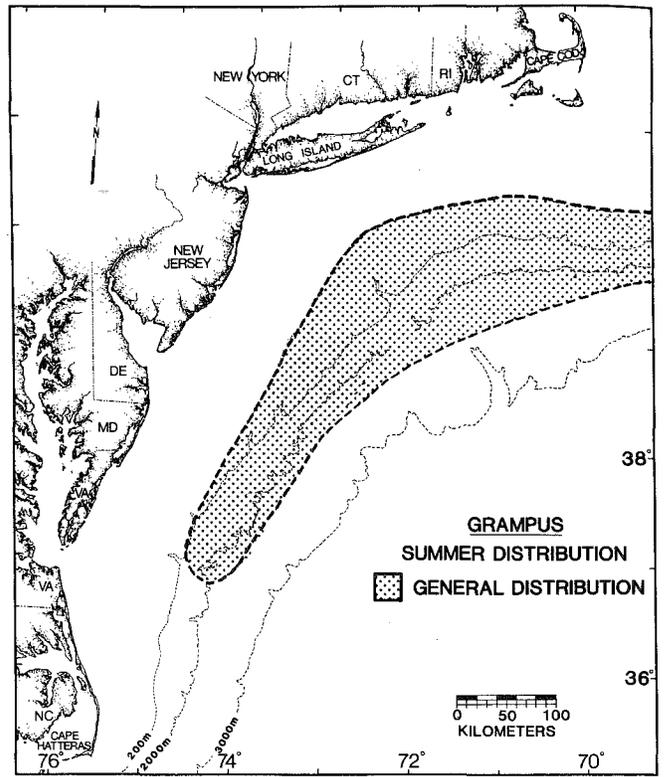
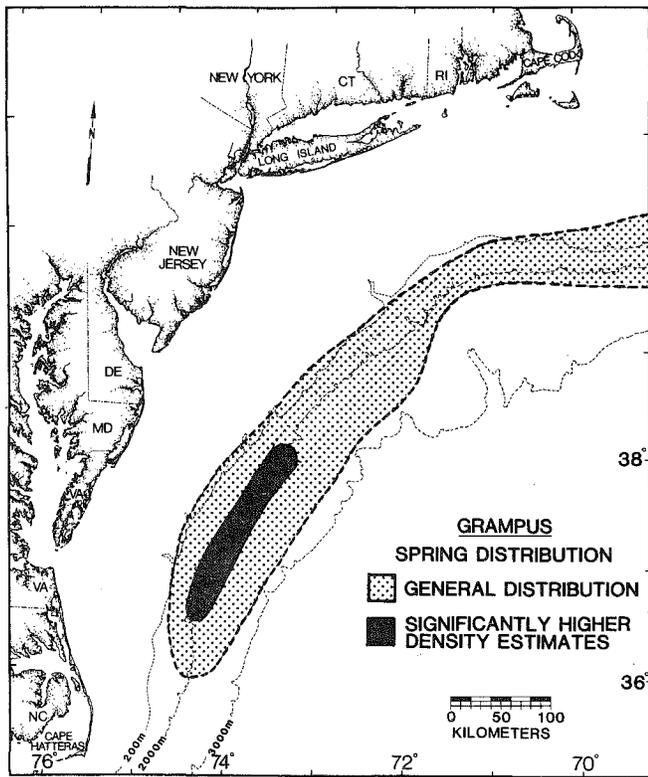


Figure 9. Seasonal distribution, Grampus.

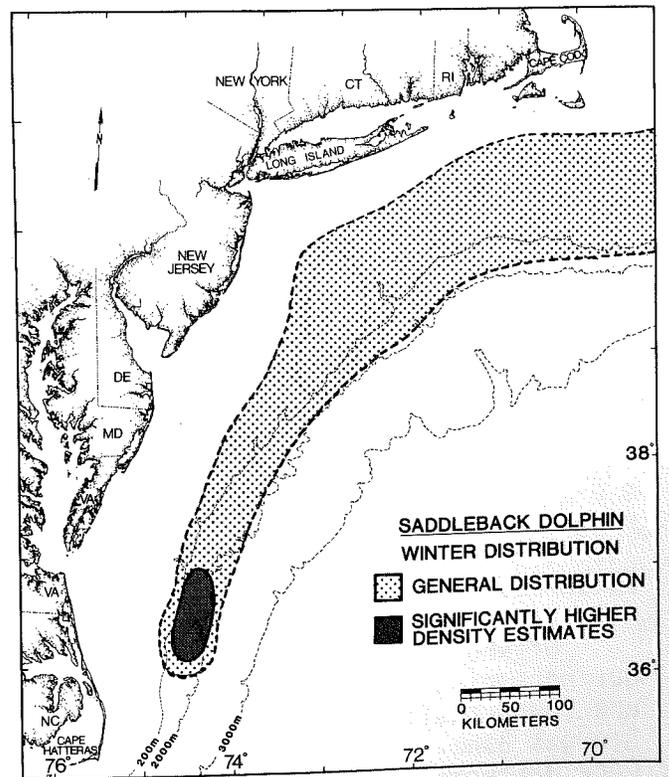
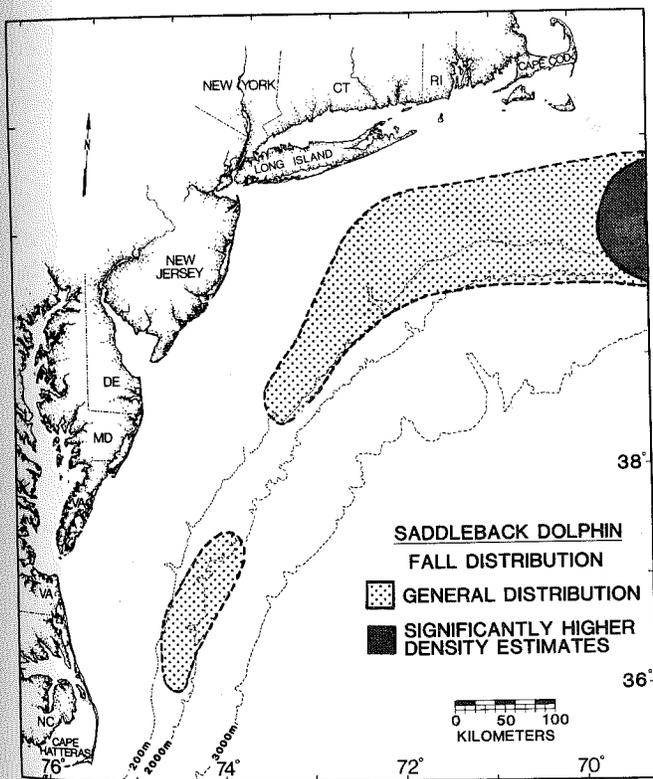
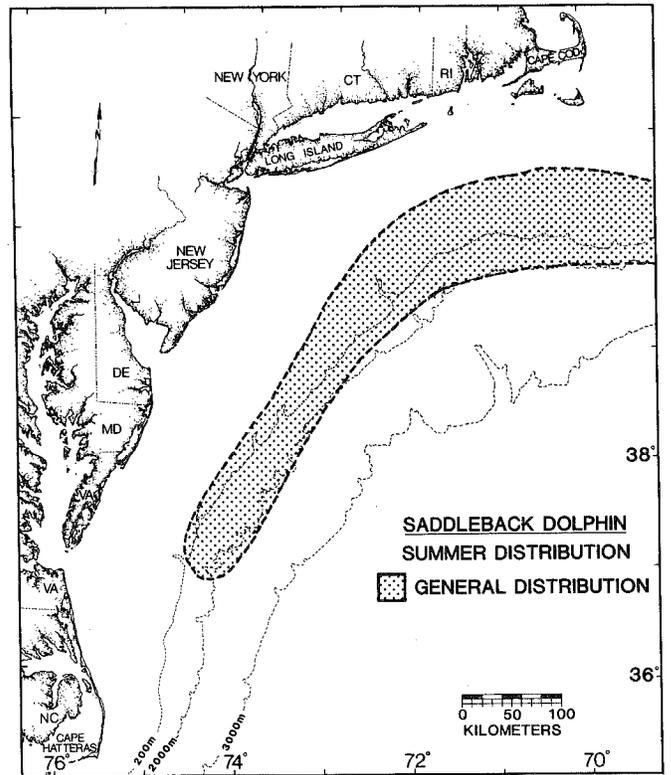
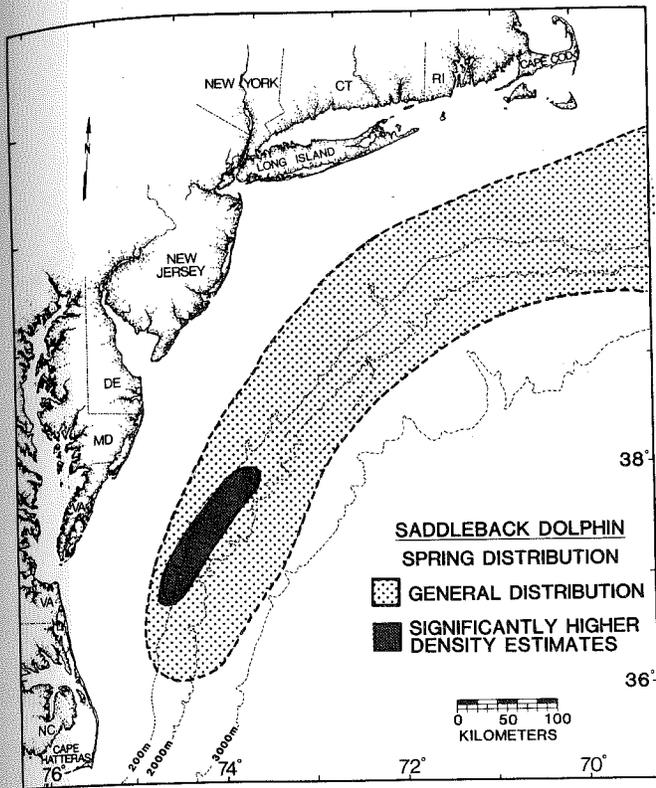


Figure 10. Seasonal distribution, Saddleback dolphin.

Their distribution may indicate habitat preferences or availability of prey species. Common dolphins feed on herring, mackerel, hakes, and squid (Kenny et al., 1983).

Little information is available on reproductive behavior. Males and females may segregate between mating seasons, especially when females are nursing or about to bear young. Cows are thought to bear one calf every three years. The gestation period is about 11 months, and lactation lasts for about 6 months (NMFS, 1984).

#### STRIPED DOLPHINS

Striped dolphins occur along the shelf edge, 1000 m depth contour from south of Cape Hatteras to the southern margin of Georges Bank, and offshore over the continental slope and rise within the MAWMU area (Powers and Payne, 1983). Sightings seaward of the 2000 m depth contour suggest a general inshore/offshore movement between the slope and rise region (URI, CeTAP, 1982).

Seasonal variation in distribution and abundance common to many marine mammals is not seen for striped dolphins. In spring, they occur along the shelf edge in the Mid-Atlantic Bight and southeast of Nantucket (Figure 11). They may occur between Hydrographer's Canyon and the south central margin of Georges Bank in the WMU area throughout the year. However, this distributional information is influenced by difficulties with reliably identifying species of the genus Stenella from the air (URI, CeTAP, 1982).

Striped dolphins feed on a range of prey items, including mackerel, herring, and squid (Kenney et al., 1983).

No information is available on the reproductive behavior of Atlantic striped dolphins. Spring and fall breeding seasons are reported for striped dolphins inhabiting Japanese waters (NMFS, 1984). The gestation period is thought to be 12 months and lactation may occur for up to 18 months. Cows probably bear a calf every three years (NMFS, 1984).

#### ATLANTIC BOTTLENOSE DOLPHIN

Bottlenose dolphins occur in two distinct areas in the western North Atlantic. The offshore distribution generally extends from Cape Hatteras to the eastern tip of Georges Bank along the shelf edge, centered about the 1000 m depth contour, but occasionally deeper (URI, CeTAP, 1982). Nearshore, they range from south of Cape Hatteras to Cape Henlopen, Delaware (URI, CeTAP, 1982), periodically moving into the mouth of the Chesapeake Bay and other estuaries (Blaylock, 1982).

Offshore distributions remain relatively constant throughout their range during spring, summer, and fall (Figure 12). In winter, bottlenose dolphins are found inside the 2000 m contour from Cape Hatteras to the southern edge of Georges Bank. The nearshore distribution follows the coastline from south of Cape Hatteras north to Cape Henlopen. Relatively constant in spring and summer, it shifts southward in fall. In winter, bottlenose dolphins are

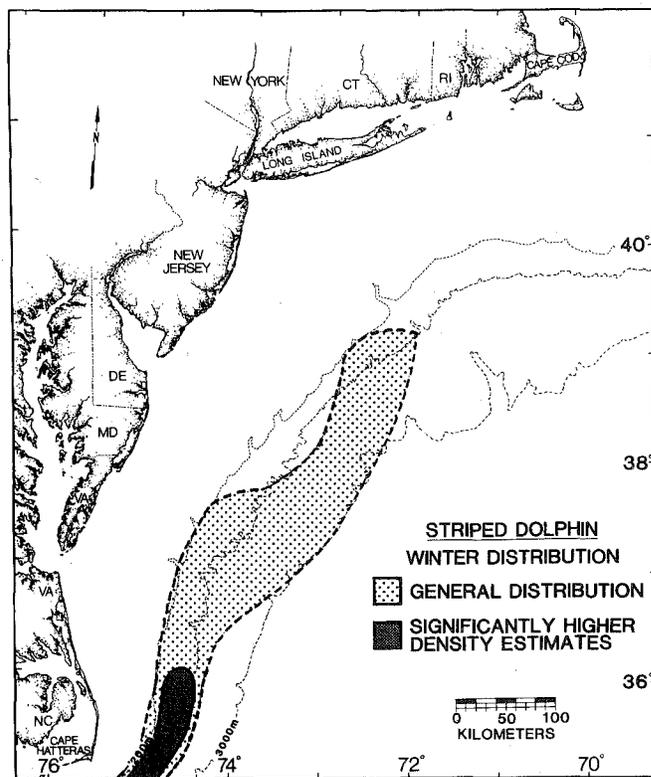
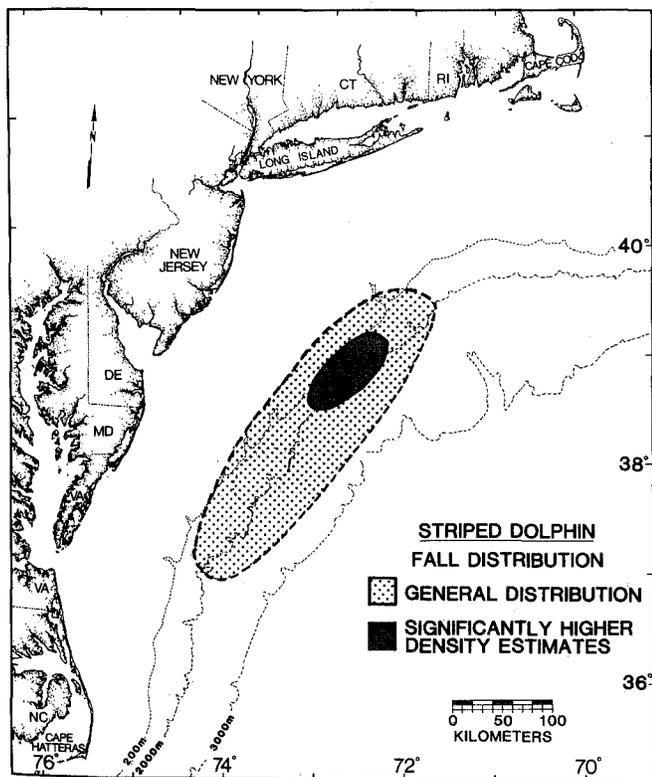
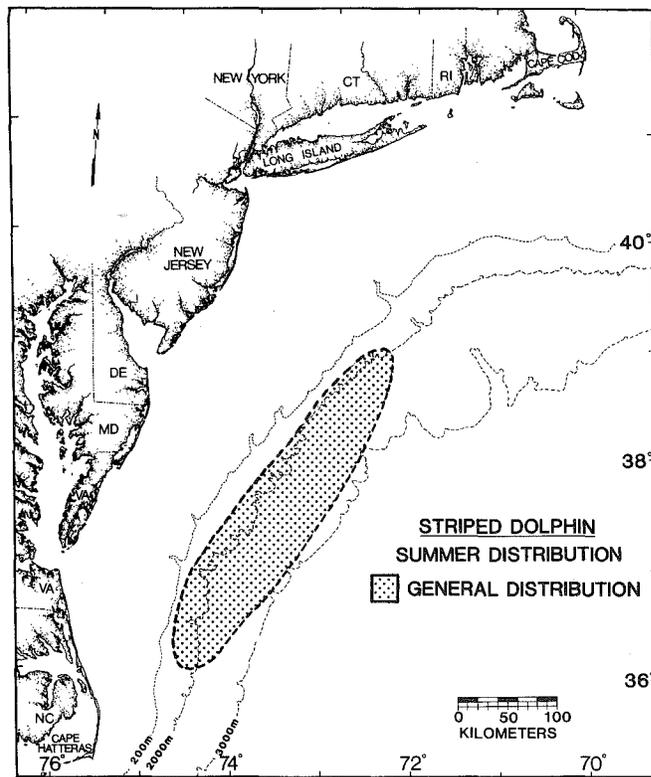
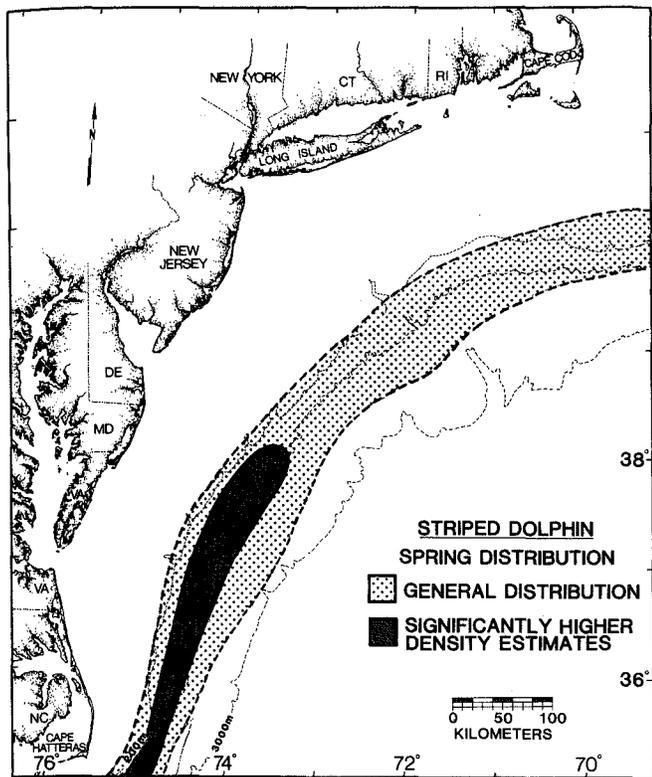


Figure 11. Seasonal distribution, Striped dolphin.

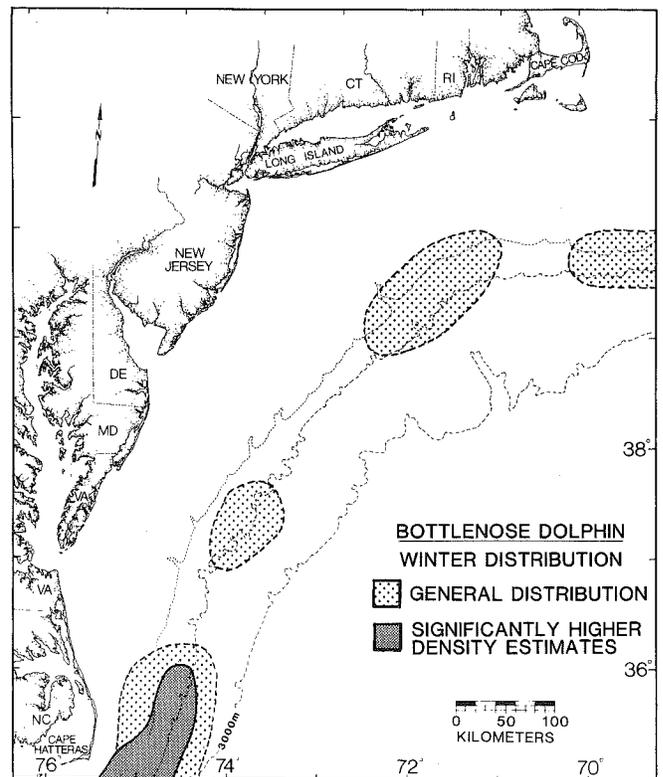
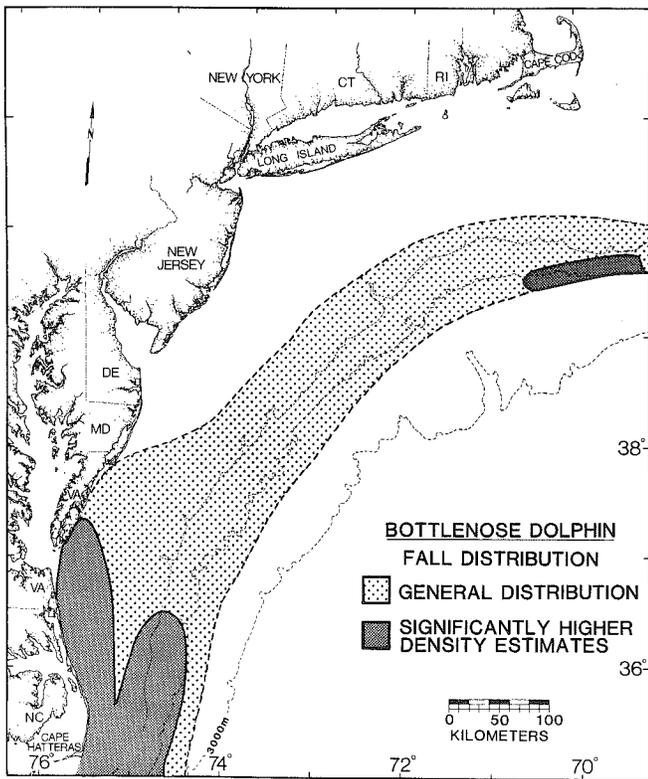
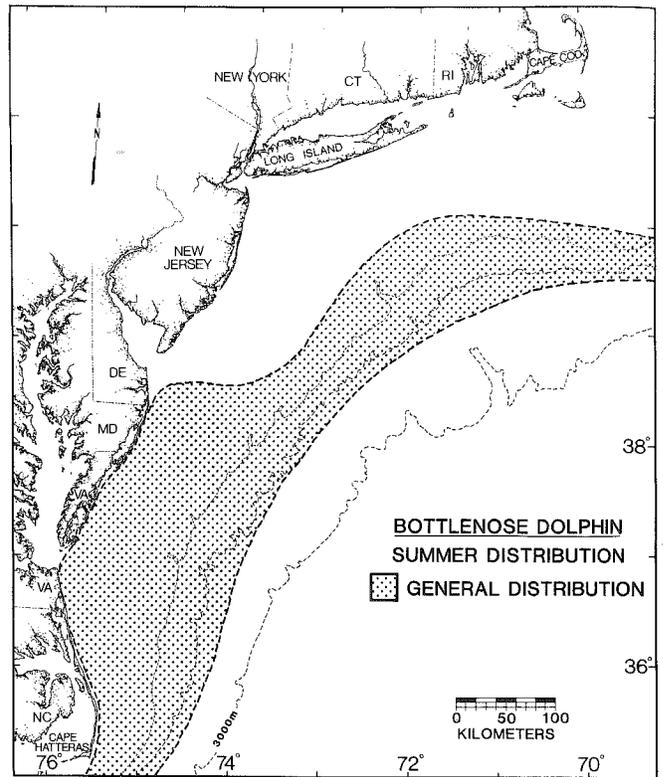
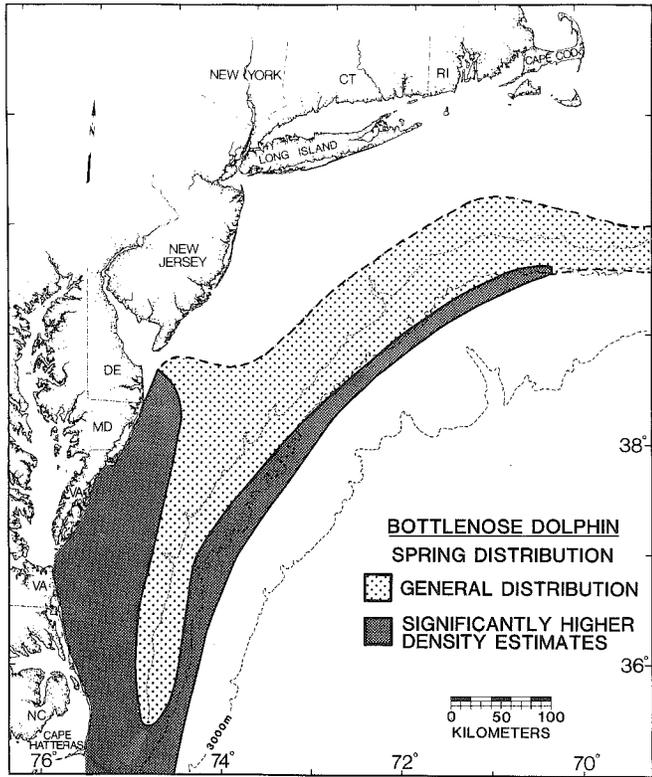


Figure 12. Seasonal distribution, Bottlenose dolphin.

almost completely absent from the nearshore areas of the WMU area. A decrease in distribution and abundance in winter suggests a general movement south and supports the hypothesis of seasonal migratory behavior (Hogan, 1983).

Bottlenose dolphins feed below the water surface almost exclusively on fish (Keeney et al., 1983) although squids and molluscs are known to make up part of their diet. They have been observed to use cooperative behavior to feed on fish schools (Hoese, 1971, 1982) and are often seen in close association with pilot whales (Norris and Dohl, 1980; URI, CeTAP, 1982).

Bottlenose dolphins appear to mate and calve throughout the year (NMFS, 1984), and adults bear one calf every two years. The gestation period is about 12 months and lactation can occur for one year although it is not uncommon for calves to start eating solid food in about six months. Calves may remain with adults for several years after birth.

#### SPOTTED DOLPHIN

Two species of spotted dolphins, (Stenella attenuata or frontalis) and (S. plagiodon) occur in the northwest Atlantic Ocean and are considered together here because their taxonomic definitions are still unresolved. Their distribution is generally confined within the WMU area to waters along the shelf edge centered about the 200 m depth contour and offshore over deep water from New Jersey southward (Figure 13). Occasional sightings occur on the shelf north of New Jersey (URI, CeTAP, 1982). In spring, spotted dolphins occur along the shelf in the MAWMU.

As with S. coeruleoalba there is no information available on the distributional variances between sexes and age classes of spotted dolphins. Their distribution may be a general response to the distribution and abundance of prey, particularly along the shelf break area from Cape Hatteras to Cape May (URI, CeTAP, 1982). Spotted dolphins generally feed below the water surface on fishes and squid (Kenney et al., 1983).

Little information exists on the reproductive behavior for the northwest North Atlantic spotted dolphin. It is suggested that breeding is seasonal with prolonged calving seasons in spring and fall (NMFS, 1984). The gestation period is about 11-12 months and lactation occurs for approximately 11 months (NMFS, 1984).

#### HARBOR PORPOISE

Harbor porpoises are distributed north of the 40°N latitude in New England waters (URI, CeTAP, 1982). They have been sighted south to the Chesapeake Bay (Prescott and Fiorelli, 1980).

In spring, harbor porpoises are widely distributed and abundant in the northern Gulf of Maine/lower Bay of Fundy entrance area (outside of the WMU area) and east and southeast of Cape Cod (Figure 14). Summer sightings are generally confined to the northern Gulf of Maine area (Kraus and Prescott, 1984), and summer sightings in the Cape Cod area are almost absent. They are almost completely absent from the MAWMU area in fall and winter. The adults range further to waters off of New Jersey in their distribution. Differences

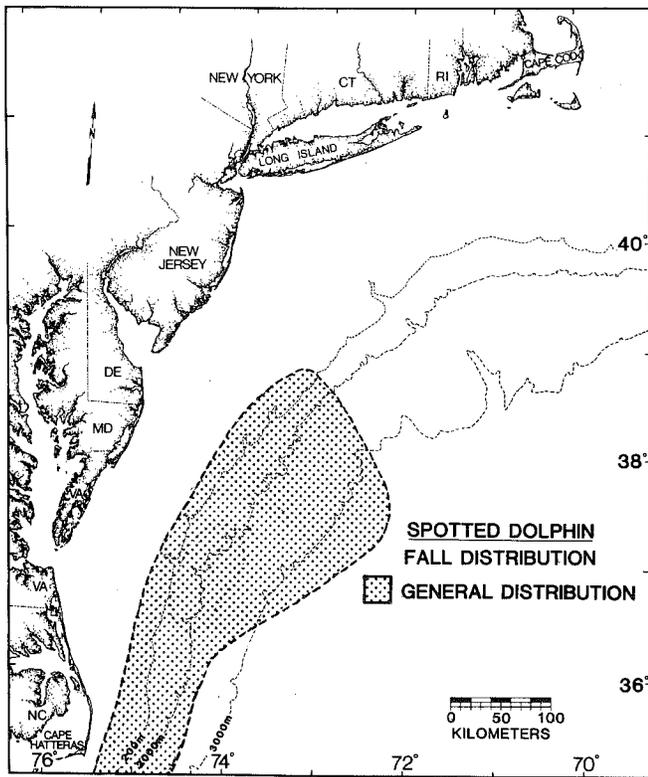
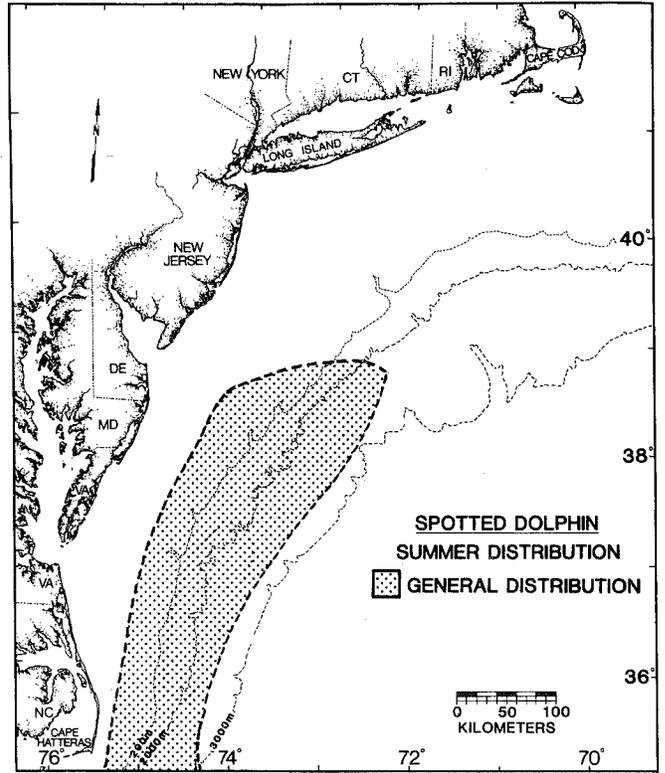
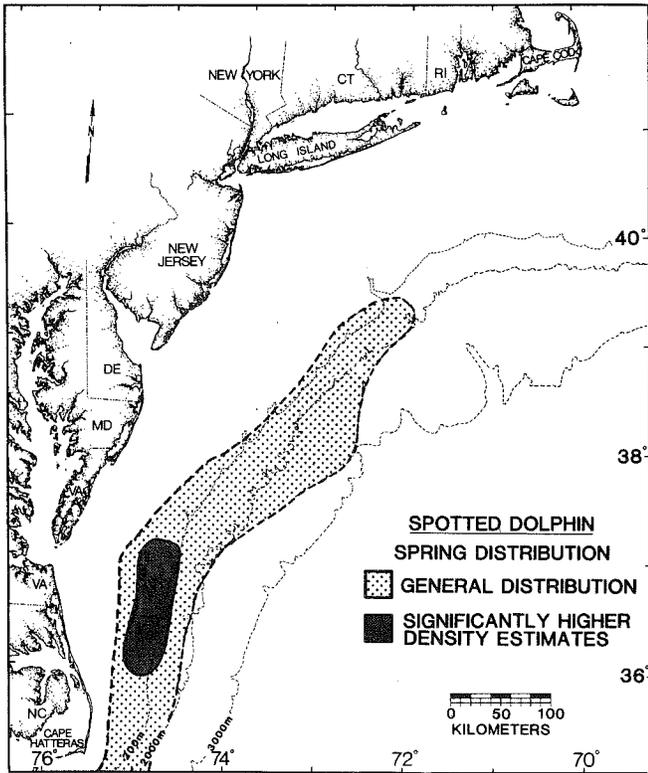


Figure 13. Seasonal distribution, Spotted dolphin.

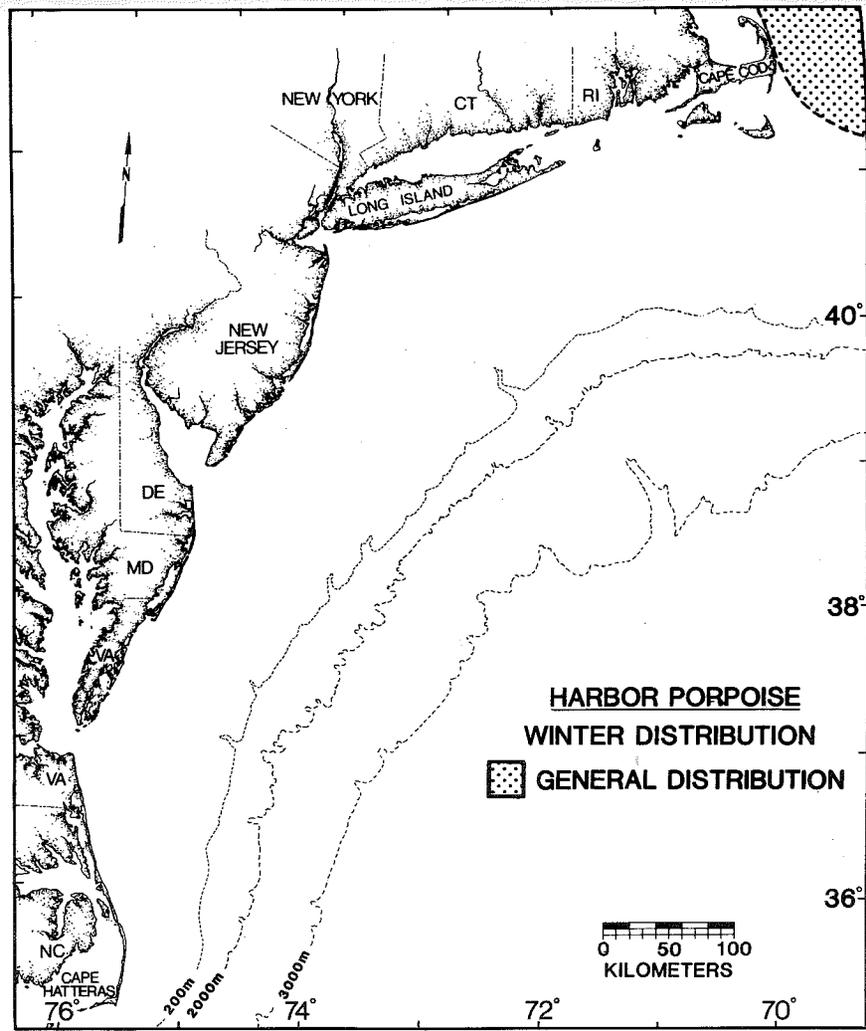
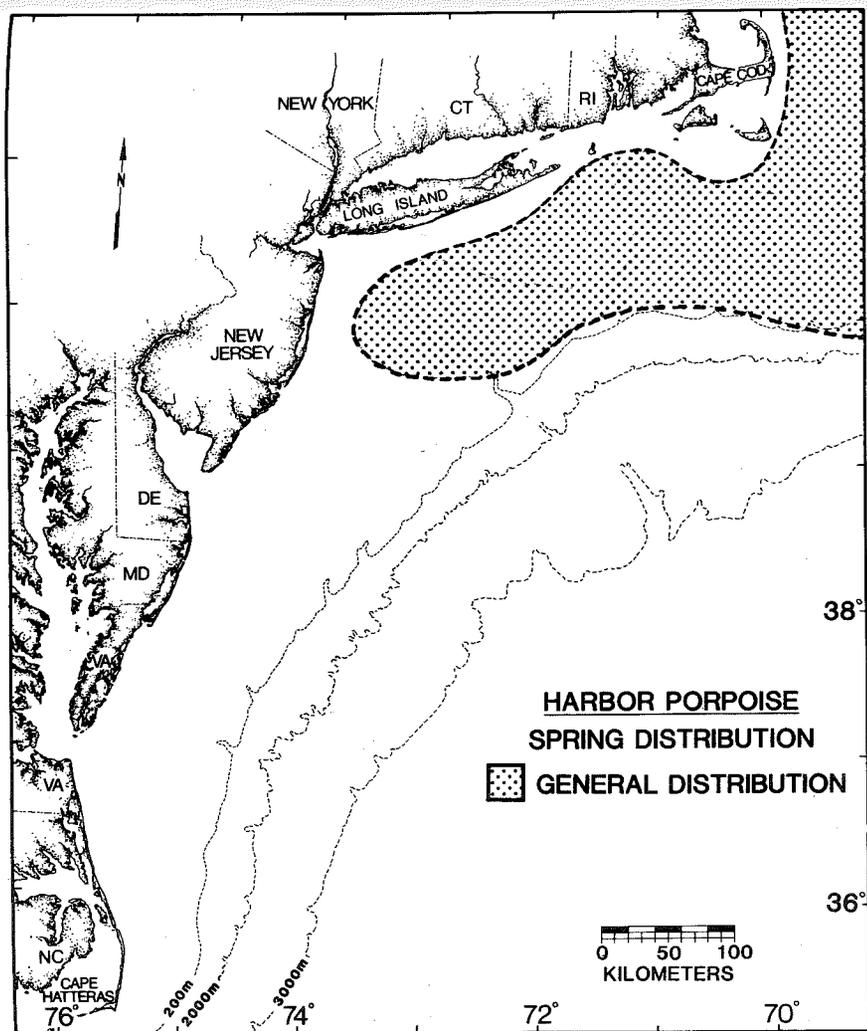


Figure 14. Seasonal distribution, Harbor porpoise.

in relative abundance indices developed by Kraus and Prescott (1984) support the Gaskin et al. (1983) hypothesis of a combined inshore-offshore/north-south migration.

Harbor porpoises often feed near the bottom of the ocean on cod, mackerel, herring, and benthic invertebrates (Smith and Gaskin, 1974; Kenney et al., 1983; Gilbert and Wynne, 1984).

Prescott and Fiorelli (1980) suggest that birth frequency of calves born reaches a peak during June and July. Given the seasonal distribution of adults and sightings of calves, a higher percentage of births may take place north of Cape Cod to the Bay of Fundy.

## SEA TURTLES

### LEATHERBACK SEA TURTLE

Endangered leatherback sea turtles occur primarily south of New England, although they range to Newfoundland in summer. They are predominately a pelagic species, although they were sighted in the Severn River in the Chesapeake Bay system (Musick, 1979). Leatherbacks are the only sea turtle capable of regulating their body temperature above ambient.

The distribution of leatherback sea turtles varies seasonally; these animals are common in nearshore and the mid-shelf regions of the New York Bight (URI, CeTAP, 1982) in summer (Figure 15). Sightings drop dramatically in spring, fall, and winter. Based on higher densities observed in the summer, it is thought that these animals follow particular isothermal conditions as they seek out concentrations of boreal jellyfish, their primary prey species.

Nesting activities occur along Florida beaches and throughout the Caribbean from April through August. Females nest at intervals of 2-3 years and lay as many as six clutches of eggs with each clutch averaging 80-85 eggs (Fritz and Reynolds, 1981).

### LOGGERHEAD SEA TURTLE

Threatened loggerhead sea turtles are the most common sea turtle species occurring in the western North Atlantic (Shoop et al., 1981). They are primarily distributed along the continental shelf from south of Cape Hatteras to Cape Cod. However, they also enter major embayments (i.e., Chesapeake Bay, Delaware Bay, Cape Cod Bay, and Long Island Sound).

Spring and fall distributions of loggerheads are similar, with sightings occurring south of New Jersey in shelf/slope waters (Figure 16). In summer, they are widely distributed throughout the MAWMU area in nearshore areas of the New York Bight extending southeast to the shelf edge. Their winter distribution is limited to the southern area of their range in waters above 10°C.

Loggerheads feed on a wide variety of benthic prey items including sponges, bivalve molluscs, gastropods, squids, crabs, shrimp, barnacles, and various species of sea grass (Musick, 1979).

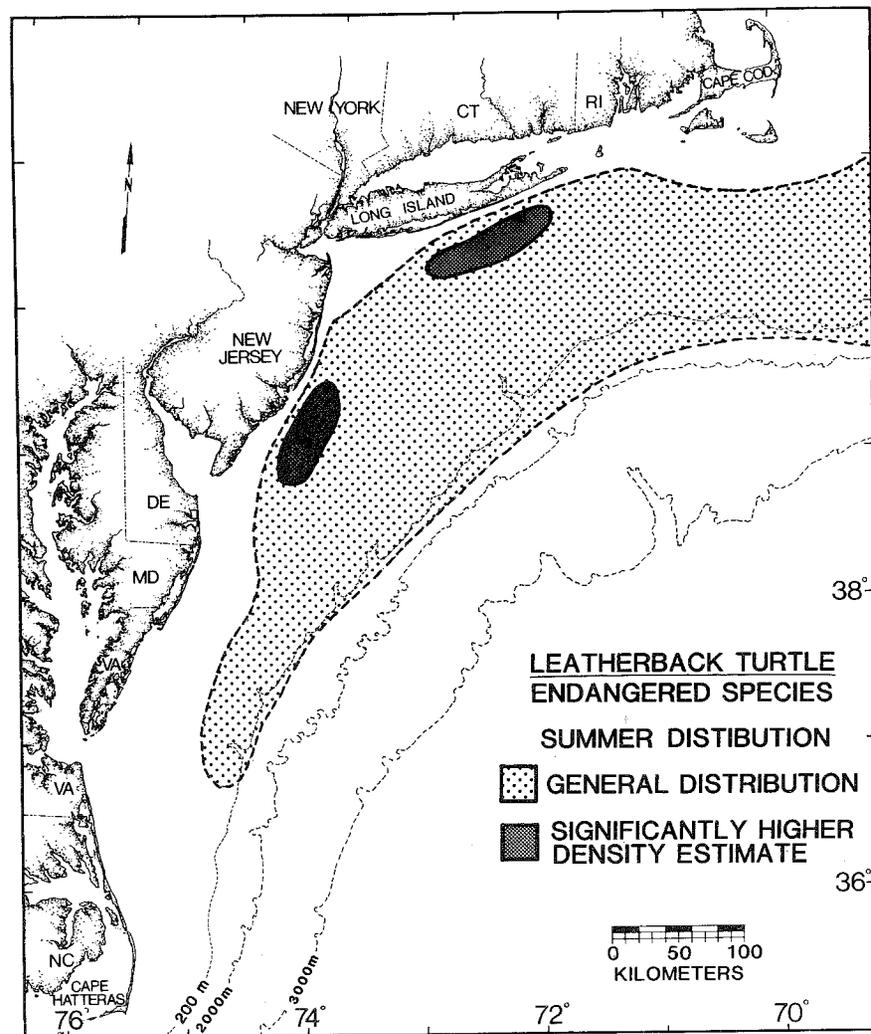
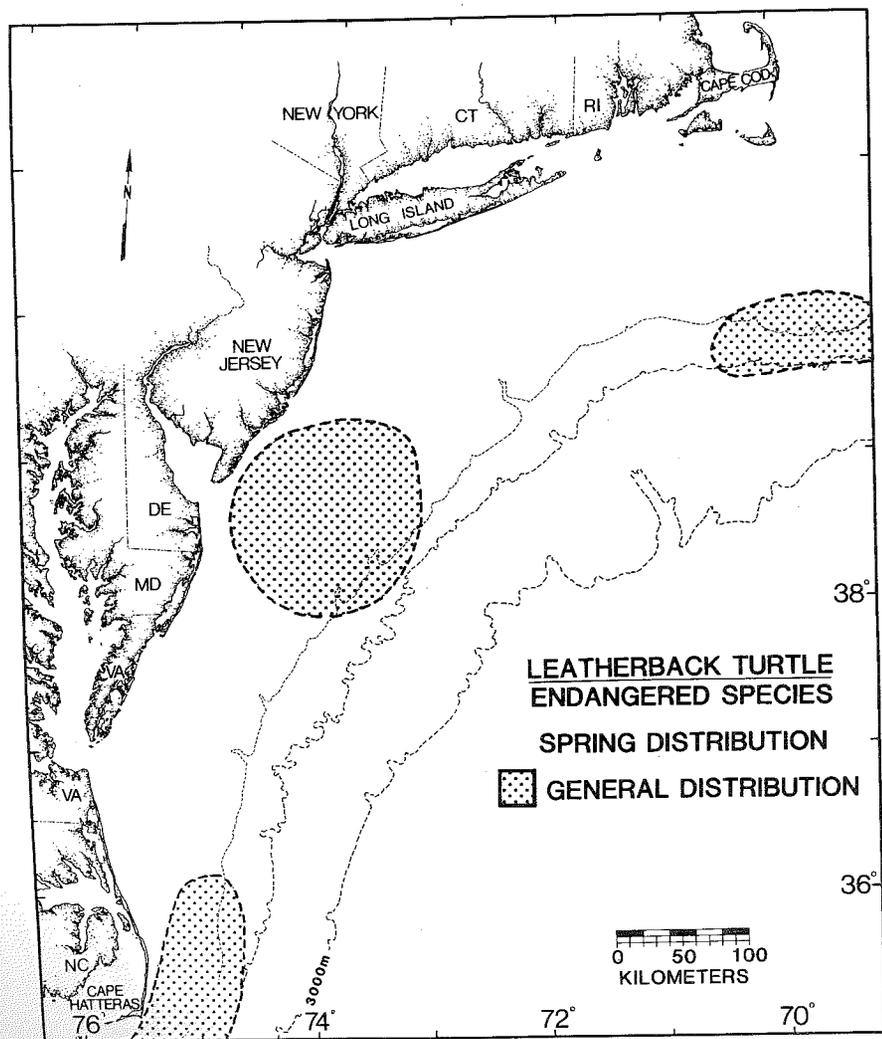


Figure 15. Seasonal distribution, Leatherback turtle.

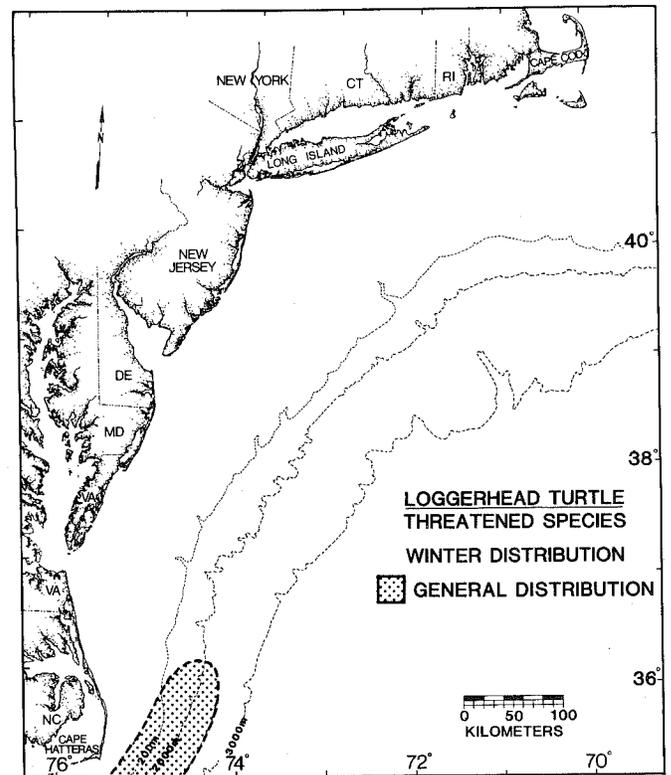
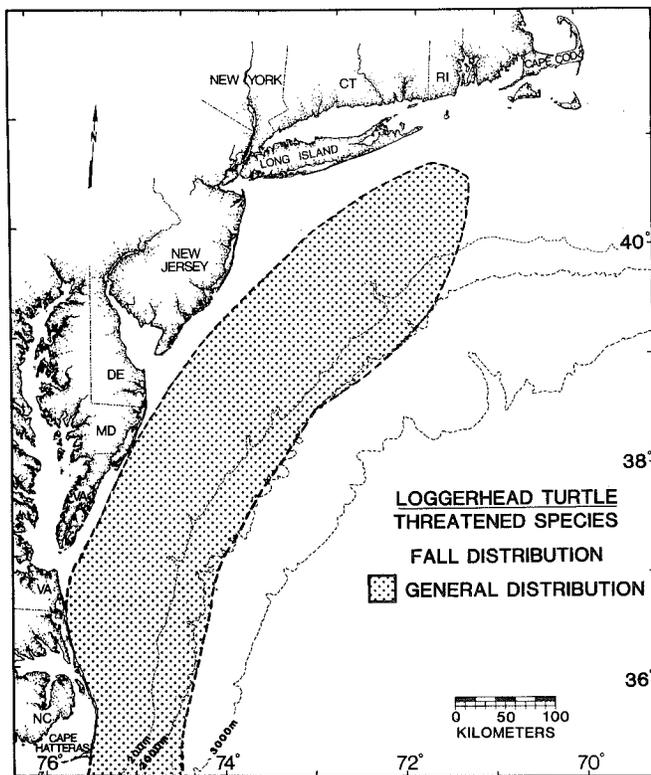
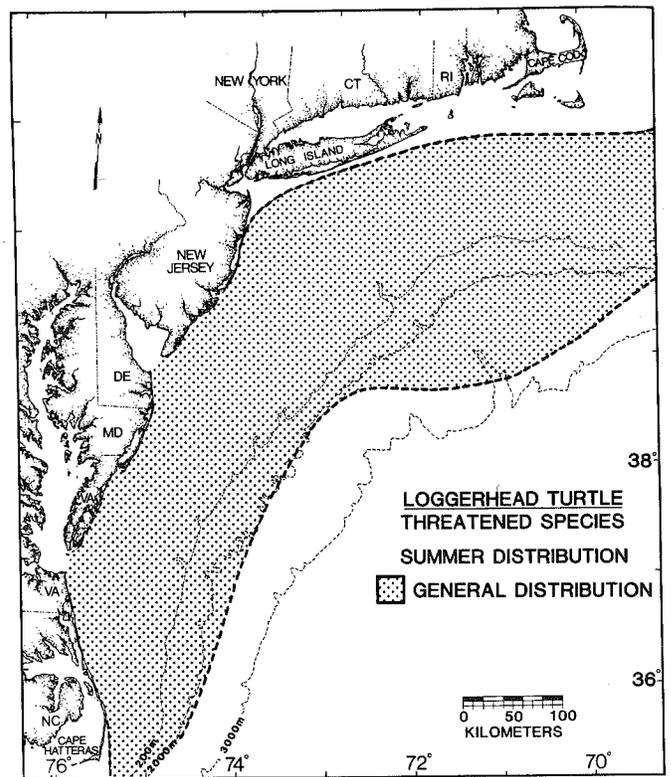
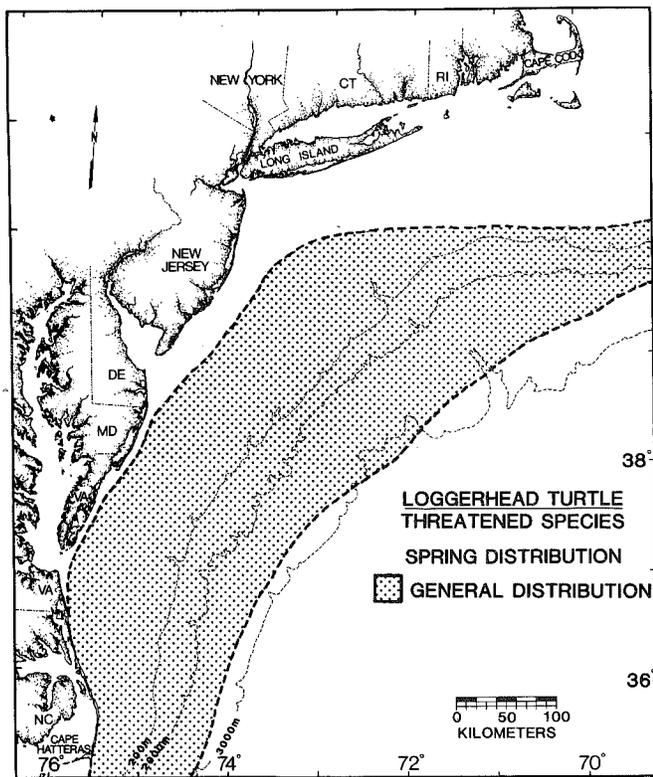


Figure 16. Seasonal distribution, Loggerhead turtle.

Nesting activities are limited within the U.S. from Florida to Virginia beaches from April through August (Musick et al., 1983). Nesting sites in Virginia have been reported on the barrier islands off the Eastern shore and near the Back Bay Wildlife Refuge, south of Sandbridge in Virginia Beach (Musick et al., 1979).

#### KEMP'S RIDLEY SEA TURTLE

A distributional figure is not provided because of lack of sighting data. Kemp's ridley sea turtles are the most endangered sea turtle species. Their distribution is poorly understood, and is known almost exclusively through strandings (URI, CeTAP, 1982). Kemp's ridleys favor inshore shallow bays where crabs and mollusks provide their major food. Cape Cod Bay, Long Island Sound, Delaware, and Chesapeake Bay are occupied by Kemp's ridleys in summer and fall. Stranded immature and juvenile ridleys are found in the bays listed above.

Kemp's ridleys feed mostly on benthic organisms including crustaceans and mollusks.

They nest from April to August on one beach at Rancho Nueve, Mexico. There are approximately 500 nesting females remaining in the population.

#### PINNIPEDS

##### GREY SEAL

Grey seals occur in a strictly defined area of the Middle Atlantic region, from the west end of Nantucket to Martha's Vineyard and Muskeget Island. Approximately 30-50 animals occur in this area. This colony is believed to be part of the Canadian stock of grey seals.

##### HARBOR SEAL

The range of harbor seals is centered in the Gulf of Maine, but it extends south of Cape May, with the highest concentration in the Cape Cod area in winter.

Movement of harbor seals into southern New England area from their northern breeding areas occurs from December to March. In spring, harbor seals begin to move north and arrive at their breeding areas in early summer, and remain through fall. Harbor seal haul-out sites have been identified in Maine by Gilbert and Wynne (1983) and in southern New England by Payne and Selzer (1983). Primary haul-out sites adjacent to the MAWMU area are on Cape Cod at Monomoy Point, Race Point, Billingsgate Shoals, and eastern Nantucket Island (Paine and Selzer, 1982). Sightings of harbor seals in Long Island Sound also occur in winter (Sam Sadove, personal communication).

Harbor seals are opportunistic feeders and prefer small, off-bottom schooling fishes such as Atlantic cod, sand lance, and squid.

Pupping occurs from early May to mid-June on rocky ledges in mid-coastal Maine (Gilbert and Wynne, 1983). Gestation is approximately 10-11 months and the young pups nurse for only 4 to 6 weeks (NMFS, 1984).

## DISCUSSION

Marine mammals and sea turtles use the MAWMU area for feeding, nursing, breeding, and as a migratory pathway north to the Gulf of Maine region and south to breeding/calving/nesting areas. Research and models on the relative importance and role that these species play in the dynamics of the northwest Atlantic ecosystem are not extensive, and therefore not well understood. It has been implied that cetaceans, as apex predators, perform relatively minor functions in influencing energy flow and nutrient recycling within this ecosystem (Cohen et al., 1982; Sissenwine et al., 1983). In the Southern Ocean (Beddington and May, 1982; May et al., 1979) and in the northeast Pacific (Laevastu et al., 1979) marine mammals are known to play a significant role in the energetics of the ecosystem. Using CeTAP data, Scott et al. (1983) prepared quantitative assessments of the whale component in continental shelf waters between Cape Hatteras and Cape Sable, Nova Scotia. Their study was divided into four ecosystems; the Gulf of Maine (GOM), Georges Bank (GB), Southern New England (SNE), and the Mid-Atlantic Bight (MAB). Two of the four ecosystems, SNE and MAB, occur within the MAWMU area.

Scott et al. (1983) determined consumption estimates of cetaceans based on a framework developed by Gaskin (1976, 1982). Whales were grouped as plankton, fish, or squid eaters. Use of SNE and MAB areas by cetaceans were indexed by the total cetacean density and biomass density. Of the four ecosystems examined, the MAB had the lowest use, based on total cetacean and biomass density. The MAB showed maximum cetacean biomass density in spring and generally a low biomass density thereafter. In SNE, peak cetacean density is in winter, and peak biomass density occurs in summer. Fish eaters (i.e., spotted, white sided, bottlenose, and common dolphins) dominate in the MAB and SNE except for summer and fall in the MAB when squid eating cetaceans (i.e., sperm and pilot whales, and grampus dolphins) are dominant. Feeding type diversity in SNE generally mirrors species diversity while feeding diversity in the MAB was generally invariant over seasons (Scott et al., 1983). Prey species consumption by whales varies between SNE and MAB. Zooplankton consumption had relatively minor importance in SNE and MAB waters; squid consumers correlated with the assumed concentrations of *Loligo* sp. and *Illex* sp. along the continental shelf. The consumption of zooplankton, squid, and finfish necessary to meet metabolic requirements of whales occurring in SNE south to Cape Hatteras was estimated based on the primary productivity in this area. Total consumption by whales in SNE is estimated at 7.9 thousand metric tons (mT) zooplankton, 286.3 thousand mT finfish, and 99.4 thousand mT squid. Direct consumption of prey species in the MAB is estimated to be 0 zooplankton, 130.6 thousand mT finfish, and 118.8 thousand mT squid. These levels of consumption account for 18-31.0% of measured primary productivity in SNE and 16-28% in the MAB. These estimates are conservative due to the abundance and biomass estimates on which they were based and the simple trophic model used; they could be 2-3 times greater (Scott et al., 1983). Hain et al. (1985) estimated food requirements for shelf edge cetaceans to be about 480 thousand mT and suggests that consumption by whales along the shelf edge region is in the same range for Georges Bank. Consumption by whales on Georges Bank is about 8% of the total production of fish, man takes about 11% of the total fish production, and roughly 75% is consumed by their own kind. Consumption of fish by whales in western North Atlantic shelf waters may not be as insignificant as previously suggested. A significant portion of finfish

consumed is American sand lance Ammodytes sp., primary prey species for humpback and finback whales. Increases in sand lance abundance have been dramatic, ranging from less than 50% of the total ichthyoplankton community in 1974 to more than 85% in 1979 from Cape Hatteras to the Gulf of Maine (Sherman, 1981). Recent NEFC survey data indicate a decrease in the sand lance population. Standing stock biomass of sand lance in the western North Atlantic is estimated at about 2 million mT, but appears to be declining. Information presented by Scott et al. (1983) and Hain et al. (1985) on whale consumption estimates suggest that they may be significant predators on marine resources of the western North Atlantic and place large energetic demands on the ecosystem (Kenney and Winn, 1987; Scott et al., 1983). Differences in cetacean frequency distributions, biomass, and feeding diversities are apparent, and may reflect behavioral patterns like migration like migration, response to prey species, and habitat partitioning (Scott et al., 1983).

Seals are opportunistic feeders, and feed in waters adjacent to their haul-out locations on fish that are seasonally abundant (Payne and Selzer, 1983). Assuming harbor seals consume 4% of their body weight a day, using NMFS/NEFC inshore stratum for Cape Cod, and haul-out sites within these stratum, Payne and Selzer (1983) estimated the amount of fish consumed by a winter population of approximately 3,000 animals in southern Massachusetts from November-April to be about 2.0 mT. When compared with landing data from that area, harbor seals have relatively minor effects on commercially important prey species in the Mid-Atlantic areas in which they feed (Payne and Selzer, 1983).

Since sea turtle species do not use the MAWJU area to nest, the occurrence of these animals is in response to food availability and/or other favorable environmental conditions. Loggerhead sea turtles are omnivorous, feeding on crustaceans, bivalve mollusks, squids, cnidarians, and some seaweeds. Leather-backs feed in temperate waters primarily on cnidarians and Kemp's ridleys feed on crabs and mollusks. No consumption rates or biomass estimates have been made for sea turtles.

#### Human Activities and Effects on Whales, Sea Turtles, and Seals

Some literature is available on effects of anthropogenic activities on marine mammals and turtles. Extensive information exists on the potential effects of oil and gas exploration, production, and associated activities on mysticete (baleen) and odontocete (toothed) cetaceans, and pinnipeds (Gales, 1981; Baker et al., 1982; Geraci and St. Aubin, 1982); Malme et al., 1983; LGL Ecological Research Associates, 1983; and NMFS, NER Biological Opinions. Levels of toxic compounds in some marine mammal and turtle tissues from non-point source pollution (i.e., urban, industrial, and agricultural runoff) and from point source pollution (i.e., ocean dumping) have been analyzed (Englehardt, 1983; Gaskin, 1982). Cumulative and synergistic effects of these activities on short- and long-term survival of individuals and populations remain undefined and speculative because no cause and effect relationships have been established.

Interest in effects of oil and gas, ocean dumping, incineration, and non-point source pollution activities on marine mammals and turtles has been stimulated by the general assumption that adverse impacts from these activities will occur directly to individuals, or indirectly through

contamination of prey species and/or disruption of habitat. Contact with viscous oils can lead to ingestion, inhalation of volatile components, coating of the body surface, interference with swimming and thermoregulatory abilities, and fouling of the filtering mechanisms of baleen whales. Some seals can absorb oil through skin, the gastrointestinal tract through ingestion, and lungs through inhalation. Seals and certain whale species appear to have detoxifying mechanisms to break down ingested compounds into less toxic forms that can be excreted regularly (Gaskin, 1982; Engelhardt, 1983). Although marine mammals tend to be grouped together by their life habitats, responses to major impacts and susceptibility to petroleum toxicity may be species specific. Investigations of oil spill incidents to define toxicities of petroleum to marine mammals and turtles and, investigations of other effects of oil and gas activities on these animals are not conclusive, though mortality has been attributed to oil exposure at sea (Engelhardt, 1983). Certain species may be vulnerable to the effects of oil through the food chain. Bivalves and crustaceans are known to bioaccumulate hydrocarbons (Bieri, 1982) and it is likely that biotransfer to marine mammals and turtles will occur where these animals, prey species, and oil or other discharges coincide. If marine mammals are vulnerable to oil, their ability to detect and avoid oil on water or in their food may be worth investigating and is important in assessing impacts to those species. Data from oil-coated seals indicate that some seal species do not consistently avoid oil. Conflicting evidence exists on the ability of odontocete species to detect and avoid oil. Gooddale et al. (1981) indicate that a wide range of cetacean species did not actively avoid oil in the water from the Regal Sword spill that occurred June, 1979, southeast of Cape Cod in 82 m of water. Animals were found swimming and feeding in both oil-covered and oil-free waters. Surface and sub-surface feeding by whitesided dolphins, humpback, and finback whales was observed. These observations strongly suggest that these species do not actively avoid oil covered water. Laboratory studies (Geraci and St. Aubin, 1982) indicate that trained bottlenose dolphins are able to detect oil at the water surface both visually and by echolocation when the oil is above a certain level of optical density and thickness. While odontocetes have echolocation capability (Norris, 1969), mysticetes apparently do not (Beamish, 1977; Eberhardt and Evans, 1962). Geraci and St. Aubin (1979) studied the behavior of grey whales in the presence of oil slicks from natural seeps and showed that they did not actively avoid surface oil. Alterations of their respiratory patterns may indicate an ability to avoid or react to oil slicks by means other than echolocation. Observations indicate that cetacean distribution and abundance adjacent to the New Jersey coast in the Department of Interior's Lease Sale Areas was "grossly" influenced by the presence of oil rig activities (Sorensen et al., 1984). These results are similar to LGL (1983) observations of bowhead whales near industrial operations in the Beaufort Sea. Concerns remain among managers, scientists, and the general public that oil and gas exploration, production, and development could directly and/or indirectly effect these animals by disrupting normal feeding behavior, migratory pathways, or by degradation of food sources and/or habitat. If so, long-term survival of individuals may be affected, and subtle changes at the population level may go undetected for a long period.

Information on effects of oil and gas activities on turtles is generally not available. It has been hypothesized that platform rigs may act as attractants for turtles. It is reasonable that turtles surfacing in an oil slick could become sufficiently fouled with oil to suffocate.

A widespread threat to marine mammal and turtle species, directly or indirectly through the food chain, is the cumulative and synergistic effects from toxic chemicals reaching the ocean from urban, industrial, and agricultural effluents and from ocean dumping (Gaskin, 1982; NMFS, unpublished documents). Marine mammals are long-lived relative to most marine organisms so exposure to toxic chemicals occurs over a long period. Lipid depot reserves that can be large in proportion to body size and weight, make them likely candidates for accumulating high concentrations of chlorinated hydrocarbons (Gaskin, 1982). A well documented case concerns the reproductive fitness in seals in the Baltic where high levels of polychlorinated biphenyls and DDT were correlated with a reduced number of offspring (Englehardt, 1983). Most marine mammals have lived with metal trace element contamination from natural sources and some apparently have evolved cellular mechanisms to mitigate the toxic effects from these elements. Chlorinated hydrocarbons, biphenyls, and chlorinated pesticides are present in Chesapeake Bay sediments and benthic biota (Bieri et al., 1982). Typical hydrocarbon pollutants found in sediments have been reported in the horseshoe crab Limulus polyphemus (Smith et al., 1979), a major food source for loggerhead sea turtles. The presence of hydrocarbons in the habitat and food of loggerheads and other turtle species result in measurable accumulation within tissues of stranded specimens (Musick, 1983). Hydrocarbon compounds commonly found in other areas of the Chesapeake Bay were present in loggerhead and leatherback sea turtles taken from the Bay and Virginia waters. However, impacts to sea turtle populations remain unknown. Leatherback sea turtles feed mostly in the water column on jellyfish and other coelenterates. Such prey may provide less of an opportunity for exposure of leatherbacks to hydrocarbon pollutants than occurs in loggerheads or Kemp's ridleys.

Information on effects of ocean dumping in the MAB show that waste inputs have caused environmental damage at coastal shelf sites including adverse effects to shellfish, finfish, and other marine resources. Characteristics of deepwater dumping areas such as the 106 Mile Site allow for much greater dispersion and dilution of disposed material. No evidence exists that indicates waste dumped at this site reaches the sea floor in detectable amounts. O'Conner et al. (1985) developed a monitoring strategy to determine spatial distribution of contamination in the sediment and water column. The Environmental Protection Agency, in coordination with NOAA and NMFS, has developed a monitoring program for the deep water 106-mile site. Observations on endangered species spatial distribution, seasonal abundance, site tenacity, if any, and juveniles are included in the monitoring program. Due to the dispersive characteristics, and available models for estimating distribution of sludge constituents for the 106-mile site, ocean dumping at deep water sites is not likely to jeopardize endangered species that pass through those areas on migrations.

Behavior and habitat preference must be considered and evaluated when discussing or assessing impacts of exposure of all types of pollutants on marine mammals and turtles. Exposure of these animals can occur through direct exposure to habitat and ingestion of contaminated sediment or prey species. Toxic materials may affect availability of certain prey species and sublethal doses of pollutants may become entrained in the food chain. Logically, those animals using inshore habitats and feeding close to shore would be more affected from urban and agricultural pollution than those which feed in open water. The cumulative impacts of all types of ocean dumping

including dredged material, sewage sludge, industrial waste, and proposed incineration of wastes remain a concern since their interaction along with increased pollutant loading could adversely affect habitat, prey, and protected species in contaminated areas.

Direct and indirect interactions between marine mammals and commercial fishing operations exist in directed and joint venture fisheries for squid, mackerel, and butterfish in Mid-Atlantic offshore shelf/slope waters as well as domestic commercial fisheries. Direct interactions occur between sea turtles and both pound net and trawl fisheries in the Chesapeake Bay (Musick et al., 1986) and in Long Island waters. Fishery gear involved in these interactions include gillnets, lobster traps, purse seines, otter trawls, pound nets, stop seines, and longline gear.

Waring et al. (in prep.) documented the incidental take of individual whales in directed and joint venture fishing operations in well defined areas of the Mid-Atlantic area. Pilot whales and common dolphins are the primary species involved in squid and mackerel fisheries. Differences in time of incidental catch were noted. Based on available whale population estimates, it does not appear that the level of take is significantly impacting those mammal populations. NMFS, NER fishery compliance inspectors aboard foreign fishing vessels collect incidental take data so that monitoring can continue. In addition, under a marine mammal research permit issued to NMFS, Northeast Fisheries Center, foreign fishery inspectors collect and retain carcasses of incidentally caught animals for laboratory and onboard necropsies. NMFS will obtain valuable information on the population and social structure, biology, food habits, and general life history of some odontocete species from these efforts. Few valid or substantiated reports are available on the incidental take of marine mammals and endangered species by domestic trawl, trap, net, pot, or line fisheries. Without a General Permit or Small Take Exemption, incidental taking is illegal and therefore, is usually not reported. However, direct interactions between small cetaceans (i.e., harbor porpoise), seals, and groundfish gillnet and tub trawl fisheries in New England waters is being investigated under a Small Take Exemption permit and preliminary results reported (Gilbert and Wynne, 1983, 1984, 1985). Groundfish gillnet fisheries entangle small cetaceans and seals and sustained damage from marine mammal collisions. The exemption reporting system has proven to be an effective mechanism of interacting with gill netters to obtain data and carcasses for examination. Mitigating measures are currently being investigated that could reduce the level of take, and damage to catch and gear. Herring weir fishermen reported damage to traps and loss of trapped fish from seal intrusions to the weirs on the west coast (Mate, 1980). Potters have recently reported losses of lobsters from seal intrusions in Maine.

Large whales like humpback, finback and right whales also become entangled or entrapped in fishing gear. Interactions occur between whales and lobster, gillnet, purse seine, weir, and trap gear. Large whales are rarely entrapped in trawl gear. Thirty-three percent of identifiable right whales have scars or markings indicative of interactions with nets and lines. No comparison has been done for identified humpback whales. Entanglement information submitted to NMFS, NER indicates that, currently, this activity is not jeopardizing whale populations involved at present. Disentanglement gear, developed and used by a private research organization, has successfully

released five humpback whales entangled in gillnets. However, more efficient mechanisms for timely reporting of entanglements of all endangered species is needed to reduce injury to the animal, damage to gear and catch, and to effectively assess these interactions. NMFS has asked U.S. Coast Guard operating units to report any sightings of dead and live whales entangled in gear. Additionally, NMFS in cooperation with the New England Fisheries Management Council and states should continue to gather information, and support disentanglement efforts that will reduce harm to whales, gear, and catch.

Incidences of sea turtles caught in pound net leaders that have drowned or have been retrieved alive are documented by Musick et al. (1983, 1986). Of the over 450 turtles examined by the VIMS staff since 1979, about 35% of total turtle mortality in the Chesapeake Bay in summer resulted from net entanglement. Their 1984 data support earlier findings. From mid-May to June entanglements increase steadily then, increase sharply, and level off by late June. Thus, the majority of turtle mortalities occur in a short period even though turtles are present from March to October. Musick et al. (1983) suggest that movement of turtles within foraging ranges expose them to staked pound nets and that incidental takes of turtles alive or dead in pound nets is dependent, in part, on the position of the net. Nets set close to shore in moderate tidal current areas are more likely to catch turtles alive and nets set in areas of strong tidal currents in deep water are more likely to entangle and drown turtles. In addition large meshes (12" to 16" stretch mesh) are more likely to tangle and drown turtles than smaller meshes (8" to 12" stretch mesh). Significant turtle mortalities occur in nets with leaders with large stringer mesh (16" to 18") in the top half and smaller mesh on the lower half (Musick et al., 1986). Time of year, area, net configuration, and the turtles' physical condition are all important variables affecting turtle mortality in Chesapeake Bay pound nets. The impacts of this source of mortality on turtle populations is largely unknown because of inadequate methods for determining age, survivorship rates, and recruitment of turtles. NMFS, NER also has reports of sea turtle entanglements in traps and trawls in Gulf of Maine and southern New England waters. Information is currently being collected and compiled from members of the NMFS Sea Turtle Stranding and Salvage Network. Compilation and analysis should yield information on the level of take, species involved, and aid managers and industry components in developing mitigation procedures.

Other impacts to marine mammals and endangered species may result from the disposal of solid debris and fishing gear at sea. Marine debris has been addressed on a global, regional, state, and local basis, and was the focus of an international symposium in 1984 (Shomura and Yoshida (eds.), 1985). In the NER, quantitative studies on the distribution and density of ghost gillnets is being conducted by NOAA and Massachusetts Division of Marine Fisheries. Results are available for two of the three-year study (Carr et al., 1985). Initial results suggest that ghost gillnets in the Gulf of Maine do not pose a threat to fishery or marine mammal resources. Investigations are ongoing. Marine mammals and sea turtles may ingest solid marine debris (i.e., plastics, styrofoam). Ingestion of and entanglement in plastics and other solid matter may interfere with normal digestive processes, inhibit their ability to swim or forage for prey, and result in substantial injury or death to an animal. As more information becomes available on entanglement and digestion of foreign particles by marine mammals and turtles that occur in the

NER, NMFS will integrate it into their continuing examination of impacts to marine mammals and endangered species from man's activities.

## SUMMARY

General distribution patterns are apparent for cetaceans of the WMU area. Seasonal distribution patterns reflected by north-south and/or offshore-inshore movement are evident. The SNE and MAB continental shelf edge area is generally utilized by toothed whales like sperm and pilot whales, and some dolphin species (Haine et al., 1985; Payne et al., 1984; URI, 1982) and is defined as a high use area (Kenny and Winn, 1986). Sei whales appear to be unique among baleen whales for their tendency to occupy shelf edge waters of Georges Bank (Kenney and Winn, 1986). The shelf edge area of the OCS is an area known for upwellings. Upwellings are known for high levels of zooplankton and pelagic cephalopods. Baleen whales use the shelf edge area seasonally and/or as a migratory pathway. These general whale distribution patterns may indicate habitat preferences where certain species generally occupy a given depth zone along the shelf edge in response to prey abundance (URI, CeTAP 1982). Whales are significant predators on marine resources, appear to place large energetic demands on the ecosystem (Scott et al., 1985; Kenney et al., 1985), and their impact on available resources is substantial and comparable to man's take (Hain et al., 1985; Scott et al., 1983).

Before URI's CeTAP survey, no comprehensive studies were done on spatial and temporal distributions of sea turtles in the western North Atlantic ocean. Distinctively different spatial distribution patterns for loggerhead, leatherback, and Kemp's ridleys sea turtles exist. Loggerhead sea turtles are present in the WMU area in spring, expand north to Massachusetts in summer and shift south in fall. Leatherback sea turtles are commonly distributed in the WMU area in summer and only rarely in fall, winter, and spring. Ridley's occupy inshore bay waters in summer where their food source is abundant. Harbor and grey seals occur in the WMU area in winter and in strictly defined areas (i.e., Muskegat Island, Monomoy Point) and primarily use these areas to feed. Grey seals also breed in the area in which they occur.

While general marine mammal and sea turtle distribution patterns are indicated, it is apparent that the Mid-Atlantic outer continental shelf area is seasonally important and not homogenous in use.

Singular, cumulative, and synergistic impacts from ocean dumping, non-point source pollution, habitat degradation, and other anthropogenic activities on individuals or populations of marine mammals and endangered species are difficult to identify and investigate. Cetaceans, as apex predators with relatively long life spans, show high levels of pollutants in their tissues when compared with their environment. This is especially true for species occurring in coastal waters. Even in cases where physiological processes, reproductive failures, etc., could be associated with high levels of some contaminants, a direct cause and effect relationship still remains to be established (Bergmann et al., 1981; Reijnders, 1982). A large sample size of a species is needed, and many parameters need to be defined or easily obtainable to effectively establish cause-effect relationships. Whaling nations do provide samples from animals assumed to be healthy for pollutant analyses. However, U.S. laws protecting endangered species do not easily allow one permission to undertake this kind of research. Other problems with

mammal/pollutant studies are the inherent differences in sampling and analytic procedures, and the physical and physiological state of the animals (Reijnders, 1982). Contaminant burdens will vary with age and sex (Donkin et al., 1981; Gaskin, 1976; Reijnders, 1982; and Sergeant, 1980), changes in blubber thickness, feeding habits, and reproductive rates (Drescher et al., 1977; and Henry and Best, 1982), geographic location, and species specificity (Reijnders, 1986), and temporal use of inshore and offshore habitats. Data on uptake and excretion rates, and distribution of contaminants in tissues will allow development of models that describe the fate of a pollutant in a marine mammal in terms of uptake, deposition, and excretion (Reijnders, 1986). Assuming food availability and competitive interactions between these species, other predators, and man are the more important factors controlling their distribution then research may be useful. Such topics include food habits and general life history studies in relation to prey availability, and oceanographic conditions and variabilities. Results of these investigations may help evaluate potential effects of man's activities on protected species and provide information on their impact to fisheries resources in the western North Atlantic ecosystem.

#### REFERENCES

- Baker, S. C., L. M. Herman, B. G. Bays, W. P. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. National Marine Fisheries Service Contract No. 81-ABC-00114.
- Beamish, P. 1977. Evidence that a captive humpback whale (Megaptera novaeangliae) does not use sonar. *Deep Sea Res.* 25: 469-472.
- Beddington, J. R. and R. M. May. 1982. The harvesting of interacting species in a natural ecosystem. *Sci. Am.* 247: 62-69.
- Bergmann, A., M. Olsson and L. Reutergard. 1981. Lowered reproduction in seal populations and PCB concentration. *ICES C.M.*: 1-10.
- Best, P. B. 1979. Social organization in sperm whales (Physeter macrocephalus). In Winn, H. E. and B. C. Olla (eds.), Behavior of Marine Animals (3), Cetaceans. Plenum Press, New York.
- Blaylock, R. A. 1982. Aerial surveys of bottlenose dolphins (Tursiops truncatus), in Virginia's nearshore coastal waters. Contract Report to NMFS, Contract No. NA-80-FA-D-0008, 22 pp.
- Brown, S. G. 1958. Whales observed in the Atlantic Ocean: Notes on their distribution. *Mar. Obs.* 28: 142-146.
- Caldwell, D. K., M. C. Caldwell and D. W. Rice. 1966. Behavior of the sperm whale, Physeter catodon. pp. 677-717. In K. S. Norris (ed.), Whales, Dolphins, and Porpoises. University of California Press, Berkeley.
- Carr, A., E. H. Amaral, A. W. Hulbert and R. Cooper. 1985. Underwater survey of simulated lost demersal and lost commercial gill nets off New England. In R. S. Shomura, H. O. Yoshida (eds.), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 27-29 November 1984, Hawaii. NOAA-TMONMFS-SWFC-54.

- Cohen, E. B., M. D. Grosslein, M. P. Sissenwine, F. Steimle and W. R. Wright. 1982. Energy budget of Georges Bank. In M. C. Mercer (ed.), Multispecies approaches to fisheries management advice. Can. Spec. Pub. Fish. Aquat. Sci. 59: 95-107.
- Donkin, P., S. V. Mann and E. Hamilton. 1981. Polychlorinated biphenyl, DDT, and dieldrin residues in grey seal males, females, and mother-foetus pairs sampled at the Fanne Islands, England during the breeding season. Sci. Tot. Enviro., 19: 121-142.
- Drescher, H. E., U. Harms and E. Huschenbeth. 1977. Organochlorines and heavy metals in the harbour seal from the German North Sea coast. Mar. Biol., 41: 99-100.
- Eberhardt, R. T. and W. E. Evans. 1962. Sound activity of California gray whale, Eschrichtius glaucus. J. Aud. Eng. Soc., 10: 324-328.
- Englehardt, F. R. 1983. Petroleum effects on marine mammals. Aquat. Toxic., 4: 199-217.
- Fritz, T. H. and R. P. Reynolds. 1981. Pilot study of the marine mammals, birds and turtles in the OCS areas of the Gulf of Mexico. U.S. FWS. Office of Biological Services, Washington, D.C. FWS/OBS-81/36.
- Gales, R. S. 1981. Effects of noise of offshore oil and gas operations on marine mammals: An introductory assessment. Vols. 1 and 2, U.S. DOI, Bureau of Land Management, NOSC TR844.
- Gambell, R. 1977. Sperm whales off Durban. Report 35: 199-358.
- Gaskin, R. 1976. The evolution, zoogeography, and ecology of cetacea. Oceano. Mar. Biol. Ann. Rev. 14: 247-346.
- Gaskin, D. E. 1982. The Ecology of Whales and Dolphins. Heineman Press, Exeter.
- Gaskin, D. E., A. J. Reed, G. J. D. Smith and P. F. Watts. 1983. Population, dispersal, size and interactions of harbor porpoises in the Bay of Fundy and Gulf of Maine. Report to Dept. of Supply and Services, Canada, Contract No. UP-G-152.
- Geraci, J. R. and D. J. St. Aubin. 1982. Study of the effects of oil on cetaceans. Report to U.S. Department of Interior, Bureau of Land Management, Contract No. AA-551-CT9-29.
- Gilbert, J. and K. Wynne. 1983. Harbor Seal Populations and Marine Mammal-Fisheries Interactions, 1982. Second Annual Report to U.S. DOC, NMFS, Contract No. NA-80-PA-C-00029.
- Gilbert, J. and K. Wynne. 1984. Harbor Seal Populations and Marine Mammal-Fisheries Interactions, 1983. Annual Report to U.S. DOC, NMFS, Contract No. NA-80-FA-C-00029.

- Gilbert, J. and K. Wynne. 1985. Harbor Seal Populations and Marine Mammal-Fisheries Interactions, 1984. Annual Report to U.S. DOC, NMFS, Contract No. NA-80-FA-C-00029.
- Goodale, D. R., M. A. M. Hyman and H. E. Winn. 1981. Cetacean responses in association with Regal Sword oil spill. Chapter 11. In University of Rhode Island, 1979. A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic areas of the U.S. Outer Continental Shelf. Bureau of Land Management, Contract No. AA551-CT8-48.
- Hain, J. H. W., M. A. M. Hyman, R. D. Kenney and H. E. Winn. 1985. Role of Cetaceans in the Shelf Edge Region of the Northeast U.S. *Mar. Fish. Rev.* 47: 13-17.
- Hain, J. H. W., G. R. Carter, S. D. Kraus, C. A. Mayo and H. E. Winn. 1982. Feeding behavior of the humpback whale Megaptera novaeangliae in the western North Atlantic. *Fish. Bull.* 80: 259-268.
- Henry, J. and P. Best. 1982. Organochlorine residues in whales landed at Durban, South Africa. *Sc. Commit., IWC, SC/34-09*: 1-12.
- Hoese, H. D. 1971. Dolphin feeding out of water in a salt marsh. *J. Mammol.*, 52: 222-223.
- Hogan, T. 1975. Movements and Behavior of the Bottlenose Dolphin in the Savannah River Mouth Area. Unpublished manuscript.
- Katona, S. K., P. Harcourt, J. S. Perkins and S. D. Kraus. 1980. Humpback Whales: A catalog of individuals identified by fluke photographs. College of the Atlantic, Bar Harbour, Maine.
- Katona, S. K., W. Steiner and H. E. Winn. 1977. Marine Mammals. In Center for Natural Areas, A summary and analysis of environmental information on the continental shelf from the Bay of Fundy to Cape Hatteras. Vol. 1. Book 2. Final Report, Bureau of Land Management, Contract No. AA550-CT6-45.
- Kenney, R. D. and H. E. Winn. 1986. Cetacean High Use Habitats on the Northeast U.S. Continental Shelf. *Fish Bull.* 84: 345-357.
- Kenney, R. D., M. A. M. Hyman and H. E. Winn. 1983. Calculation of standing stocks and energetic requirements of the cetaceans of the northeast United States outer continental shelf. NMFS, Contract No. NA-83-FA-C-00009.
- Kraus, S. D. and J. Prescott. 1982. The north Atlantic right whale (Eublaena glacialis) in the Bay of Fundy, 1981, with notes on distribution, abundance, biology and behavior. Final report to NMFS, Contract No. NA-81-FA-C-00030.
- Kraus, S. D. 1985. A review of the Status of the right whale (Eublaena glacialis) in the Northwest Atlantic with a Summary of Research and Management Needs. U.S. Mar. Mamm. Comm., Contract No. MM29109150.

- Kraus, S. D. and J. H. Prescott. 1984. Seasonal movements of the harbor porpoise (Phocoena phocoena) in the Gulf of Maine. NMFS/NEFC Contract No. NA-82-FA-C-00027.
- Laevastu, T., F. Favorite, H. A. Larkin. 1979. Resource Assessment and Evaluation of the Dynamics of the Fisheries Resources in the Northeast Pacific with Numerical Ecosystem Models. NMFS, NWAFC, Seattle, Washington.
- Leatherwood, S., D. K. Caldwell and H. E. Winn. 1976. Whales, Dolphins, and Porpoises of the Western North Atlantic, A Guide to their Identification. NOAA/NMFS Tech. Memor. Circ-396.
- LGL Ecological Research Associates, Inc., W. J. Richardson, (ed.). 1983. Behavior, disturbance responses and distribution of bowhead whales (Balaena mysticetus) in the eastern Beaufort Sea, 1982. Prepared for U.S. DOI, Minerals Management Service.
- Malme, C. I., P. R. Miles, C. W. Clark, P. Tyack and J. E. Bird. 1983. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. U.S. DOI, Minerals Management Service, Contract No. AA851-CT2-39, Report No. 5366.
- Mate, B. R. 1980. Workshop on marine mammal-fishery interactions in the northeastern Pacific. Final Report. Marine Mammal Comm. 48 pp.
- May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt and R. M. Laws. 1979. Management of multispecies fisheries. Science 205: 267-277.
- Mead, J. 1975. Distribution of cetaceans along the Atlantic and Gulf Coasts of the United States. Unpublished Manuscript. Report to the Marine Mammal Commission. MMC MM4AC007.
- Mercer, M. C. 1975. Modified Leslie-Delury population models of the long-finned pilot whale (Globicephala melaena) and annual production of short-finned squid (Illex illecebrosus) based upon their interaction at Newfoundland. J. Fish. Res. Bd. Can. 321: 1145-1154.
- Mitchell, E. and W. M. Koziecki. 1975. Supplementary information on the minke whale (Balaenoptera acutorostrata) from Newfoundland fishery. J. Fish. Res. Bd. Canada 32(7): 985-994.
- Mitchell, E. D. and D. G. Chapman. 1977. Preliminary assessment of stocks of the northwest Atlantic sei whales (Balaenoptera borealis). Rept. Int. Whal. Comm. Special Issue, I: 117-120.
- Mitchell, E. D. 1974. Present status of the northwest Atlantic fin and other whale stocks. pp. 108-169. In W. E. Schevill (ed.), The Whale Problem. Harvard University Press, Cambridge, Massachusetts.
- Musick, J. A., R. Byles, R. E. Klinger and S. Bellmund. 1983. Mortality and behavior of sea turtles in the Chesapeake Bay, Summary report for 1979 through 1983. NMFS Contract No. NA-80-FA-C-00004.

- Musick, J. A., S. A. Bellmund, R. C. Klinger and R. A. Byles. 1986. Ecology of Sea Turtles in Virginia. Final Draft Contract Report to NMFS, NER, Contract No. NA-80-FA-C-00004: 1-39.
- Musick, J. A. 1979. The marine turtles of Virginia with notes on identification and natural history. Sea Grant Program, VIMS, Gloucester Point, Virginia.
- National Marine Fisheries Service. 1984. Marine Mammal Protection Act. Annual Report to Congress.
- Nemoto, T. 1970. Feeding patterns of baleen whales in the ocean. In J. H. Stelle (ed.), Marine Food Chains. University of California Press, Berkeley.
- Nicolas, J. 1984. Prey of the longfin pilot whale (Globicephala melaena) in the shelf waters of eastern United States based on distributional co-occurrence with squid and selected finfish. Proc. N. A. Mar. Mamm. Assoc. Conf., Oct. 20, 1984.
- Nishiwaki, N. 1972. General Biology. In S. H. Ridgway (ed.), Mammals of the Sea: Biology and Medicine. C. C. Thomas Publ., Springfield, Ill.
- Norris, K. S. 1969. The echolocation of marine mammals. In H. T. Anderson (ed.), the Biology of Marine Mammals. Academic Press, New York.
- Norris, K. S. and T. P. Dohl. 1980. The structure and function of cetacean schools. In L. Herman, (ed.), Cetacean Behavior: Mechanisms and Functions. John Wiley and Sons, New York.
- O'Conner, T. P., H. A. Walker, J. F. Paul and V. J. Bierman. 1985. A Strategy for Monitoring of Contaminant Distributions Resulting from Proposed Sewage Sludge Disposal at the 106-Mile Ocean Disposal Site. Mar. Environ. Res. 16: 127-150.
- Overholtz, W. J. and J. R. Nicolas. 1979. Apparent feeding by the fin whale Balaenoptera physalus, and humpback whale Megaptera novaeangliae, in the northwest Atlantic. Fish. Bull. 77(1): 285-287.
- Payne, P. M. and L. Selzer. 1983. Population, Distribution, Abundance and Prey Requirements of the Harbor Seal in southern New England. NMFS-NEFC Contract No1. NA-82-FA-C-00007.
- Payne, P. M., L. A. Selzer, A. R. Knowlton. 1984. Distribution and Density of Cetaceans, Marine Turtles, and Sea Birds in the Shelf Waters of the Northeastern U.S., June 1980-December 1985, Based on Shipboard Observations. NMFS Contract No. NA-81-FA-C-00023.
- Payne, P. M., J. R. Nicolas, L. O'Brien and K. Powers. 1986. The distribution of the Humpback Whale (Megaptera novaeangliae) on Georges Bank and in the Gulf of Maine in Relation to Densities of the Sand Eel (Ammodytes americanus). Fish. Bull. 84(2): 271-177.

- Powers, K. and M. Payne. 1983. Mammals, Birds and Turtles. Chapter 11. In Northeast Monitoring Program-106 Mile Site Characterization Update. U.S. DOC, NOAA, NMFS, NOAA Tech. Memorandum NMFS-F/NEC-26.
- Powers, K. D., P. M. Payne and S. J. Fitch. 1982. Distribution of cetaceans, sea birds, and turtles, Cape Hatteras to Nova Scotia, June 1980-December 1981. Final Report to the U.S. DOC, NOAA, NMFS, Contract No. NA-81-PA-C-00023.
- Prescott, J. H. and P. M. Fiorelli. 1980. Review of the Harbor Porpoise (Phocoena phocoena) in the U.S. Northwest Atlantic, U.S. Marine Mammal Commission, Technical Report No. MMC-78/08.
- Reijnders, P. J. H. 1982. Threats to the harbour seal population in the Wadden Sea. In Marine Mammals of the Wadden Sea, Rotterdam, Netherlands: 38-47.
- Reijnders, P. J. H. 1986. Perspectives for studies of pollution in cetaceans. Marine Pollution Bulletin, Vol. 17(2): 58-59.
- Reeves, R., J. G. Mead and S. K. Katona. 1978. The right whale. Report to International Whaling Commission, 28: 302-312.
- Schmidley, D. J. 1981. Marine Mammals of the southeastern United States coast and the Gulf of Mexico. U.S. DOI, FWS, Biological Service Program, Report No. FWS/OBS 80-41.
- Schurman-Rough, V. 1983. Report on Nantucket gray seals, winter and spring, 1983. NMFS/NEC Contract No. NA-83-FB-A-00075.
- Scott, G. P., R. D. Kenney, T. J. Thompson and H. E. Winn. 1983. Functional roles and ecological impacts of the cetacean community in the waters off the northeastern U.S. continental shelf. ICES C.M.1983/N: 12.
- Sergeant, D. E., D. J. St. Aubin and J. R. Geraci. 1980. Life history and northwest status of the Atlantic whitesided dolphin (Lagenorhynchus acutus). Cetology 37: 1-12.
- Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien and L. Egsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature, 291: 480-489.
- Shomura, R. S. and H. O. Yoshida (eds.). 1985. Proceedings of a Workshop on the Fate and Impact of Marine Debris, 27-29 November, 1984. NOAA-TM-NMFS-SWFC-54.
- Shoop, R. C., T. L. Doty and N. E. Bray. 1981. Sea turtles in the region between Cape Hatteras and Nova Scotia in 1979. In University of Rhode Island, 1979. A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic areas of the U.S. Outer Continental Shelf, U.S. DOI, Bureau of Land Management, Contract No. AA-551-CT8-48.

- Sissenwine, M. P., E. B. Cohen and M. D. Grosslein. 1982. Structure of the Georges Bank Ecosystem. ICES, No. 31. Rapp. p.-V. Reun. Cons. Perm. Intern. Explor. Mer. 183.
- Slijper, E. J., W. L. Van Utrecht and C. Naaktgeboren. 1964. On the distribution and migration of whales based on observations from Netherland ships. *Bijdr. Dierk.* 34: 1-93.
- Smith, G. J. D. and D. E. Gaskin. 1974. The diet of the harbor porpoises (*Phocoena phocoena*) in coastal waters of eastern Canada, with special reference to the Bay of Fundy. *Can. J. Zool.*, 52(6): 777-782.
- Smith, C. L., C. W. Su, W. G. McIntyre, R. H. Bieri and M. K. Cueman. 1979. Hydrocarbons, Chapter 14. In *Middle Atlantic and Outer Continental Shelf Environmental Studies*. U.S. DOI, Bureau of Land Management, Contract No. AA550-CT6-62.
- Sorensen, P. W., R. J. Medved, M. A. M. Hyman and H. E. Winn. 1984. Distribution and abundance of cetaceans in the vicinity of human activities along the continental shelf of the northwestern Atlantic. *Mar. Environ. Res.* 12: 69-81.
- Testaverde, S. and J. G. Mead. 1980. Southern distribution of the Atlantic whitesided dolphin, (*Lagenorhynchus acutus*) in the western North Atlantic. *Fish. Bull.* 79: 167-169.
- University of Rhode Island. Cetacean and Turtle Assessment Program. 1982. A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic Areas of the U.S. Outer Continental Shelf. Ann. Rept. for the Cetacean and Turtle Assessment Program (Final Rept. 1980-81), Kingston, R.I.: 717 p. (prep. for Bur. Land Management. USDI, BLM Rept. No. BLM/YL/TR-82/01).
- Waring, G. T., P. Gerrior, J. R. Nicolas and M. P. Payne. In preparation. Incidental Take of Marine Mammals in Foreign Fishery Activity off the Northeast USA, 1977-1985.
- Watkins, W. A. and W. E. Schevill. 1976. Right whale feeding and baleen rattle. *J. of Mamm.* 57: 58-66.
- Watkins, W. A. and W. E. Schevill. 1979. Aerial observations of feeding behavior in four baleen whales: *Eublaena glacialis*, *Balaenoptera borealis*, *Megaptera novaeangliae*, and *Balaenoptera physalus*. *J. of Mamm.* 60: 15-16.
- Watson, L. 1981. Sea guide to whales of the world. E. P. Dutton, New York, 302 pp.
- Winn, H. E., D. R. Goodale, M. A. M. Hyman, R. D. Kenney, C. A. Price and G. P. Scott. 1981. Right whale sightings and the right whale minimum count. In *University of Rhode Island, 1979. A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic Areas of the U.S. Outer Continental Shelf*, U.S. DOI, Bureau of Land Management Contract No. AA51-CT8-48.

Winn, H. E., C. A. Price and P. W. Sorenson. 1986. The Distributional Biology of the Right Whale (Eublaena glacialis) in the western North Atlantic. In Report to Int. Whal. Comm. (Spec. Issue No. 10) 1986: 129-138.

# Contaminant Input, Fate and Biological Effects

by

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## INTRODUCTION

Disposal of wastes in the ocean was probably recognized by the earliest of civilizations as the cheapest and easiest method available and the most aesthetically acceptable. As early as Roman times, however, identifiable degradation of nearshore and estuarine waters was a significant problem at major cities built on such semi-enclosed bodies of water. The Industrial Revolution added vast amounts of processed water to primitive sewage transport systems in the historical capitals of European enterprise and expanded the areas of degradation. The increasing generation of wastes required extension of outfalls and actual transport offshore. Now, in the late twentieth century, these practices have come to mean the routine ocean disposal of millions of metric tons of industrial wastges and sewage sludges bymost technologically advanced countries. Much of the early analysis and assessment of pollutant effects in the marine environment arose from concerns and events outside the MAWMU, and have provided important understanding in these areas.

The effects and the longevity of wastes discharged in the marine environment are dependent on a complex, often synergistic, relation between the nature of the material being discharged and the waters receiving it. For the past twenty years, extensive studies have tried to determine these relationships, but have generally been crisis-oriented rather than exploratory in nature. Less than one-third of the earth's surface is land and much of that land mass must be protected from contamination to insure biological survival. Because the oceans occupy so much surface area of our planet, dilution often seems a reasonable technique for disposal. However, in many cases, dilution is not really disposal because the material has not been dealt with properly; rather, the material has been merely translocated, and can return to inshore areas. Virtually all oceanic resource-contamination scares can be traced to this dilution presumption and the belief that the activity was innocuous. Mercury, DDT, and PCB all have been "crisis"-managed without a complete resolution of the problem other than to stop product manufacture.

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## CONTAMINANT INPUT

### Non-Point Source

Domestic waste discharges and other non-point sources are the major contributors to the contaminant burden of nearshore waters and sediments (Kneip et al., 1982). Daily, a highly variable and indeterminate mix of contaminants pours or rains into our coastal waters. Domestic wastes include heavy metals (such as lead and copper from pipes and conduits) and fecal contaminants (Cunnerson et al., 1982). Riverine and estuarine plumes add agricultural runoff of pesticides and nutrients, leachate from landfills, road and urban runoff, chemical spills into tributaries, and increased sediment loading (with attendant associated PCBs, PAHs, etc.) during peak riverine outflows (Swanson et al., 1977; Mueller & Anderson, 1978; Swanson & Sindermann, 1979; Wolfe et al., 1982). Such discharges, typically non-regulated, tend to become diluted as they move downriver and offshore. Another non-point source, atmospheric contaminants, can be carried far out to sea before aerosol fallout. Sindermann et al. (1982) have compiled estimates of the amounts of major pollutant classes entering the New York Bight Apex (that area of the Atlantic Ocean directly effected by the Hudson River and within a line drawn from New Jersey and Fire Island Inlet, New York).

### Point-Source Ocean Dumping

Less dramatic than oil spills but more amenable to management is ocean dumping, a common and ongoing practice (Steimle et al., 1982). A site for disposal of processed sludge, for example, lies only 12 miles from land, within the New York Bight Apex (Carriker et al., 1982). Recent site designation action by the EPA has moved sludge disposal operations after December 1987 from that site to the Deepwater 106 Mile Site on the edge of the continental shelf. This action, and the defining of the legislation term "unreasonable degradation", will surely be tested in court actions brought by the permittees. As landbased alternatives become more expensive, the NMFS fully expects other municipalities to seek similar offshore disposal sites for their sludge volumes. At this writing, Boston, MA has mounted such an effort.

The physical properties of dumped wastes vary with the form (liquid or solid) and nature of the material. These characteristics, in turn, will affect the habitat(s) and resource(s) that might be impacted. Acid wastes are discharged as liquids with metal suspensions, but neutralization (from exposure to the buffering effect of ocean waters) usually creates flocculents which vary widely in settling rate (Mytelka et al., 1982). The type of acid also affects the character of the flocculent. Coal fly ash is a waste derived from coal combustion, its exact nature depends on the source of the coal and the amount of oxygen available during combustion. Dumped as a slurry, the ash has a general density more than twice ocean waters, yet the particles are mostly spherical-shaped and small (0.5  $\mu\text{m}$  - 200  $\mu\text{m}$ ). The smallest particles settle so slowly that wide dispersal is assured. There is also a cenosphere fraction of the ash waste. Cenospheres, glass bubbles filled with nitrogen and/or carbon dioxide may represent twenty percent of the load and float.

Sewage sludge has a density roughly equal to ocean disposal site surface waters. A portion of the material slowly sinks through the surface layer, but may ride on internal waves at the thermocline for miles beyond the disposal

site (Mytelka et al., 1982). The solid fraction is a heterogenous mixture of fibers, minerals, food residues, and micro-organisms which routinely represents less than ten percent of the total volume. Most of the remainder is liquid, primarily freshwater, carrying a representative load of materials introduced into the sewage treatment facility. The lack of pretreatment of industrial wastes prior to introduction into sewage flows remains a problem of unknown dimensions. Sewage treatment plants are designed to remove solids and biologically decompose organic material(s); they are not capable of altering detergents or most industrial contaminants (Charup & Parice, 1981). Finally, sludge contains films or sheens; although not thoroughly characterized, they are often hydrocarbon residues appearing in parts-per-million concentrations. As with fly ash, sludge characteristics not only vary widely from facility to facility, but also over the course of a collection day (Duedall et al., 1983). This results from the changing nature of the influent stream being processed by a facility.

Pharmaceutical wastes dumped at sea are not well-characterized, because of proprietary restrictions and the mixing of multiple by-products and carrier media prior to disposal. Particulates in such a waste stream tend to be very fine-grained, however, and thus, tend to persist in the water column. They may also carry "stop agents" designed to terminate biological activity in the waste and which also, therefore, prolong the rate of decay or decomposition by marine flora or fauna (Duedall et al., 1983).

#### Point-Source Pollution: Drilling and Mining

Outer Continental Shelf (OCS) development in the MAWMU has had an erratic history. As non-renewable resources are depleted in upland and nearshore zones, attention has returned to offshore drilling and mining. For the moment, petroleum hydrocarbon exploration has stopped as a result of less-than-encouraging borings in the Baltimore Canyon and the southern flank of Georges Bank. Hard-mineral extraction of sand and gravel for construction purposes remains primarily a land-based activity, but nearshore permits in such metropolitan areas as New York City have identified sites for mining more than 100 million cubic yards of aggregate. The technology for deep (150 ft.) mining for aggregate is presently limited by cost. Deep-sea nodule extraction technology is presently being refined but legal and economic obstacles remain.

1. Offshore petroleum activities offer several potential threats to living marine resources. These threats include impacts associated with the overboard discharge of cutting wastes and used drilling "muds", disposal or loss of material(s) from drilling rigs, and accidental or intentional discharge of crustal water and petroleum.

Disposal of drill cuttings (Liss, 1979) exposes unweathered rock surfaces to oceanic environments. These cuttings may contain mobile chemicals or compounds that adversely affect localized areas around the disposal site. When discharged, drilling muds can contain more than forty different additives, including pH stabilizers and corrosion inhibitors. The muds also become contaminated with soluble and insoluble fractions from the cuttings and drilling. Because of the use of "downshunting" (mid to nearbottom disposal), these materials sink as a dense plume and spread across the bottom as fluid

mud until dilution and/or sedimentation effectively alter the mixture. These disposables can cause burial and subsequent suffocation of any organism unable to reposition itself at the sediment-water interface.

Loss of material is not so much a biological problem as it is a hazard to trawling. Drilling rigs occupy a relatively small area, but moorings for dynamic stabilization systems reach well outside of the immediate drilling rig area. Mooring gear, pipe, and other usable materials have been routinely discharged overboard although many permits now require disposal of all wastes at upland sites.

Leakage of fluids from within the earth at the well site is a constant concern. Geologically trapped fluids other than petroleum (formation waters) are frequently associated with pockets of gas and oil (Harper and McKinney, 1982). These fluid mixtures are normally laden with such soluble mineral fractions as sulfur. Because they are under pressures similar to petroleum deposits, blowouts do occur discharging these materials into the oceans.

Petroleum "spills" are visible at the surface. Vertical mixing, however, can be important; several studies have shown that wave action can drive particles to depths of 80 meters. In shallow water areas, suspended sediment is readily accumulated and held by petroleum. The density of this petroleum-sediment slurry causes it to sink to the bottom where it acts much like fluid mud but is more persistent. This situation was of prolonged concern when noted at the Amoco Cadiz spill in France (NOAA, 1978). The environmental impact of drilling, therefore, may reach from surface waters to the bottom and actually into the substrate. Atlantic coast OCS petroleum development has, to date, remained well offshore, typically adjacent to submerged canyons. Environments most at risk are those areas and ecosystems where shelf and slope abut canyons.

2. Hard-mineral extraction entails overboard disposal of substandard grain sizes, raising local suspended sediment levels. Deep dredging activity creates persistent subaqueous "borrow pits" (Brinkhuis, 1980), which become sites of fine-grained material deposition, often with anoxic conditions and biologically unfit sediment characteristics. Finfish appear to seek out these warmer pockets in the late fall, possibly as a result of declining water temperatures in surrounding areas.

3. Deep-ocean extraction of mineral nodules is a source for some non-renewable minerals now facing depletion on land. Such operations are proposed for the deep ocean proper, where the nodules are bedded on oceanic oozes with settling rates of well below a meter per second (Brigham, 1983). Resuspension of these oceanic oozes can affect water clarity over wide areas and, if roiled to the surface, could also affect photosynthetic activity. Altered water movements may result from altered density characteristics. Nodule concentrations have been located along the slope/ocean deep zone in Georgia and the Carolinas.

#### CONTAMINANT FATE

When a waste enters the water column, it is immediately acted upon by forces of dispersion and advection, and changed by biological, chemical and physical processes. The biological and chemical processes are normally short-

lived, but are dependent upon the physical processes which dilute the discharge. For example, presence of strong-thermocline or pycnocline may slow or halt the settling out of fine material. If discharged material reaches the bottom without much dilution, the physical forces are effectively limited, a circumstance that protracts the biological and chemical processes. Bioturbation and geochemical activities within benthic deposits become dominant forces controlling the mobility of most wastes. Because the forces are so large and varied both in their nature and rates of action, the fate of wastes disposed of in the ocean is complex and uncertain, requiring a difficult integration of biological, chemical, physical, and geological analyses of the water column as well as epibenthic data, or a mixture of the two.

The Environmental Protection Agency (EPA) is aware of the difficulty in monitoring disposal activities and the theoretical value in seeking rapid dilution. To encourage dilution of some types of materials, EPA requires disposal operations that produce mixing rates from moving vessels of approximately 1000 to 100,000:1 in the wake of the discharge vessel (pers. comm., EPA NYC, 1985). Disposal vessels are also required to make parallel dumping tracks across the dumpsite, rather than routes which bisect previous passes. At the sludge dumpsite in the Bight Apex, this requirement has resulted in the largest accumulations of settleable material to collect on the bottom slightly outside the area designated as the disposal site.

The actual rate of dilution depends on the character of the waste being discharged, but background (actually non-detection) levels are usually attained in time spans from tens of minutes to several days. Displacement of the contaminated water column with new water depends on the column exchange rate, a much slower process requiring from months to years. It is this latter replacement that may cause the largest long-term problems. Where wastes are generated in large volumes, multiple or continuous disposal operations must be undertaken. For sewage sludge, this means that vessel discharges to the disposal site are more frequent than desirable, thus water quality does not fully recover between disposal events (Ingham et al., 1982). Because the water column replacement operates on an even slower schedule, large water masses become inoculated with significant loads of materials released from the sludge matrix.

In effect, dumpsites are point-sources of pollution, with the effluent plume extending in the direction of water mass movement. Should the movement be circular, pollutant background levels in the gyre may increase over the course of several rotations. If disposal operations are continuous, background levels of some contaminants could conceivably be raised in a major water mass to significant amounts. Because deep ocean disposal is only now beginning, tidal eddies and estuarine gyres are the only evidence that this may occur in the open ocean. However, heat disposal from steam-electric plants have been shown to create just such problems.

#### BIOLOGICAL EFFECTS

Marine fisheries supply the world with much of its essential protein. It is in our own interest, therefore, to protect especially critical marine habitats and nurseries from pollution and overexploitation, and to maintain and regulate fisheries stocks. For these reasons we must understand the

nature and degree of pollutant effects upon marine animals, particularly how they affect the capacity to survive and reproduce. Research in this area has grown rapidly in the past two decades (Pearce et al., 1985), focusing not only on commercial and recreational species, but also on indicator animals like polychaete worms and copepods. In the following discussion of biological effects of marine pollution, we have examples for each major pollutant category.

1. Petroleum Hydrocarbons. The most dramatic and highly publicized cases of marine pollution are oil spills, from tanker accidents such as the Torrey Canyon, Argo Merchant, Amoco Cadiz (Southward, 1979; NOAA, 1977; and NOAA, 1978, respectively) and drilling blowouts (North Sea, Santa Barbara, Gulf of Mexico: see Malins, 1977 a & b). They are also the most thoroughly documented, as in the case of the inshore West Falmouth oil spill (e.g., Sanders et al., 1980).

Most scientists agree that early life forms are more susceptible to oil toxicity than are adults, as, for example, the quahog clam Mercenaria mercenaria (Byrne and Calder, 1977). Molluscs are particularly sensitive to toxic effects of petroleum oils (Jeffries and Johnson, 1976), as are amphipods (Sanders et al., 1972; Lee et al., 1977). Radosh et al. (1978) point out that deep sea communities live in the most stable environments, and are therefore less resilient to stress than the necessarily more adaptable nearshore communities. Benthic crustaceans that walk, feed, and reproduce on the seabottom are suggested as "...valuable indicators of the quality of sediments with which they are intimately associated" (Sawyer et al., 1977).

Individual biological effects of oil contamination range from interference with egg and larval development to juvenile abnormalities and slower growth rates (Hyland and Schneider, 1976; Krebs and Burns, 1977; Vandermeulen, 1977; Radosh et al., 1978). Effects on adult crustaceans include delayed feeding, altered chemoreception and stress behavior (growing aggression) and for the mussel Mytilus, inhibited gonad development (Radosh et al., 1978). At the population level, salt-marsh crabs and clams had not yet recovered 7 years after an oil spill (Krebs and Burns, 1977; Sanders, 1977). Neoplasia was reported in the soft-shell clam Mya collected from oiled sites (Yevich and Barzcz, 1977). Mortalities for Mya are reported to be proportional to the oil content of the sediments which induces an overall reduction in abundance, biomass, and species diversity and distribution (Thomas, 1977); even the hardy marsh grass Spartina took 2 years to recover. Persistence of pollutant effects at the site of an inshore oil spill has been recorded after 8 months (Blumer et al., 1970) and as long as 11 years later (Sanders et al., 1980), with persistence of hydrocarbons in the tissues of Mercenaria (Boehm and Quinn, 1977) and a slow recolonization of the saltmarsh ecosystem (Burns and Teal, 1979).

Fish experimentally exposed to oiled sediments readily took up hydrocarbons (Roesijadi et al., 1978; McCain et al., 1978). Oiled sediments also altered burrowing behavior in clams and worms: slower and shallower burrowing activity led to greater predation on the clam Mya (Gilfillan and Vandermeulen, 1978), Protothaca (Pearson et al., 1981, and Macoma (Taylor and Karinen, 1977), and on the sandworm Nereis (Olla et al., 1984).

Field observations at the site of an offshore oil spill in an area of strong currents (the Argo Merchant incident) showed no immediate drop in density of diversity of interstitial fauna (Pratt, 1978), and a rapid recovery (2 months) of sea scallops in the area (Thurberg et al., 1978). An examination of oil in sediments and benthic animals collected after an oil spill from shallow (and cold) depths in Chedabucto Bay, Nova Scotia, showed little evidence of biomagnification (Scarratt and Zitgo, 1972). Some crustaceans appear to be attracted to oiled sediments (Thompson et al., 1977): indeed, one of the most likely long-lasting effects of oil contamination on marine populations may be the tainting of their flesh (Michael, 1977). Engler (1979) has observed a general tolerance to oil toxicity among some freshwater and estuarine animals. Polychaete worms are able to metabolize petroleum hydrocarbons (Lee, 1977). Inducible mixed-function oxidases (MFO's), which metabolize hydrocarbons of many sorts, have been found not only in marine finfish (Stegeman and Sabo, 1982), but also in crustaceans (Stegeman and Kaplan, 1981; Lee et al., 1982).

The chronic effects of an oil spill depend largely upon bioavailability and the weathering process; depuration of naphthalenes occurred within a day to 2 weeks in sipunculid worms first exposed to contaminated sediments and then transferred to clean water (Anderson et al., 1977). Of the Chedabucto oil spill, Thomas (1973) reported that initial effects disappeared quickly, but that the sediments became re-oiled in warmer months, as the oiled surfaces softened, causing extensive mortalities among Mya.

Attempts to lessen the impacts of oil spills have sometimes caused additional harm to the environment. Detergents have been shown to decrease survival and fecundity in marine animals (Hyland and Schneider, 1976). Efforts are being made to produce a biologically "acceptable" dispersant (Cowell, 1977).

2. Cuttings, Drilling Muds, and Mining Activity. Benthic organisms such as sea scallops, ocean quahogs, Atlantic herring spawn, flounder spawn, sand lance, tilefish, and lobster appear to be the most susceptible to localized impacts associated with cuttings and drilling muds. To a lesser degree, pelagic finfish and squid in the area might be affected, as might also krill and thus, eventually, whales. The degree of impact would be dependent upon time-of-year, life stage, severity of the spill (extent, volume, persistence), and measures taken to correct the situation. Corrective measures include the use of dispersant or sinking agents. Experimentally, exposure to sublethal concentrations of the drilling mud components attapulgit and 0-broxin produced gill damage in the sea scallop, Placopecten magellanicus (Morese et al., 1982). Hard-mineral extractions pose threats to basically the same group of organisms in cutting and drilling mud discharges. These threats would be most persistent within the borrow pits since refilling of the holes is a protracted activity, even nearshore. Deep-ocean silting caused by nodule mining carries the hazard of burial or organisms living downdrift of the mining site.

Direct effects of suspended sediments associated with these activities vary with animal species (Peddicord, 1980), but can affect the respiration of filter-feeders like the scallop and ocean quahog, and interfere with their water transport rates and their filtering efficiency. Such animals would need to draw upon the energy normally used for maintenance and growth. Peddicord,

who studied immediate effects only, concluded that dredge disposal operations and similar activities are not likely to cause benthic mortalities. Saila et al. (1978), however, caution that chronic exposure can lead to gill clogging and abrasions, impaired respiration and feeding, reduced larval growth and survival and, ultimately, to lowered productivity of benthic populations.

3. Heavy Metals. Both the order and degree of toxicity of heavy metals vary not only with such expected parameters as temperature, salinity and metal salt form, but also with animal life stage and species (e.g., Waldichuk, 1974; Calabrese et al., 1982). Greig et al. (1982) have pointed out that although a cause-and-effect relation between heavy metal concentrations in tissues and tissue pathology may be demonstrable under laboratory conditions, such association in nature cannot readily be determined. There are too many unknown additive, synergistic, or antagonistic factors that may influence any metal effect. Moreover, many marine animals, most notably bivalve molluscs, have mechanisms for sequestering excess metals and rendering them metabolically inert (e.g., George, 1982; Roesijadi, 1981).

In the field, Bryan and Hummerstone (1971, 1973) have reported the adaptive capacity of the polychaete Nereis diversicolor to high concentrations of heavy metals in polluted estuarine sediments. At an oceanic dumpsite, Pesch et al (1977) found higher tissue concentrations of cadmium, copper, and nickel in sea scallops and ocean quahogs collected from the dumpsite than in the same species collected from sites distant from the dumping area.

Experimentally, direct effects of exposure to heavy metals can be demonstrated in many less tolerant marine teleosts, crustaceans, and molluscs (e.g., Calabrese et al., 1982; Gould et al., 1985; Yevich and Yevich, 1985; Fowler et al., 1985). Exposure to very low levels of copper, especially, has been shown to inhibit reproduction in the sea scallop (Gould et al., 1985b). Reish et al. (1974) demonstrated the induction of lethal abnormalities in second-generation polychaete larvae from copper-exposed adults. Reise and Carr (1978) found that reproduction decreased in two polychaete species exposed to chromium. Perhaps more significantly, when an experimental marine ecosystem was contaminated with copper or mercury, phytoplankton that supported a food chain leading to fishes disappeared and were replaced by phytoplankton species that supported only commercially worthless, gelatinous zooplankton (Mensel, 1977).

4. Chlorinated Hydrocarbons: [Polychlorinated Hydrocarbons (PCB)]. This class of pollutant is possibly the most insidious because of persistent residence times. PCB-contaminated sediments, such as are found in the upper Hudson River, eventually are deposited on the ocean floor. These compounds will likely continue as important contaminants. Nimmo et al. (1971) reported PCB concentrations in tissues of experimentally exposed fiddler crabs and pink shrimp were related to the PCB content of sediments. After 27 days of continual exposure, only the digestive gland contained detectable PCBs, therefore Nimmo suggested that PCB exposure induced MFOs for the detoxication of the pollutant. Other laboratory investigations have implicated PCB exposure to a variety of effects in marine animals, including reduced survival, lesions, and behavioral abnormalities (Sindermann et al., 1982). Freeman and Idler (1975) observed interference with male hormone metabolism in brook trout exposed to PCBs. These chlorinated aromatic hydrocarbons have also been linked with fin erosion in flounder (Sherwood, 1982) and with skeletal abnormalities in striped bass (Mehrle et al., 1982; Buckley et al., in press).

Experimental exposures to chlorophenols have produced toxic responses in grass shrimp (Ranga Rao et al., 1981) and mullet and polychaete worms (Thomas et al., 1981). Organophosphate pesticides diminished swimming stamina in a mysid (Cripe et al., 1981), and parathion impaired antipredator activity in grass shrimp (Farr, 1977).

#### EVALUATION OF EFFECTS

Although petroleum operations have not yet produced any major impact on our fishery resources, they have caused extreme hardship to localized groups of harvesters in other countries. The oyster and lobster farms of Brittany were closed by the French government after the Amoco Cadiz oil spill, and the remaining animal crops were ordered to be destroyed. The French then took the unheard-of step of compensating local fishermen for their losses. Although this did not help the fishermen who foraged in the area, it did lessen the impact on the local mariculture business. Little was done to help the tourist industry, beyond the massive cleanup activities. The Canadians have also provided on-scene support services for affected fishermen by cleaning fouled nets in a portable washer and by providing daily reports of spill locations. The United States has yet to operate such a redress system as do France and Canada.

Potential socio-economic impacts from petroleum operations include a reduction in areas available to commercial trawling in or near rich fishing grounds like Georges Bank. Drilling rigs themselves may compact the bottom and increase litter and contaminant buildup under and around the platforms, which may exclude infauna (and fish that feed on them) from such areas (Radosh et al., 1978). These possibilities have not yet been found to be a problem in the Southern California Bight (Pequenat, 1974; Mearns and Moore, 1976). On the positive side, closing of drilling areas to commercial fishing could protect some spawning stocks, if they are not otherwise affected by spills, drilling muds, cuttings, and the like. Platforms also may serve as attachment sites for epifauna and in the Gulf of Mexico are recreational fishing attractants.

Hard-mineral extraction is such a localized activity that socio-economic impacts are concentrated in small pockets. Because the borrow holes attract finfish in the fall, they also attract party and charter fishing boats. The creation of these holes, which become fine depositional sinks for entrapment of heavy metals and hydrocarbons, can be managed by recovery plans such as are now required by stripmining regulators.

Any human activity such as ocean dumping that contributes to reducing dissolved oxygen concentrations in bottom waters must be considered environmentally harmful. Combined with natural events such as large planktonic blooms, early thermocline formation, and minimal water mass movement, it may lead to hypoxic or even anoxic conditions such as occurred in the New York Bight in the summer of 1976 (e.g., Swanson and Sindermann, 1979; MacKenzie et al., this report).

Based on clapper frequency, ocean quahog mortalities have been linked to ocean dumping (Lear, cited in Radosh et al., 1978). Benthic macrofauna and meiofauna are at greatest risk from contaminants that reach and are incorpo-

rated into the sediments. Benthos species are a prime forage and thus represent a potential contaminant hazard to resource fish species.

The most immediate and probable faunal impact of sludge dumping and contaminated sediments is the weakening or disappearance of pollution-sensitive populations like the majority of amphipods, and increasing dominance of animals more tolerant of pollutant stress, like polychaete worms. With few exceptions (notably the rock crab, *Cancer irroratus*), crustaceans are among the most sensitive of taxa (Reid, pers. comm.). Bivalve molluscs, because they are filter feeders and can bioaccumulate exceptionally high concentrations of contaminants, are at risk in terms of survival and reproductive potential. Because they also represent a hazard to the consumer, contaminated shellfish are a very real loss to the fisheries.

Following pollution abatement, recovery of a dumpsite would largely depend upon the time required to disperse and cleanse the bottom sediments of the bulk of accumulated pollutants. The most successful recolonization will be by species that produce large numbers of planktonic larvae (surf clams, sea scallops, ocean quahogs). If the numbers of predators also decreased or disappeared during the period of pollutant input, the increased shellfish survival will probably produce large year classes. This occurred with surf clams in the New York Bight after the anoxic event of 1976.

#### REFERENCES

- Anderson, J. W., L. J. Moore, J. W. Blaylock, D. L. Woodruff, and S. L. Kiesser. 1977. Bioavailability of sediment-sorbed naphthalene to the sipunculid worm, *Phascolosoma agassizii*. In: Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. (D. A. Wolfe, ed.). Pergamon Press, Oxford. pp. 276-285.
- Bigham, G. N. 1983. Ocean disposal of manganese nodule processing wastes. In: Ocean Waste Management: Policy and Strategies. Internatl. Ocean Disposal Symp. Series, Whispering Pines Conference Ctr., W. Alton Jones Campus, URI, 5/2-6, 1983.
- Blumer, M., J. Sass, G. Sousa, H. L. Sanders, J. F. Grassle, and G. R. Hampson. 1970. The West Falmouth oil spill. Persistence of the pollution eight months after the accident. Woods Hole Oceanographic Institution Tech. Rept. 70-44.
- Boehm, P. D., and J. G. Quinn. 1977. The persistence of chronically accumulated hydrocarbons in the hard-shell clam *Mercenaria mercenaria*. Mar. Biol. 44: 227-233.
- Brinkhuis, B. H. 1980. Biological Effects of Sand and Gravel Mining in the Lower Bay of New York Harbor: An Assessment from the Literature. Special Report 34. Marine Sciences Research Center, SUNY, Stony Brook, NY, 193 pp.
- Bryan, G. W., and L. G. Hummerstone. 1971. Adaptation of the polychaete *Nereis diversicolor* to estuarine sediments containing high concentrations of heavy metals. I. General observations and adaptations to copper. J. Mar. Biol. Assoc. U.K. 51: 845-863.

- Bryan, G. W., and L. G. Hummerstone. 1973. Adaptation of the polychaete Nereis diversicolor to estuarine sediments containing high concentrations of zinc and cadmium. *J. Mar. Biol. Assoc. U.K.* 53: 839-857.
- Buckley, L. J., T. A. Halavik, G. C. Laurence, S. J. Hamilton, and P. P. Yevich. In press. Comparative swimming stamina, biochemical composition, backbone mechanical properties, and histopathology of juvenile striped bass from rivers and hatcheries of the eastern United States. *Am. Fish. Trans.*
- Burns, K. A., and J. M. Teal. 1979. The West Falmouth oil spill: Hydrocarbons in the salt marsh ecosystem. *Estuarine Coast. Mar. Sci.* 8: 349-360.
- Byrne, C. J., and J. A. Calder. 1977. Effects of the water-soluble fractions of crude, refined, and waste oils on the embryonic and larval stages of the quahog clam Mercenaria sp. *Mar. Biol.* 40: 225-231.
- Calabrese, A., E. Gould, and F. P. Thurberg. 1982. Effects of toxic metals in marine animals of the New York Bight: Some laboratory observations. In: *Ecological Stress and the New York Bight: Science and Management*. (G. Mayer, ed.). Estuarine Reserch Federation, Columbia, SC. pp. 281-197.
- Carriker, M. R., J. W. Anderson, W. P. Davis, D. R. Franz, G. F. Mayer, J. B. Pearce, T. K. Sawyer, J. H. Tietjen, J. F. Timoney, and D. R. Young. 1982. Effects of pollutants on benthos. In: *Ecological Stress and the New York Bight: Science and Management*. (G. F. Mayer, ed.). ERF, Columbia, SC, pp. 3-21.
- Champ, M. A., and P. K. Park. 1981. Ocean dumping of sewage sludge: A global review. *Sea Technology*, 22(2): 18-24.
- Cowell, E. B. 1977. Oil spill dispersants. *Mar. Pollut. Bull.* 8: 288.
- Cripe, G. M., D. R. Nimmo, and T. L. Hamaker. 1981. Effects of two organophosphate pesticides on swimming stamina of the mysid Mysidopsis bahia. In: *Biological Monitoring of Marine Pollutants*. (F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg, eds.). Academic Press, New York. pp. 21-36.
- Duedall, I. W., B. H. Ketchum, P. K. Park, and D. R. Kester (Eds.). 1983. *Wastes in the Ocean. Vol. I. Industrial and Sewage Wastes in the Ocean*. Wiley-Interscience, NY, 431 pp.
- Engler, R. M. 1979. Bioaccumulation of toxic substances from contaminated sediments by fish and benthic organisms. In: *Management of Bottom Sediments Containing Toxic Substances*. (S. A. Peterson and K. K. Randolph, eds.). Proc. 4th U.S.-Japan Experts Mtg., Tokyo, USEPA 600-3-79-102. pp. 325-354.
- Farr, J. A. 1977. Impairment of antipredator behavior in Palaemonetes pugio by exposure to sublethal doses of parathion. *Trans. Amer. Fish. Soc.* 106: 287-290.

- Fowler, B. A., D. W. Engel, and E. Gould. 1985. Ultrastructural and biochemical effects of prolonged cadmium and copper exposure on kidneys of the scallop Placopecten magellanicus. Mar. Environ. Res. 17(2-4), 199 (Abstract).
- Freeman, H. C., and D. R. Idler. 1975. The effect of polychlorinated biphenyl on steroidogenesis and reproduction in the brook trout (Salvelinus fontinalis). Can. J. Biochem. 53: 666-670.
- George, S. G. 1982. Subcellular accumulation and detoxication of metals in aquatic animals. In: Physiological Mechanisms of Marine Pollutant Toxicity. (W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg, eds.). Academic Press, New York. pp. 3-52.
- Gilfillan, E. S., and J. H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shell clams, Mya arenaria, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-1976. J. Fish. Res. Bd. Can. 35: 630-636.
- Gould, E., R. J. Thompson, and L. J. Buckley. 1985a. Exposure of the scallop Placopecten magellanicus (Gmelin) to sublethal copper and cadmium: Effects on the reproductive effort. Mar. Environ. Res. 17(3-4): 288-289 (Abstract).
- Gould, E., R. A. Greig, D. Rusanowsky, and B. C. Marks. 1985b. Metal-exposed sea scallops, Placopecten magellanicus (Gmelin): A comparison of the effects and uptake of cadmium and copper. In: Marine Pollution and Physiology: Recent Advances. (F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg, eds.). U. South Carolina Press, Columbia, SC, pp. 157-186.
- Greig, R. A., T. K. Sawyer, E. J. Lewis, and M. E. Galasso. 1982. A study of metal concentrations in relation to gill color and pathology in the rock crab. Arch. Environm. Contam. Toxicol. 11: 539-545.
- Gunnerson, C. G., R. Adamski, P. W. Anderson, R. S. Dewling, D. A. Julius, G. S. Kleppel, D. W. Lear, J. T. Mearns, E. P. Miller, J. J. Myers, S. Roswell, S. Schroeder, D. A. Segar, C. J. Sindermann, and C. M. Stern. 1982. Management of Domestic Wastes. In: Ecological Stress and the New York Bight: Science and Management. (G. F. Mayer, Ed.). ERF, Columbia, SC, pp. 91-112.
- Harper, D., and L. McKinney. 1982. Effects of brine disposal on benthic communities of Freeport, Texas. In: Marine Pollution Papers, Oceans '82. Conference Proceedings. NOAA/OMPA, Marine Tech. Soc., and Inst. Electrical Engrs/Council on Oceanic Engineering. Washington, DC. 9/20-22, 1982, p. 1117.
- Hyland, J. L., and E. D. Schneider. 1976. Petroleum hydrocarbons and their effects on marine organisms, populations, communities, and ecosystems. In: Sources, Effects, and Sinks of Hydrocarbons in the Aquatic Environment. Proc. Symp. American University, Washington, DC, 9-11 August 1976.

- Ingham, M. C. (Ed.). 1982. Summary of the Physical Oceanographic Processes and Features Pertinent to Pollution Distribution in the Coastal and Offshore Waters of the Northeastern United States, Virginia to Maine. NOAA Tech. Memo. NMFS/F/NEC-17, 166 pp.
- Jeffries, H. P., and W. C. Johnson II. 1976. Petroleum, temperature, and toxicants. Examples of suspected responses by plankton and benthos on the continental shelf. In: Effects of Energy-Related Activities on the Atlantic Continental Shelf. (B. Manowitz, ed.). Conference at Brookhaven National Laboratory, 10-12 November 1975. pp. 96-108.
- Kneip, T. J., N. H. Cutshall, R. Field, F. C. Hart, P. J. Lioy, J. Mancini, J. A. Mueller, C. Sobotowski, and J. Szeligowski. 1982. Management of non-point sources. In: Ecological Stress and the New York Bight: Science and Management. (G. F. Mayer, Ed.). ERF, Columbia, SC, pp. 145-161.
- Krebs, C. T., and F. A. Burns. 1977. Long-term effects of an oil spill on populations of the salt-marsh crab Uca pugnax. Science 197: 484-487.
- Lee, R. F. 1977. Accumulation and turnover of petroleum hydrocarbons in marine organisms. In: Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. (D. A. Wolfe, ed.). Pergamon Press, Oxford. pp. 60-70.
- Lee, R. F., J. W. Conner, D. Page, L. E. Ray, and C. S. Giam. 1982. Cytochrome p-450 dependent mixed-function oxidase systems in marsh crabs. 1982. In: Physiological Mechanisms of Marine Pollutant Toxicity. (W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg, eds.). Academic Press, New York. pp. 145-159.
- Lee, W. Y., M. F. Welch, and J. A. C. Nicol. 1977. Survival of two species of amphipods in aqueous extracts of petroleum oils. Mar. Pollut. Bull. 8: 92-94.
- Liss, R. G. 1979. Uptake and depuration of metals by sea scallops (Placopecten magellanicus) exposed to drilling mud. M.S. Thesis, MIT, Cambridge, MA.
- Malins, D. C. (Ed.). 1977b. Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. I. Nature and Fate of Petroleum. Academic Press, NY. 321. pp.
- McCain, B. B., H. O. Hodgins, W. D. Gronlund, J. W. Hawkes, D. W. Brown, M. S. Myers, and J. H. Vandermeulen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (Parophrys vetulus), and pathological consequences. J. Fish. Res. Bd. Can. 35: 657-664.
- Mearns, A. J., and M. D. Moore. 1976. Biological study of oil platform Hilda and Hazel, Santa Barbara Channel, California. Final Report to Inst. Mar. Resource, U. Cal. San Diego. 79 pp. + app.
- Mehrle, P. M., T. A. Haines, S. J. Hamilton, J. L. Ludke, F. L. Mayer, and M. A. Rivick. 1982. Relationship between body contaminants and bone development in east coast striped bass. Am. Fish. Trans. 111: 231-241.

- Menzel, D. W. 1977. Summary of experimental results: Controlled ecosystem pollution experiment. *Bull. Mar. Sci.* 27: 142-145.
- Michael, A. D. 1977. The effects of petroleum hydrocarbons on marine populations and communities. In: *Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms*. (D. A. Wolfe, ed.). pp. 129-237. Pergamon Press, New York.
- Morse, M. P., W. W. Robinson, and W. E. Wehling. 1982. Effects of sublethal concentrations of the drilling mud components attapulgit and Q-broxin on the structure and function of the gill of the scallop (*Placopecten magellanicus* (Gmelin)). In: *Physiological Mechanisms of Marine Pollutant Toxicity*. (W. B. Vernberg, A. Calabrese, F. P. Thurberg, and F. J. Vernberg, eds.). Academic Press, New York. pp. 235-259.
- Mueller, J. A., and A. R. Anderson. 1978. *Industrial Wastes*. MESA New York Bight Atlas Monograph 30. NY Sea Grant Inst., Albany, NY, 39 pp.
- Mytelka, A. I., J. Ciancia, R. R. Delgado, A. M. Levinson, T. P. O'Connor, J. C. Prager, W. B. Pressman, E. A. Regna, M. M. Sadat, J. T. B. Tripp, and M. Wendell. 1982. Management of Industrial Wastes. In: *Ecological Stress and the New York Bight: Science and Management*. (G. F. Mayer, Ed.). ERF, Columbia, SC, pp. 135-143.
- Nimmo, D. R., P. Wilson, R. Blackman, and A. Wilson, Jr. 1971. Polychlorinated biphenyl absorbed from sediments by fiddler crabs and pink shrimp. *Nature* 231: 50-52.
- NOAA (P. L. Grose and J. S. Mattson, Eds.). 1977. *The Argo Merchant oil spill*. USDC, 133 pp., 1-6, 11-19, 111-123, IV-28, V-45, VI-11, VII-58.
- NOAA (W. N. Hess, Ed.). 1978. *The Amoco Cadiz oil spill*. NOAA/EPA Special Report. U.S. GPO, 283 pp., p. 66.
- Olla, B. L., A. J. Bejda, A. L. Studholme, and W. H. Pearson. 1984. Sublethal effects of oiled sediment on the sand worm, *Nereis (Neanthes) virens*: Induced changes in burrowing and emergence. *Mar. Environm. Res.* 13.
- Pearce, J. B., C. R. Berman and M. R. Rosen (eds.). 1985. *Annual NEMP Report on the Health of the Northeast Coastal Waters, 1982*. NOAA Tech. Mem. NMFS-F/NEC-35: 86 pp.
- Pearson, W. H., D. L. Woodruff, P. C. Sugarman, and B. L. Olla. 1981. Effects of oiled sediments on predation on the littleneck clam *Protothaca staminea*, by the Dungeness crab, *Cancer magister*. *Estuarine Coast. Shelf Sci.* 13: 445-454.
- Peddicord, R. K. 1980. Direct effects of suspended sediments on aquatic organisms. In: *Contaminants and Sediments*. (R. A. Baker, ed.). Vol. I. Ann Arbor Science, Michigan. pp. 501-536.

- Pequenat, W. F. 1974. Some effects of platform on the biology of the continental shelf. In: Marine Environmental Implications of Offshore Oil and Gas Development in the Baltimore Canyon Region of the Mid-Atlantic Coast. Proc. Est. Res. Fed. OCS Conference and Workshop, College Park, MD, December 1974. pp. 455-466.
- Pesch, G., B. Reynolds, and P. Rogerson. 1977. Trace metals in scallops from within and around two ocean disposal sites. Mar. Pollut. Bull. 8: 225-228.
- Pratt, W. D. 1978. Interactions between petroleum and benthic fauna at the Argo Merchant spill site. Proc. Symp. In the Wake of the Argo Merchant, University of Rhode Island, January 1978. Abstract only.
- Radosh, D. J./, A. B. Frame, T. E. Wilhelm, and R. N. Reid. 1978. Benthic survey of the Baltimore Canyon Trough, May 1974: Final Report. NMFS Northeast Fisheries Center, Sandy Hook Laboratory Rept. No. SHL-78-8.
- Ranga Rao, K., F. R. Fox, P. J. Conklin, and A. C. Cantelmo. 1981. Comparative toxicology and pharmacology of chlorophenols: Studies on the grass shrimp, Palaemonetes pugio. In: Biological Monitoring of Marine Pollutants. (F. J. Vernberg, A. CaTabrese, F. P. Thurberg, and W. B. Vernberg, eds.). Academic Press, New York, pp. 37-72.
- Reish, D. J., and R. S. Carr. 1978. The effects of heavy metals on the survival, reproduction, development, and life cycles for two species of polychaetous annelids. Mar. Pollut. Bull. 9: 24-27.
- Reish, D. J., F. Piltz, J. M. Martin, and J. Q. Word. 1974. Induction of abnormal polychaete larvae by heavy metals. Mar. Pollut. Bull. 5: 125-126.
- Roesijadi, G. 1981. The significance of low molecular weight, metallothionein-like proteins in marine invertebrates: Current status. Mar. Environm. Res. 4: 167-179.
- Roesijadi, G., J. W. Anderson, and J. W. Blylock. 1978. Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: Influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons. J. Fish. Res. Bd. Can. 35: 608-614.
- Saila, S. B., T. T. Polgar, and B. A. Rogers. 1972. Results of studies related to dredged sediment dumping in Rhode Island Sound. Proc. Annm. Northeastern Regional Antipollution Conf., University of Rhode Island, pp. 71-80.
- Sanders, H. L. 1977. The West Falmouth oil spill - Florida, 1969. Oceanus 20: 15-24.
- Sanders, H. L., J. F. Grassle, and G. R. Hampson. 1972. The West Falmouth oil spill. I. Biology. W.H.O.I. Tech. Rept. 72-20.

- Sanders, H. L., J. F. Grassle, G. R. Hampson, L. S. Morse, S. Gaines-Price, and C. C. Jones. 1980. Anatomy of an oil spill; long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. *J. Mar. Res.* 38: 265-380.
- Sawyer, T. K., S. A. MacLean, J. E. Bodammer, and B. A. Harke. 1979. Gross and microscopical observations on gills of rock crabs (Cancer irroratus) and lobsters (Homarus americanus) from nearshore waters of the eastern United States. *Proc. Second Biennial Crustacean Health Workshop*, 20-22 April 1977, Galveston, Texas.
- Scarratt, D. J., and V. Zitko. 1972. Bunker C oil in sediments and benthic animals from shallow depths in Chedabucto Bay, N.S. *J. Fish. Res. Bd. Can.* 29: 1347-1350.
- Sherwood, M. J. 1982. Fin erosion, liver condition, and trace contaminant exposure in fishes from three coastal regions. In: *Ecological Stress and the New York Bight: Science and Management*. (G. Mayer, ed.). Estuarine Research Federation, Columbia, SC. pp. 359-377.
- Sindermann, C. J., S. C. Esser, E. Gould, B. B. McCain, J. L. McHugh, R. P. Morgan II, R. A. Murchelano, M. J. Sherwood, and P. R. Spitzer. 1982. Effects of pollutants on fishes. In: *Ecological Stress and the New York Bight: Science and Management*. (G. Mayer, ed.). Estuarine Research Federation, Columbia, SC. pp. 23-38.
- Southward, A. J. 1979. Cyclic fluctuations in population density during eleven years recolonization of rocky shores in West Cornwall following the Torrey Canyon oil spill in 1967. In: *Cyclic Phenomena in Marine Plants and Animals*. (E. Naylor and R. G. Hartnoll, Eds.). Pergamon Press, Oxford, pp. 85-92.
- Stegeman, J. J., and H. B. Kaplan. 1981. Mixed-function oxidase activity and benzo(a)-pyrene metabolism in the barnacle Balanus eburneus (Crustacean, Cirripedia). *Comp. Biochem. Physiol.* 68C: 55-61.
- Stegeman, J. J., and D. H. Sabo. 1982. Aspects of the effects of petroleum hydrocarbons on intermediary metabolism and xenobiotic metabolism in marine fish. In: *Sources, Effects, and Sinks of Hydrocarbons in the Aquatic Environment*. A.I.B.S., Washington, DC. pp. 423-436.
- Steimle, G. F., J. Caracciolo, and J. B. Pearce. 1982. Impacts of dumping on the New York Bight benthos. In: *Ecological Stress and the New York Bight: Science and Management*. (G. F. Mayer, Ed.). ERF, Columbia, SC, pp. 213-223.
- Steimle, F. W., Jr., and C. J. Sindermann. 1978. Review of oxygen depletion and associated mass mortalities of shellfish in the Middle Atlantic Bight in 1976. *Mar. Fish. Rev.* 40(12): 17-26.
- Swanson, R. L., G. M. Hansler, and J. Marotta. 1982. Long Island Beach Pollution: June 1976. NOAA/MESA Special Report. 75 pp.

- Swanson, R. L., and C. J. Sindermann (eds.). 1979. Oxygen depletion and associated benthic mortalities in the New York Bight, 1976. NOAA Prof. Paper No. 11, 345 pp.
- Taylor, T. L., and J. F. Karinen. 1977. Response of the clam Macoma balthica (Linnaeus), exposed to Prudhoe Bay crude oil as unmixed oil, water-soluble fraction, and oil-contaminated sediment in the laboratory. In: Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. (D. A. Wolfe, ed.). Pergamon Press, Oxford. pp. 229-237.
- Thomas, M. L. H. 1973. Effects of Bunker C oil on intertidal and lagoonal biota in Chedabucto Bay, Nova Scotia. J. Fish. Res. Bd. Can. 30: 83-90.
- Thomas, M. L. H. 1977. Long-term effects of Bunker C oil in the intertidal zone. In: Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford. pp. 238-245.
- Thomas, P., R. S. Carr, and J. M. Neff. 1981. Biochemical stress responses of mullet Mugil cephalus and polychaete worms Neanthes virens to pentachlorophenol. In: Biological Monitoring of Marine Pollutants. (F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg, eds.). Academic Press, New York. pp. 73-103.
- Tompson, H. C., R. N. Farrgut, and M. H. Thompson. 1977. Relationship of scarlet prawns (Plesiopenaeus edwardsianus) to a benthic oil deposit off the north-west coast of Aruba, Dutch West Indies. Environm. Pollut. 13: 239-253.
- Thurberg, F. P., E. Gould, and M. A. Dawson. 1978. Some physiological effects of the Argo Merchant oil spill on several marine teleosts and bivalve molluscs. In: In the Wake of the Argo Merchant. Proc. Symp. 11-13 January 1978, University of Rhode Island, Center for Ocean Management Studies. pp. 103-108.
- Vandermeulen, J. H. 1977. The Chedabucto Bay spill - Arrow, 1970. Oceanus 20: 31-39.
- Waldichuk, M. 1974. Some biological concerns in heavy metals pollution. In: Pollution and Physiology of Marine Organisms. (F. J. Vernberg and W. B. Vernberg, eds.). Academic Press, New York. pp. 1-57.
- Wolfe, D. A., D. F. Boesch, A. Calabrese, J. J. Lee, C. D. Litchfield, R. J. Livingston, A. D. Michael, J. M. O'Connor, M. Pilson, and L. V. Sick. 1982. Effects of toxic substances on communities and ecosystems. In: Ecological Stress and the New York Bight: Science and Management. (G. F. Mayer, ed.). ERF, Columbia, SC, pp. 67-86.
- Yevich, C. A. and P. P. Yevich. 1985. Histopathological effects of cadmium and copper on the sea scallop Placopecten magellanicus. In: Marine Pollution and Physiology: Recent Advances. (F. J. Vernberg, A. Calabrese, F. P. Thurberg, and W. B. Vernberg, eds.). U. South Carolina Press, Columbia, SC, pp. 187-198.

Yevich, P. P., and C. A. Barzcz. 1977. Neoplasia in soft-shell clams (Mya arenaria) collected from oil-impacted sites. Ann. N.Y. Acad. Sci. 298: 409-426.

(continued from inside front cover)

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