OXYGEN DEPLETION AND ASSOCIATED ENVIRONMENTAL DISTURBANCES IN THE MIDDLE ATLANTIC BIGHT IN 1976

A REPORT
ON A SERIES OF INTERAGENCY
WORKSHOPS HELD IN
NOVEMBER AND DECEMBER 1976

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PREFACE

Major and abnormal environmental events occurred in coastal waters of the Middle Atlantic Bight in the summer and autumn of 1976. An extensive offshore phytoplankton bloom began in late winter and persisted until early summer. Bottom waters over an estimated 4,8000 square kilometers became anoxic and a hydrogen sulfide system developed in part of the area affected. Fish and shellfish died in numbers sufficient to be described, for at least one economic species (surf clam, Spisula solidissima), as a resource disaster. Since part of the affected area receives the most concentrated ocean dumping known in the world, concern was expressed in news media that these drastic and harmful environmental happenings may be related to human chemical additions to coastal waters. A direct relationship could not be established with certainty, and it seemed clear that large-scale natural phenomena were also involved.

A number of federal, state, university and private industry research groups were involved throughout the summer and autumn of 1976, to varying degrees, in attempts to understand the events that were occurring. Much data were collected, and are being analyzed by the research groups involved. It was felt, however, that there would be distinct advantage in calling together all participants for a series of workshops.

to share observations and data, and to prepare an interim report on the status of our understanding. An Interagency Steering Committee was formed to plan and organize the workshops, with membership drawn from groups participating actively in the studies. The Committee consisted of representatives from the New Jersey State Department of Environmental Protection, National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the academic community, and the American Littoral Society.

Seven workshops were held during November and December, 1976, to discuss the causes and consequences of the fish kills observed off the New Jersey coast during July, August, and September, 1976. The workshops and their chairmen were as follows:

Benthos - Frank Steimle, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Highlands, N.J. 07732

Fisheries - Paul Hamer, N. J. Dept. of Environmental Protection, Div. of Fish and Game, Absecon, N.J. 08201

Meteorology - Stan Chanesman, MESA-NYB Project Office, SUNY Old Biology Bldg., Stony Brook, N. Y. 11794

Physical Oceanography - William Librizzi, U.S. Environmental Protection Agency, Research Laboratory, Edison, N. J. 08817

Chemical Oceanography - Peter Anderson, U. S. Environmental Protection Agency, Region II Edison, N. J. 08817

Plankton - Thomas C. Malone, Lamont-Doherty Geological Observatory, Palisades, N. Y. 10964

Sediments - D. W. Bennett, American Littoral Society, Sandy Hook, Highlands, N. J. 07732

Stated purposes of the workshops were: (1) to compile and examine available data, (2) to summarize available data and prepare interim conclusions, (3) to prepare a summary status report on our present understanding, and (4) to make recommendations for future research.

This document contains summary reports of each of the workshops, with appendices consisting of individually authored papers where pertinent. It should be reemphasized that these reports are interim documents summarizing our information as of December, 1976. Some of the appendices are still in draft form, kindly made available by the authors in the interest of early dissemination of information, and some will appear subsequently in other publications. Further analyses of data by the research groups involved will undoubtedly produce new insights, and will result in additional and more definitive reports.

Invited workshop participants were:

- National Marine Fisheries Service, NOAA, (Sandy Hook, N. J. and Oxford, Md. Laboratories; Atlantic Environmental Group, Narragansett, R.I.)
- New Jersey Department of Environmental Protection
- U. S. Environmental Protection Agency (Edison, N.J., Region II)
- Atlantic Oceanographic and Meteorological Laboratories, ERL, NOAA, Miami
- Rutgers University (Department of Biology)
- Adelphi University
- American Littoral Society
- Bigelow Laboratory for Ocean Sciences
- Brookhaven National Laboratory, ERDA
- Brooklyn College
- Columbia University (Lamont-Doherty Geological Observatory)
- Ichthyological Associates, Inc.
- MESA, New York Bight Project, NOAA
- State University of New York at Stony Brook
- University of Rhode Island
- Virginia Institute of Marine Sciences

Note: This report is the second in a series of interim summarizations of information about the oxygen depletion phenomenon in the Middle Atlantic Bight in 1976. The first report, "Anoxia on the Middle Atlantic Shelf during the Summer of 1976" contains results of a workshop held on October 15 and 16, 1976, sponsored by the National Science Foundation/International Decade of Ocean Exploration. That workshop report was prepared at the University of Delaware, edited by Jonathan H. Sharp, and issued in November, 1976.

THE 1976 NEW JERSEY FISH KILL: SUMMARY OF WORKSHOPS

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Introduction

Mortalities of finfish and shellfish populations occurred off the New Jersey coast between Sandy Hook and Atlantic City from late June through September, 1976. This has had immediate impacts on commercial and sport fisheries and could have long term effects as a consequence of larval mortality and reductions in the size of spawning populations. The fish kills were apparently caused by the development of an oxygen minimum layer and local hydrogen sulfide production below the thermocline in waters 15 to 40 m deep between 5 and 40 km offshore.

Because of these fish kills and other unusual episodes in the New York Bight during the first half of 1976 (e.g. the *Ceratium tripos* bloom), workshops were organized to collate existing environmental data, to document the environmental impact of the oxygen minimum layer and to determine why exceptionally low oxygen concentrations developed off the New Jersey coast during summer, 1976. The following is an integrated summary of these workshops.

Benthic Populations and Fisheries

Benthic organisms did not appear to play an important role in the initial development of the oxygen minimum layer. Best estimates indicate that benthic respiration is only 2 - 5% of water column respiration. Consequently, in lieu of an unusually large input of oxidizable organic matter to the sediments, it is unlikely that benthic respiration was a major factor. This is consistent with the observation that bottom sediments in the impacted area are almost exclusively clean sands with low silt and clay content. (Sediments rich in organic matter usually have high silt and clay contents.)

Low oxygen concentrations and hydrogen sulfide production resulted in high mortalities of benthic populations and changes in the distributions and migratory patterns of demersal and pelagic fish populations. High mortalities were first reported off the northern New Jersey coast in early July between 3 and 25 miles (5 - 40 km) offshore in waters of intermediate depth (15 - 40 m). As the summer progressed, mortalities increased and high mortalities became more widespread to the south so that by October the impacted area extended from Manasquan Inlet to Cape May. Mortality rates were highest in a zone 20 - 40 m (65 - 130 ft) in depth between Barnegat

Inlet and Ocean City.

Of the benthic organisms which experienced high mortality rates, the surf clam, *Spisula solidissima* was most severely affected. Other impacted populations included rock crabs (*Cancer irroratus*, *C. borealis*), starfish (*Asterias forbesi*), moon snails (*Lunatia heros*), mud shrimp (*Axius serratus*), lobsters (*Homarus americanus*), sea mussels (*Mytilis edulis*), sea scallops (*Placopecten magellanicus*), sand dollars (*Echinarachnius parma*), mantis shrimp (*Squilla* sp.), polychaetes, razor clams (*Ensis* sp.), sea cucumbers (*Thyone* sp.), ocean quahog (*Arctica islandica*) and the anemone (*Ceriantheopsis americanus*).

Of the economically important species, mortalities were highest among surf clams, ocean quahogs, scallops and lobsters. Surf clam mortality increased in the most heavily impacted area off the central New Jersey coast from 7.5% in August to 53.5% in September and 92.1% in October. Ocean quahog and scallop mortalities were about 13.3% and 10.5%, respectively. Based on landing statistics, lobster catches were down during July - September by an average of 29% compared to the same period in 1975.

While local finfish mortalities were observed, mortality rates of adult finfish populations caused by low oxygen concentrations were probably low due to the avoidance of the effected areas. The effects on egg and larval survival are unknown. The presence of oxygen deficient water did appear to influence the distribution of finfish species. For example, bluefish usually migrate north along the coast during spring with the smallest fish close to shore and the largest fish offshore. During 1976, the medium size class, which usually migrates north in 15 to 40 m of water, migrated south instead.

The distribution of summer flounder was drastically influenced by the location of the oxygen minimum layer. Low oxygen waters forced this epibenthic species inshore resulting in unusually large but localized fishing mortalities.

Atmospheric and Hydrographic Conditions

The fish kill episodes which occurred during the summer and early fall probably reflected (but were not necessarily caused by) meteorological and hydrographic conditions in the New York Bight during the months preceeding the actual fish kills. Three major anomalies characterized the meteorology of the New York Bight region during the first half of 1976. Atmospheric circulation patterns during February and March exhibited an increase in the southerly component of the wind field (and a concurrent decrease in the northerly component), a situation more typical of April and May than of February and March. Secondly, surface air temperatures were unusually high during the first six months of 1976 as indicated by the observation that temperatures were 1 - 3°C higher than seasonal norms. Finally, storm activity was lower than it has ever been during the period of record (10 years). The average number of cyclones (strong winds associated with low pressure centers) passing through the New York Bight area between February and June is 14.5. During this same period in 1976 only six storms passed through the New York Bight.

These atypical atmospheric conditions were undoubtedly reflected in the hydrography of shelf waters in the New York Bight. Surface water temperatures were near the high end of the seasonal ranges observed from 1966 through 1974. In addition, river runoff was unusually high from January through March. This, in combination with the meteorological anomalies noted above, would tend to enhance the degree of isolation of bottom water, especially during the period from April through August when the water column is thermally stratified. (Thermal stratification with warm surface water separated from cold bottom water usually begins to develop in April with maximum stratification in July and August.)

Since variations in the oxygen content of bottom water generally parallel changes in vertical stratification, such a decrease in mixing between bottom and surface water (rich in oxygen) could be critical given the high rates of organic loading (natural and anthropogenic) to which New York Bight waters are subject. Oxygen concentrations are high (6 - 8 ml/liter) and near saturation during the winter months. As the water column stratifies, the oxygen concentration of bottom water below the thermocline begins to decline. The maximum rate of decline (about 0.06 ml O_2/liter/day) usually occurs during July and minimum bottom water concentrations (2-4 ml/liter) are reached in August.

During 1976, dissolved oxygen concentrations in waters deeper than 20 m off New Jersey (bounded by $39^{\circ}-40^{\circ}$N and

and 73°-74°W) were as low in May (4.5 - 5.5 ml/liter) as they usually are in July. Bottom water concentrations were less than 2 ml/liter by late June and by mid-July anoxic bottom waters were reported off of Barnegat Inlet. At this time the oxygen minimum layer (less than 2.0 ml O_2/liter) extended about 55 miles (90 km) offshore from near Sandy Hook south to Atlantic City. The center of anoxia moved south during July and was located off Atlantic City in early August. Hazardous concentrations of hydrogen sulfide ($>$0.01 mg H_2S/liter) were associated with the anoxic water. The oxygen minimum layer appeared to develop off northern New Jersey and expanded south affecting an area of about 4800 km^2 by mid-August. Low oxygen concentrations persisted until water column stratification began to break down in September and October.

An oxygen minimum layer also develops off the Long Island coast during the summer. However, during 1976, as in previous years, the minimum layer was not as pronounced, and fish kills were not observed off Long Island. This probably reflects differences in bottom topography. The slope of the continental shelf is initially greater near the coastline off of Long Island than off New Jersey. Consequently, while both the New Jersey and Long Island shelves have broad flat areas, the bank off of Long Island is in 40 - 60 m of water while off New Jersey it is in 20 - 40 m of water. Since the depth of the pycnocline (a layer separating low density surface water from high density bottom water) is about the same over both banks during the summer (20 - 30 m), the thickness of the bottom layer is less (10 - 20 m) off New Jersey than off Long Island (30 - 40 m). In addition, there is evidence that the residence time of bottom water off the New Jersey coast is longer than off Long Island.

Thus, increased water column stability created the potential for unusually low oxygen concentrations in bottom waters of the New York Bight, and bottom topography favors the development of anoxic conditions off the New Jersey coast.

The Ceratium tripos Bloom

An extensive bloom of the dinoflagellate (a type of single celled, photosynthetic organism which can swim) Ceratium tripos occurred in the Middle Atlantic Bight between January and July, 1976. The bloom apparently began throughout the New York Bight in January with maximum cell densities developing in the mid-shelf to shelf break region in late March prior to the onset of thermal stratification. The large area over which the bloom occurred indicates that it did not develop in response to local nutrient enrichment of the coastal zone during the actual period of the bloom. This is supported by the observation that C. tripos cell densities were lowest near the mouth of the Hudson-Raritan estuarine complex (including the ocean dump sites) where local enrichment is greatest. The causes of the bloom probably involved processes operative on spatial scales on the order of the continental shelf and time scales on the order of months to years.

As the water column began to stratify, the C. tripos population aggregated in a narrow band (1 - 3 m thick) at the base of the thermocline, and by mid-June the center of maximum abundance had shifted from offshore to within 100 km (60 miles) of the New Jersey coast east of Seaside Park (39°55'N, 73°15'W). A large population of cells was situated below the thermocline in a bottom layer about 15 m thick overlying a relatively flat region of the New Jersey shelf between the 20 and 40 m isobaths. This is in contrast to the population off Long Island which was situated near the top of a subthermocline layer 30 m thick.

Population size declined rapidly from late June through July. Concurrent with the collapse of the bloom, a flocculent suspension of *C. tripos* cells collected on the bottom between Sandy Hook and Atlantic City from 5 to 50 km offshore. Steady decomposition of this material occurred during July.

C. tripos is a slow growing species which has few known predators. The *C. tripos* bloom resulted in a gradual accumulation of a large quantity of organic matter which did not enter pelagic food chains and which does not usually accumulate in the water column. The respiration of this biomass and its decay below the thermocline were probably major factors in the development of the oxygen minimum layer off the New Jersey coast in June and July. The localization of the oxygen minimum off New Jersey reflects bottom topography and the distribution of *C. tripos* biomass.

Phytoplankton productivity *per se* was probably not a major factor even through quantitatively it accounts for most of the input of particulate organic matter to the region. There is no evidence that a significant portion of phytoplankton production accumulates below the thermocline during the summer. Most of the phytoplankton production is rapidly turned over and accumulates as biomass in higher trophic levels. In effect, the <u>C. tripos</u> bloom provided a mechanism by which large quantities of organic matter accumulated in the water column over an extended period (several months). It was this process in combination with the unique atmospheric and hydrographic conditions which resulted in the development of oxygen deficient bottom waters off New Jersey during the summer, 1976.

INTRODUCTION

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First indication of an environmental disturbance appeared during the fourth of July weekend of 1976, when sport divers reported that they had observed dead fish and invertebrates on or around shipwrecks off the north New Jersey coast. These initial observations were confined to an area between Long Branch and Barnegat Inlet, New Jersey and in a band 5 to 30 km offshore. A commercial trawler had collected dead fish, up to 75% of his catch, on June 30 in 50 meters of water in the apex of the Hudson Shelf Valley. Prior to this there hadn't been any deaths reported, although the previous weekend, June 27th, divers had observed stressed animals on many of the same wrecks. The animals were considered stressed because, although alive, they were unusually sluggish and were often congregated on the highest parts of the wrecks.

The animals affected were predominantly demersal species usually closely associated with rough bottoms; for example, ocean pout, cunner, crabs, and lobsters. Other species were also affected; for example, red hake and surf clams. These observations were limited to north of Barnegat Inlet, until the middle of July, then similar reports of mortalities were received from divers as far south as the Atlantic City area.

Besides the mortalities, the divers also reported only wrecks which were beneath the thermocline, which then was about 20 meters deep, were affected. The surface temperature was about 20°C and the bottom about 10°C, with a visually distinguishable layer near or just above the thermocline of about 12°C. This 12°C zone was described as a "yellow-brown haze". The surface waters, down to about 15 meters, were relatively clear. The bottom waters were described as being very dark, with powerful lights being required even at midday to clearly distinguish objects on the bottom. Dark colored, stringy particles were also reported present in this bottom water with accumulations of more than a centimeter of a dark, loose material covering most of the predominantly sand bottom. The divers reported they had never found this before, except for occasional minor accumualtions in depressions.

Some of this bottom material was collected later by Sandy Hook Laboratory divers and examined by Dr. John Mahoney, a microbiologist at the NMFS Sandy Hook Laboratory who specializes in red tide studies. He found the dark bottom material to be predominantly a mass of phytoplankton cells in an amorphous matrix. The dominant species, visually, was *Ceratium tripos*; other *Ceratium* species, as well as several species of diatoms, were also obvious. Many of the cells were disrupted and numerous bacteria, some motile, were present along with ciliates and pennate diatoms.

Investigations of the phenomenon began during the week of July 7, with the National Marine Fisheries Service, the New Jersey Department of Environmental Protection and the U. S. Environmental Protection Agency as principal participants. Other groups, such as the American Littoral Society, also were involved in an attempt to assess and understand what was happening. From past experience with similar, but much more localized problems of this type (Ogren and Chess, 1969; Young, 1973), there was a general aggreement among involved groups that there was a high degree of probablity that the situation was caused by deficient D.O. concentrations. So initially the research and monitoring emphasis was interested in defining the problem and the impacts on resource species.

The sampling to mid-July, found the depressed dissolved oxygen (D.O.) values, as anticipated, some values below the level of detection by standard Winkler procedures, in an area 3 to 30 kms off Barnegat Inlet. Values of less than 2 ppm were found between Long Branch and Beach Haven. Trawl surveys found dead epibenthic invertebrates and stressed surf clams in this zone and a notable absence of the normal finfish populations known to inhabit the area in the summer.

By early August, prior to hurricane Belle, the anoxic area had moved or expanded southward, with the D.O. depleted area being found between Barnegat Inlet and Atlantic City. Extremely high levels of hydrogen sulfide (to 1.76 mg/l^{-1}) were also detected near the center of the D.O. depleted area. The hydrogen sulfide was present up to 15 meters from the bottom, but not above the thermocline.

Hydrogen sulfide was also evident in an apparent upwelling of anoxic bottom water along very restricted portions of the central New Jersey coast. Hundreds of fish of several species, including sharks, were trapped along the beach and killed. A period of strong westerly winds was thought responsible.

At the same time, unusual concentrations of fish, especially summer flounder, were found near the beach and in the bays and estuaries, most likely avoiding the anoxic area.

The hurricane, from which many had hoped for relief, did not significantly alter the situation. Immediately after its passage, resurveys of stations off Atlantic City which had been surveyed just prior to the storm found some possible coastal mixing or an offshore shift resulting in the less than 2 ppm D.O. area moving from three km off the coast to 30 km offshore as the only apparent effect. This was only temporary, because a second resurvey, five days later, indicated the anoxic water mass had resumed most of its pre-hurricane distribution with further movement or expansion south-southeast.

In late July, Dr. Mahoney examined additional samples collected at the thermocline and on the bottom, off Sandy Hook and Barnegat Inlet. He found viable Ceratium tripos cells in both thermocline samples, but they were more abundant to the south. In the bottom samples, however, *Ceratium* was less evident than before, with existing cells being attacked and eroded by bacteria, generally indicating to Dr. Mahoney a more advanced state of decay than previously found.

During February, 1976, researchers had found an unusual bloom of a dinoflagellate phytoplankton, *Ceratium tripos* in progress over most of the outer continental shelf area of the Middle Atlantic Bight. This was also noticed by biologists at Sandy Hook Laboratory in an ichthyoplankton survey during March. This dinoflagellate clogged nets from Long Island to off Virginia in abundances which had not been observed in the ten years' experience of the ichthyoplankton group sampling in this area.

Beginning in late July, assessments of the impact on the surf clam stocks were begun. Signs of stressed surf clams were noted by divers as early as the July 4th weekend. These were clams that were not embedded in the sediment but were lying free on the surface. Several later trawl surveys also found live, but gaping clams in their nets. The first specific surf clam survey was completed by the end of July under the direction of John Ropes of NMFS, NEFC Oxford Laboratory. He found mortalities in a restricted area off Barnegat Inlet ranging between 0 to 56%. A second survey, in early August, found an average mortality of 10% in clam stocks in the impacted area. The normal mortality is 2%.

Subsequent expanded resurveys in September and October found that the average mortality had risen to 100% at some stations in a 14,000 square km section off New Jersey, generally covering the area from Manasquan Inlet to Avalon and between 5 and 60 kms offshore. It was estimated that this represented a loss of 143,000 metric tons of surf clam meats, thus representing about 69% of the offshore surf clam stocks of New Jersey. Because July is the normal spawning season for surf clams, the impact on future stocks may also be severe.

Mortalities have also been observed in New Jersey's ocean quahog population, a potentially valuable resource species, which is usually found in deeper water than the surf clam. In early August mortalities for this species were less than 1%. Mortalities increased in September to almost 8%, with a high of 40% at some individual stations. The total loss to N.J. stocks was estimated at about 0.8%.

It is also becoming apparent that the lobstering industry off New Jersey was affected, with some inshore stocks being killed, and apparently the migration of offshore stocks, inshore, being interrupted.

To continue with a chronology of the phenomenon, during mid- to late September, the anoxic area, defined here by the 2 ppm limits, reached its greatest known distribution, covering approximately half the New York Bight, including a tongue off Long Island. The new developments off Long Island were interesting. A surf clam assessment survey there, however, revealed no serious problems with the exception of a few stations off Jones Inlet (approximately 30 kms east of Sandy Hook) where stressed surf clams were collected.

By the first week in October, surveys found that the thermocline was apparently decaying because bottom D.O. concentrations inshore, out from the coast to 40 km, were increasing to non-hazardous levels and by early November no trace of oxygen depletion was evident, and the 1976 anoxia phenomenon had evidently ended, except for a complete understanding of why it occurred and what the long range impacts to marine population might be.

Grateful acknowledgements for vitally needed vessel services, repeatedly and graciously extended under extremely short notice, are made to the U.S. Coast Guard and specifically to the then Commander, Atlantic Area, and to the officers and crew of the USCGC Duane, Pt. Francis and Cape Starr.

The Duane cruise enabled us to define the northern and eastern limits of the anoxic zone. The cruises by Pt. Francis and Cape Starr out of Atlantic City, enabled us to document the protracted nature and the eastern extension of the anoxic zone.

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PHYSICAL/CHEMICAL OCEANOGRAPHY WORKSHOP --

SUMMARY REPORT

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1.0 Introduction

A physical/chemical oceanographic workshop was convened on 22 November 1976 in the main conference room of the NOAA/NMFS/NEFC Sandy Hook Laboratory to discuss the summer 1976 anoxic conditon which developed in the Middle Atlantic Bight (MAB) and the fish kills associated with the condition. The workshop was convened to assess all available data, summarize such data, develop conclusions, define areas of uncertainty and make recommendations on priority monitoring needs.

2.0 Joint Physical/Chemical Oceanography Session

The workshop initially convened at 0900 as a joint physical/chemical session. By way of introduction, Frank Steimle of NMFS/Sandy Hook described the 1976 summer anoxia and reviewed the evidences of it. He discussed the discovery sequence and the NMFS/Sandy Hook data base. He pointed out that much of the clam mortality was probably not directly due to the low oxygen values but rather to the sulfide buildup resulting from it. Sulfide reached values of 1.76 mg l^{-1} (EPA limit is 0.01 mg l^{-1}). Donald Atwood (NOAA/AOML) presented a summary of the NOAA/MESA/AOML 1975 and 1976 data on dissolved oxygen distribution in the northern part of the MAB (the New York Bight) (Garside cautions that data presented herein represent portions of MAB) and discussed it in light of the Segar and Berberian (1) concept of how warm season oxygen depletion develops in the Bight, i.e., that annual warm season depletion of oxygen in lower waters of the New York Bight is a result of oxygen demand created primarily by the photosynthetically produced organic matter transported biologically or abiologically down through the thermocline, and that the quantities of organic matter photosynthetically produced is enhanced by anthopogenic nitrogen nutrient inputs particularly from the Hudson/Raritan estuary. AOML particulate organic carbon (POC) data for 1974 and early 1975 which showed high POC levels in the low salinity surface water of the Hudson/Raritan plume support the hypothesis that nutrients in the plume stimulate productivity in the Bight. Surprisingly, POC values in the deep water were quite low throughout that period, probably as a result of dead plankton material sinking rapidly to the bottom once it gets below the thermocline (Garside disagrees and suggests that this is evidence that Segar's hypothesis is inaccurate).

AOML current meter and density data available through 1975 were also discussed. Data for 1976 have not yet been reduced to a form which allows display. The 1975 data fit the Beardsley, Boicourt and Hansen (2) model for longshore (southwesterly) transport and indicate a "normal" year residence time of water in the Bight (Nantucket to Cape Hatteras) of roughly 3/4 of a year. The residence time for the portion of the Bight between Montauk, L. I. and Cape May, N. J. is indicated as about 100 days. This is in contrast to a residence time of >2 years calculated by Wright (3) considering on shelf exchange. A more detailed discussion of AOML's feelings on MAB water residence time is given in Appendix II.

Reed Armstrong of NOAA/NMFS/Atlantic Environmental Group presented a summary of historical oxygen data available for the affected area. Using the mean rate of summer bottom water oxygen depletion indicated by the data and assuming that stratification of the water column occurred about two months earlier in 1976, Armstrong showed that oxygen levels would have reached zero by late June which was the actual case. AOML's 1976 oxygen data for the area fit Armstrong's model almost exactly, indicating that the basic cause of the intense 1976 anoxia could have been the early onset of stratification. (Garside sees no evidence for early stratification and thus disagrees with extrapolation of the depletion curve by Armstrong.)

Subsequent to these presentations the meeting split up into separate chemical and physical groups. The remainder of this report deals with the chemical oceanography portion of the workshop. As physical oceanographic data was for the most part unavailable for assessment and evaluation at the time of the workshop no separate report is included.

3.0 Chemical Oceanography Sessions

3.1 Assessment of Data Base

An assessment was made of what data pertinent to the 1976

MAB anoxia were available. The result of this assessment is given in Appendix III and includes preliminary evaluations of data reduction and presentation.

Terry Whitledge of Brookhaven National Laboratory pointed out potential problems with comparisons of oxygen data from different groups. He suggested that variables such as $PO_4^{\equiv}$, NO_3^{-}, and $SiO_4^{=}$ should be presented along with the oxygen data so that elements of oxidative origin can be calculated. Back calculation of oxidative elements would then give an estimate of AOU and, using some assumptions, oxygen concentrations.

3.2 Discussion of Data Base

The following questions were posed to the group:

Can the Segar and Berberian model be assumed correct? Is there enough O_2 demand at all times to allow Bight bottom water to go anoxic if the system is stratified for long enough periods? Is this a natural condition or is there an anthropogenic input that keeps productivity stimulated during all years so that an odd year physically and meteorologically will allow it to go to total anoxia? Can such inputs be controlled? Can we develop a predictive capability and of what use would it be?

Atwood reminded the group that Armstrong's historical data plot shows that the O_2 depletion rate in any year is probably enough to carry the system to total anoxia if given enough time and that AOML's O_2 data for 1976 fall right on the predicted curve. Doug Segar stated that we know that primary production in the Bight is nitrogen limited (Malone says light limited) and that the Hudson Raritan estuary is a major source of anthropogenic nitrogen. Secondary treatment of sewage effluent dumping into the estuary amplifies the problem since it makes the nitrogen more available.

Terry Whitledge stated that BNL data showed that total production and productivity rates in the Bight were about average this year. Nitrogen levels were also about the same as other years. BNL also collected ^{15}N labelled ammonia and nitrate uptake rates in the *Ceratium tripos* bloom area. The absolute values of these rates were almost the same as observed during dinoflagellate blooms (*Gonyaulax polyhedra*) off Baja California. The unusual aspect of the nitrogen uptake by autotrophic organisms was that the ammonium uptake was two times the nitrate uptake which is the reverse of what is normally expected. Apparently the system was running on recycled material.

Whitledge also pointed out that the natural variability of productivity (carbon and nitrogen) is quite large so that any increase in nitrogen and carbon loading in the New York Bight is masked by this natural variability. This means that firm conclusions on changes in anthropogenic loading to the system are difficult.

Chris Garside of Bigelow Labs discussed data from the MESA biological program as well as some of the ideas resulting from the plankton workshop. He pointed out that POC values in the Bight this year were much higher than previous years. Normally there is a pulse on the POC curve in the spring due to the spring bloom and another less instantaneous increase due to the summer bloom. In 1976 the spring pulse was much higher than other years. Although productivity was about the same, standing crops were much higher due to the predominance of *Ceratium tripos* and the fact that nothing grazes on the *Ceratium*. Thus POC values this year were about double the mean of previous years. He noted that *Ceratium* is found every year but that this year blooms were bigger and got bigger faster.

Garside also pointed out that based on pre-1975 data (no data for 1976) there is apparently *not* enough POC in the water column at any one time to deplete all the O_2 even with an infinite residence time. Given the "AOML residence time" of 100 days (see Appendix II) it seems even less likely that total anoxia could develop leading the plankton people to feel that factors other than early stratification contributed. The MESA biological program has not seen one single instance where POC O_2 demand exceeded O_2 availablility. Perhaps the thermocline across the relatively flat Jersey shelf, being only about 5 meters off the bottom, coupled with some onshore transport of bottom water served to concentrate dead Ceratium material in the area at high enough levels to deplete O_2.

Atwood reminded the group that the "AOML residence time" of 100 days fits the 1975 data, but that nothing is known yet about 1976. There is a good chance that the prevalent southwesterly winds in 1976 increased this residence time. Segar pointed out that the 1976 physical conditions were optimum for increasing the residence time and intensifying the oxygen depletion.

Atwood also questioned the statement that there was not enough O_2 demand in the bottom water to utilize all the O_2. Both Sharp's (4) and Ketchum's calculations indicate that (assuming little or no oxygen replenishment) there is enough loading for 400% depletion of oxygen. Perhaps the dissolved organic carbon (DOC) is just as important as the POC. Open ocean DOC values are generally at least five times the POC values (5) and can be as high as one hundred times the POC values. Estuarine DOC loads are at least equal to the POC load (5). Assuming that coastal values will be intermediate to open ocean and estuarine values, it is obvious that DOC loading can be at least as great as POC loading (unless the DOC present is largely refractory). During the

ALBATROSS cruise in the MAB during September 1976, DOC values of 1.1 to 14.0 mg C l^{-1} were measured with values in the bottom water of the anoxic area being commonly several mg l^{-1}. Iver Duedall (SUNY, Stony Brook) noted that he had measured values of 1 mg l^{-1} POC in the Bight Apex during the MESA STAX-II experiment which is generally accepted as an upper limit for open ocean POC's. Duedall and Atwood went over the data presented by Sharp (4) at the IDOE ANOXIA Workshop. Sharp estimates that annual carbon inputs to the area affected by the 1976 anoxia are approximately 12 mg C l^{-1} year $^{-1}$ which (assuming little or no oxygen replenishment) will allow 400% depletion of O_2. If we assume a 100 day residence time and three to four months of stratification we could easily get 1/4 of this (probably more because organic loading is highest during the stratified season) and 100% depletion of oxygen during that time.

It is interesting that if the discovery rate of the anoxia in summer 1976 is an occurrence rate that the spreading is about right for a southwesterly flow and a residence time between Montauk and Cape May of 100 days, i.e., 30+ days from the Bight Apex to Cape May. There is a question, however, as to why the anoxia did not spread further south during September. Jim Thomas (NMFS/Sandy Hook) pointed out that at the southern extremity the anoxia seemed to spread out over the shelf more (i.e., deeper water, larger pool of DO). He also pointed out that integrated water column O_2 utilizations measured this year appeared to be "husky" but that there were no earlier data to compare with the 1976 data.

Terry Whitledge pointed out that the 1976 MAB case and a situation off Peru this year are two rare instances where sulfide was detected in the open ocean. (Another instance has been reported off Goa, India, by the Russians in both 1960 and 1968.) The Peru anoxia resulted from a dense dinoflagellate bloom. It could be that this is coincidence, however, we know that when intense El Nino phenomena occur off Peru, a similar phenomenon occurs off Baja, California. This usually coincides with good productivity years near Europe. Perhaps casual factors of these phenomena are at least partly global in nature and we are wrong to look for strictly local causes in the MAB case.

The question was posed as to what experiments could now be conducted to test the hypothesis or hypotheses presented. No satisfactory suggestions resulted; however, it was generally agreed that chemists should endeavor to learn if there were a chemically induced loading to the system which could be relieved. A major effort should be geared to producing a predictive capability as to the intensity of future anoxic conditions. Such capability could be exploited by altering fishing regulations when a heavy kill seems probable. Some predictive capability could probably be based on monitoring three parameters; i.e., dissolved oxygen levels (and changes in them), POC loading and DOC loading. Such data used in conjunction with a working diagnostic physical model of the Bight might allow prediction of future intense anoxia although Whitledge points out such predictions would probably only be within a few weeks or, at most, months of the occurrence.

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APPENDIX I

CLIMATIC CONDITIONS RELATED TO THE OCCURRENCE OF ANOXIA IN THE WATERS OFF NEW JERSEY DURING THE SUMMER OF 1976

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Introduction

Observations made by the Sandy Hook Laboratory of the NMFS in August, 1976, indicated that a major fish kill then in progress off New Jersey probably was related to the presence of exceptionally low oxygen concentrations in the bottom waters on the continental shelf. Comparison of the August, 1976, data with historic August observations from the NODC archives indicates that the thermal structure and surface-layer oxygen concentrations were not unusual this year (Figure 1). Therefore, any physical phenomena related to the anoxic condition in the bottom waters must have occurred earlier.

In order to examine environmental conditions that might have led to the generation of anoxic conditions, various sets of historical and climatological data were acquired. The data used and sources for the records were:

1) Monthly mean river discharge for the Delaware River, Hudson River and cumulative discharge into Long Island Sound, provided by the U.S. Geological Survey.

2) Monthly mean sea surface temperature, compiled from ship

reports and published in Gulfstream (National Weather Service, Jan. 1975-Aug. 1976) and in The Gulf Stream Monthly Summary (U. S. Naval Oceanographic Off., Jan. 1966-Dec. 1974).

3) Monthly mean shore station temperatures at tide stations (Sandy Hook, Atlantic City and Cape May, N. J.), acquired from the National Ocean Survey of NOAA.

4) Historical oceanographic station data including dissolved oxygen observations, provided by the National Oceanographic Data Center of NOAA's Environmental Data Service.

In addition, data from oceanographic stations occupied in the area in 1976 were provided by the Sandy Hook Laboratory of NMFS and by the Atlantic Oceanographic and Meteorological Laboratories of NOAA's Environmental Research Laboratories.

Climatological Conditions

Based on examination of climatological records, it was apparent that spring essentially began one to two months early in 1976. Comparison between the mean and 1976 annual cycles of warming and cooling in the surface waters offshore of New Jersey (Figure 2) indicates that in 1976, the waters began warming at least one month earlier (between February and March) than anytime in the preceeding ten years. The early warming in 1976 is also indicated in shore station records where, at Sandy Hook, N. J., warming between January and February, 1976, was greater than anytime for the period of record (32 years). In addition, the usual spring increase in river discharge (Figure 3) began about two months early in 1976. Spring increase in discharge into Long Island Sound was also two months early. The result of these two conditions, early warming and early occurrence of high discharge, would be to establish stratification of the water column some one to two months early.

Oxygen Cycle and Stratification

The annual cycle of dissolved oxygen in the sub-pycnocline waters is shown in Figure 4, which is a compilation of historic observations from the NODC archives for a one-degree square off New Jersey (39°-40°N latitude, 73°-74°W longitude). For this analysis oxygen measurements at the greatest sampling depth for each station were plotted by month, regardless of year of observation, and a mean annual trend was derived from the plotted values. Data included in Figure 4 are from 77 stations of 28 cruises conducted during 12 years, with observations available in all months.

During fall and winter, cooling at the surface of the shelf waters causes overturning, an event which mixes the waters from surfact to bottom and has the effect of raising bottom oxygen concentrations to an equivalent value of surface waters. Surface cooling, overturning and resultant increase in bottom oxygen concentrations typically continue until March (Figure 4), when surface warming begins and river discharge increases, causing stratification to be established. Persistence and strengthening of stratification through spring and summer limit vertical replenishment of oxygen into the sub-pycnocline waters on the shelf, where dissolved oxygen is normally being depleted by biological activity.

The persistence of the cold-core over the middle shelf and strong temperature gradient of the shelf water-slope water front over the continental slope provide evidence of little lateral mixing and oxygen replenishment by advection from offshore. The apparent lack of vertical or horizontal exchange implies that through spring and summer the bottom water on the shelf is essentially a stagnant water mass. Based on historic data in the NODC archives, sub-pycnocline oxygen values steadily decrease (Figure 4) from the time of onset of stratification in March until surface cooling and overturning begin breaking up the stratification in September.

Application of Oxygen Model for 1976

Assuming that the early warming and early spring river discharge in 1976 caused stratification to become established two months earlier than usual (January instead of March) and assuming that oxygen depletion progressed at typical rates, an extrapolated trend for sub-pycnocline oxygen concentrations was formulated (Figure 4). This shows: (1) maximum oxygen concentration was not only achieved earlier, but also at a lower value (6.5 ml/L in January versus 7.1 ml/L in March); (2) dissolved oxygen fell to 3.0 ml/L in June, which is equivalent to the mean annual August minimum; and (3) a continued decrease to 0 ml/L in July. Subsequent to developing this extrapolated oxygen trend for 1976, some actual observations of sub-pycnocline oxygen concentrations for the year were received from AOML from surveys conducted as part of the MESA New York Bight Project. The correspondence of the extrapolated trend with the AOML observations (Figure 4) seems to support the contention that the occurrence of anoxic conditions resulted from a lengthened period of bottom water stagnation which, in turn, was caused by the onset of stratification two months earlier than normal.

Comments

Although the model proposed in this study seems to fit the general conditions reported off New Jersey, three additional questions arose which seem to warrant comment:

1) Why did the bottom water oxygen concentration continue to decrease rapidly after achieving concentrations too low to support life?

2) Why did anoxic conditions and the fish kill occur only off New Jersey and not adjacent shelf regions?

3) Has a similar set of circumstances occurred before and can we anticipate recurrences?

With regard to the first question, the extrapolated trend for 1976 shows bottom water oxygen concentrations were below 2 ml/L by late June. It would be expected that by that time most mobile organisms would be evacuating the low oxygen waters and the remainder might begin dying or going into a low respiration, dormant state. Further oxygen depletion would principally be from decay, which would tend to decrease the rate at which oxygen was declining. In order for dissolved oxygen concentrations to continue rapidly decreasing, as forecast by the model and as observed in the AOML cruise at the end of June-early July and by Sandy Hook in August, it seems that an additional decay biomass, such as the dead cells from the Ceratium bloom which occurred may be necessary. With the bloom beginning in spring and the lifetime of the Ceratium being about two months, by about mid-June large numbers of the organism should be dead and decaying on the bottom. Utilization of oxygen in the decay of this apparently large biomass might cause a continued, rapid decline in oxygen concentration.

Concerning the second question, the limited extent of anoxic conditions, NODC archived data were examined for the annual cycle of near-bottom oxygen concentrations in adjacent regions. Similar to the analysis exhibited in Figure 4, historic values were plotted by months, regardless of year, for a one-degree square off Long Island (40°-41°N latitude, 72°-73°W longitude). Historic observations compiled for this analysis came from 96 stations occupied during 14 years from 32 cruises, with observations in all months except April. Here, as off New Jersey, maximum bottom oxygen concentrations normally occur in March, decrease in spring and summer and begin rising in September. Similar to New Jersey shelf waters, the annual cycle of dissolved oxygen reflects the seasonality of density stratification. Oxygen decrease in this one-degree square off Long Island proceeds more rapidly during spring than off New Jersey, but less rapidly during summer (Figure 5a). Sea surface temperatures and discharge rates into Long Island Sound and from the Hudson River in 1976 indicate that stratification should have been established two months earlier than normal off Long Island, as was the case off New Jersey. An extrapolated trend for 1976 was developed for the waters off Long Island, beginning with the typical value for January (6.5 ml/L). This extrapolation for 1976 is shown in Figure 5b, along with the extrapolation for New Jersey bottom waters. Given similar anomalous events for the two areas (two month early spring and comparable Ceratium bloom), bottom oxygens off Long Island should not have gone much below 2 ml/L in 1976.

The differences in the annual cycle of oxygen concentration between the two areas most likely are the result of bathymetric conditions. A broad bank exists off Long Island in the 40-60 m depth range. A similar bank is present off New Jersey, but about 20 m shallower. The anoxic condition in 1976 developed on this bank off New Jersey and is the region where lowest oxygens typically occur (Figure 1). As pointed out at the workshop by other investigators, an effect of this bathymetric difference would be that a lesser volume of water and, hence, lesser volume of oxygen would be available in the thinner sub-pycnocline waters off New Jersey than off Long Island. Observations in the NODC archives for an August, 1949, cruise that transited both areas, show the bottom of the pycnocline was at a depth of about 25 m over the banks of both New Jersey and Long Island. Thickness of the bottom water mass over the bank off New Jersey was only about 15 m, whereas it was about 30 m thick off Long Island. Applying the ratio of these values to oxygen content, it could be argued that twice as much oxygen is typically available below the pycnocline off Long Island than off New Jersey.

Shelf waters south of New Jersey (off the Delmarva Peninsula) also experienced early warming in 1976 and would probably be under the influence of the early occurrence of high river discharge. The lack of reports of fish kills and anoxic conditions in this area in 1976 again is attributed to bathymetric differences. Off the Delmarva Peninsula the continental shelf is only about half as wide as off New Jersey and Long Island, which would allow for greater across-shelf exchange, accompanied by a better chance for oxygen replenishment. Historic observations in the NODC archives for the waters off the Delmarva Peninsula were too few to develop an annual cycle of bottom oxygen.

In regard to the question of frequency of occurrence, three previous fish kills off New Jersey have been reported--in September through early October, 1968 (Ogren and Chess, 1969), in October, 1971 (Young, 1973) and in August, 1974.[1] Apparently none of these earlier fish kills was as extensive or enduring as in 1976. Low oxygen conditions in the bottom waters were reported with all of these fish kills.

To determine if conditions similar to 1976 occurred in these earlier cases (and at other times) climatological records of sea

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[1] Personal communication from C. J. Sindermann, Sandy Hook Laboratory, NMFS, Nov., 1976.

surface temperature from shore station reports and discharge rates for the Hudson River were examined for the last 30 years (1947-1976). During this 30-year period, high discharge (arbitrarily defined as greater than 150% of the monthly mean) occurred five times in January (1949, 1950, 1952, 1973 and 1974) and three times in February (1951, 1954 and 1976). Shore station temperature records for Sandy Hook, N. J., and Atlantic City, N. J., indicated early warming of the water (monthly mean for February warmer than for January) occurring 12 times at Sandy Hook and nine times at Atlantic City. No observations were made in 1970 and 1971 at Atlantic City, which were two of the times of early warming at Sandy Hook. Coincidence of early warming and high discharge occurred in 1949, 1952, 1954, 1974 and 1976. Therefore, these five years are considered as potential times when low oxygen conditions might have developed in summer as the result of early onset of stratification. For the 30-year record, highest warming rates and record highest discharge in February all occurred in 1976. Included in the list of potential years of early onset of stratification is 1974, one of the times of a reported fish kill, but not included are the other two instances (1968 and 1971).

A significant point to consider here is that the fish kills of 1974 and 1976 occurred during summer, but not until fall in 1968 and 1971. The implication is that very low oxygen conditions may result from either an early spring or late arrival of fall, either of which would tend to lengthen the period of stratification.

In examining conditions that might imply the late arrival of fall, surface temperatures were considered as the only factor of significance, since river discharge in summer and fall is typically small (highest discharge of 30-year record for August is less than the monthly means for December, January and February and highest of record for September is about the same as the December through February means). Sea surface temperature records from Atlantic City show that August was typically the warmest month and September was warmer than August only seven times during 1947-1976. The instances of higher September temperatures were in 1948, 1957, 1959, 1965, 1966, 1968 and 1971. Of these years the highest rate of warming between August and September was in 1968 with 1971 second, the years of fall fish kills. None of the cases of early spring and late fall occurred in the same year.

Included in the historical observations from NODC used in formulating the model of bottom water oxygen concentration were some values in February and June of 1968, and March of 1971. At these times, bottom water oxygens were above or equal to the average trend values, implying that the low oxygen reported with the fish kills did not result from early onset of stratification.

Over the past 30 years, conditions that could have let to lengthening the period of stagnation of bottom waters occurred 12 times, or 40% of the time. Fish kills have been reported in the four most recent cases. Five of the 12 occurrences resulted from the early arrival of spring, and seven from the late arrival of fall.

Conclusions

Stratification that develops in the shelf waters off New Jersey in spring and persists through summer, along with limited exchange with offshore waters, tends to develop a stagnant water mass along the bottom. During this period of stagnation, bottom oxygen concentrations typically decline until fall, when cooling at the surface leads to overturning and replenishment of dissolved oxygen. Conditions that would lengthen the season of stratification and thereby, stagnation, are considered to be the principal elements that would set the stage for generation of anoxic conditions.

The period of stratification can be prolonged by either the early arrival of spring (early warming and early occurrence of increased spring river discharge) or the late arrival of fall (late initiation of cooling). Over the last 30 years (1947-1976), by these definitions, spring began early five times (with fish kills reported in the two most recent cases--1976 and 1974) and fall arrived late seven times (with fish kills again reported in the two most recent times--1971 and 1968), for a total of 12 potential instances. Both an early spring and a late fall never occurred in the same year. For the 30-year period of record, highest discharge and warming rates for an early spring occurred in 1976, implying that this year was the most extreme case of prolonged stratification.

Bathymetric differences on the continental shelf seem to cause the effects of stagnation to be more intense off New Jersey than in adjacent shelf waters off Long Island and Delmarva Peninsula.

The role that plankton blooms play in the generation of anoxic conditions is not clear, but they may be a necessary ingredient.

Although the occurrence of very low oxygen concentrations is bound to have a catastrophic effect on benthic organisms and bottom fish, perhaps the most severe impact may be on recruitment of fish stocks, resulting from the cumulative effect of frequent recurrence of low oxygen conditions. Considering the 12 instances of the last 30 years when climatic conditions may have led to very low oxygen concentrations, such conditions occurred every 2-3 years from 1948 through 1959 and similarly for 1965-1976 (12 years with six potential occurrences each period). During these two 12-year periods, prospects for recruitment might have been severely limited. During the intervening five years (1960-1964), when there were no indications of either an early spring or late fall in any of the years, recruitment might have been considerably higher.

Recommendations

Although the proposed model of oxygen depletion follows the principals of physical oceanography, it is still basically an empirically derived, stochastic model. Shortcomings that have been noted during the course of the investigation include:

1) Currents and circulation are, by inference, considered to be meager and of no consequence. Based on recoveries of bottom drifters, Bumpus (1973) concluded that bottom currents in the Mid-Atlantic Bight are about 0.5 NM per day which is only about 5% of his estimates of surface flow. He also noted a lack of any

significant annual cycle to the bottom flow. If these estimates are correct, then the currents are probably inconsequential. The current meter records of AOML from the MESA New York Bight Project should clarify this point.

2) The significance of plankton blooms on oxygen concentrations needs to be ascertained.

3) In examining records of monthly mean surface temperatures, differences and contraditions were found, particularly between compilations of ship reports as archived by the National Climatic Center versus those published in the Gulfstream and The Gulf Stream Monthly Summary. These differences should be adjudicated. Within this study water temperatures from shore station records were widely used because of the lengths of record and consistency of methodology. How well these records describe conditions occurring over the continental shelf is uncertain. Perhaps observations from the two Environmental Buoys in the area may now give more relevant data.

4) After re-examining the data from the NODC archives that went into formulating the oxygen model, it was realized that the only values available representing the month of August came from a single cruise conducted in 1949. Since 1949 was identified as one of the years in which stratification may have begun early, inclusion of these observations in deriving the typical trend of oxygen is suspect. EDS should be tasked to try and locate and archive other oxygen data that may add to the historical file.

5) A monitoring program of temperature-salinity observations and oxygen determinations should be initiated with re-occupation of standard stations on about a monthly schedule to determine the validity of the proposed model. Likewise, assurances should be solicited that ongoing monitoring of river discharge and shore station temperatures will continue.

6) The proposed model affords an opportunity for early prediction of fish kills, or at least in the event of an early spring condition. To test and validate the model, and in the event of a possible recurrence in 1977, a monitoring effort should be begun by January, 1977. Such an effort should include:

a) Making arrangements for early delivery from the reporting agencies of river discharge and sea surface temperatures from shore stations, ship intake reports and buoy recordings;

b) operating surveys on about a fortnightly schedule during Jan-Mar, and monthly thereafter (Observations should be made on the New Jersey and Long Island shelf regions and include temperature, salinity, dissolved oxygen, turbidity and transparency, and plankton abundance);

c) providing analysts to insure that the survey and climatological data are worked-up and examined on a timely basis.

Although the prospects of predicting a late arrival of fall are unlikely, survey operations should continue through summer and fall, with cruises about every two weeks during Aug-Oct. Whether or not a late fall condition develops in 1977, a valuable record would be acquired of the chain-of-events occurring during the period of breaking-up of stratification.

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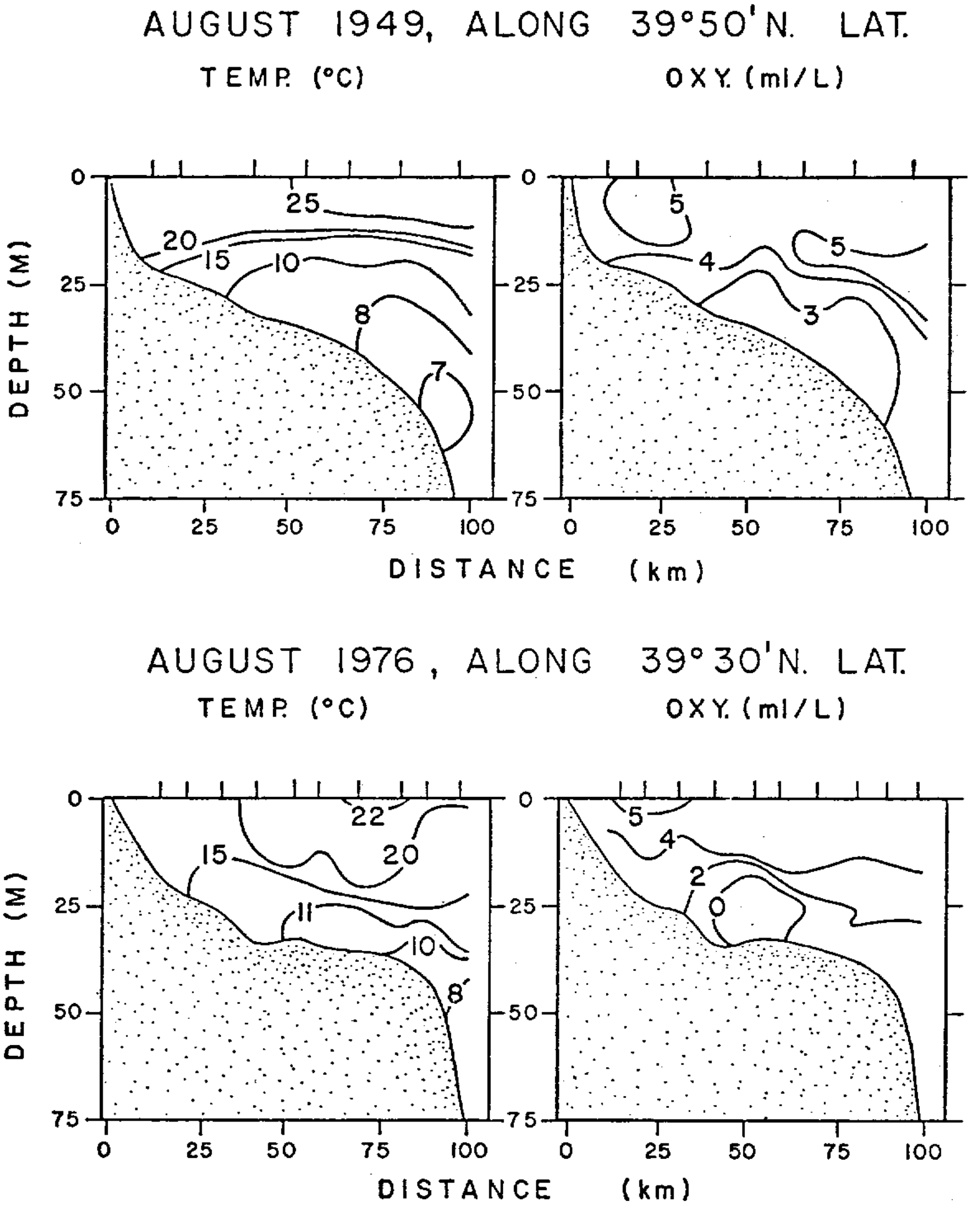

Figure 1. Temperature and dissolved oxygen structure off central New Jersey (Aug. 1949 data from NODC archives; Aug. 1976 data from Sandy Hook Laboratory, NMFS).

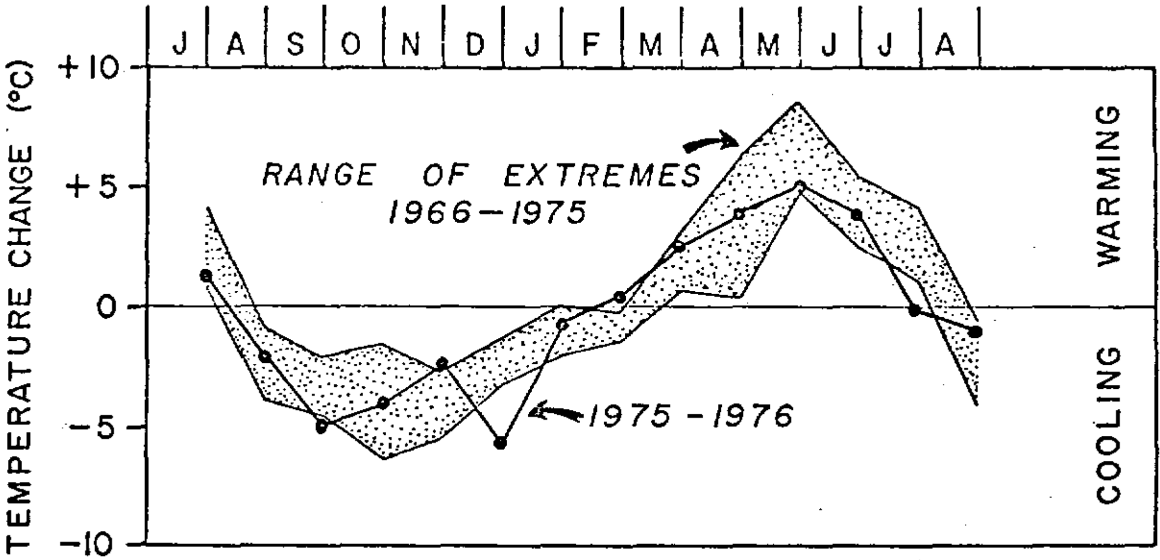

Figure 2. Comparison of monthly sea surface temperature change for 1976 with range of historic values at 39°-40°N, 73°-74°W (Values from Gulfstream Nat. Weather Ser., NOAA, Jan. 1975-Aug. 1976; and The Gulf Stream Monthly Summary, U. S. Nav. Ocn.Off., Jan. 1966-Dec. 1974).

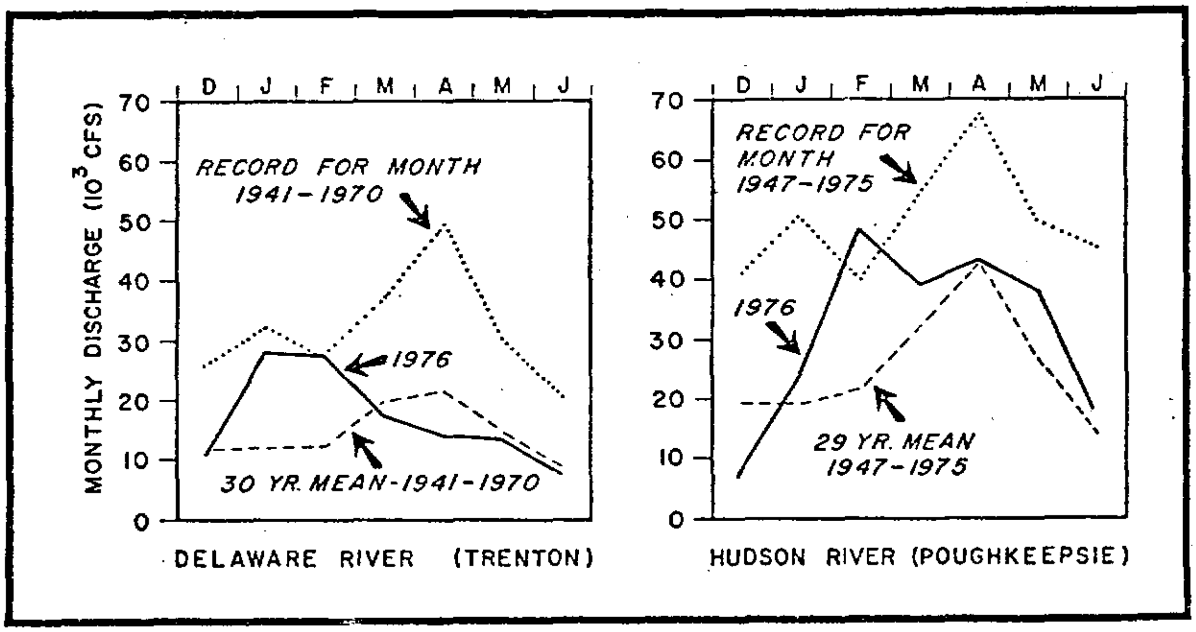

Figure 3. Comparison of monthly river discharge rates for 1976 with long-term means and extremes (from USGS provisional records).

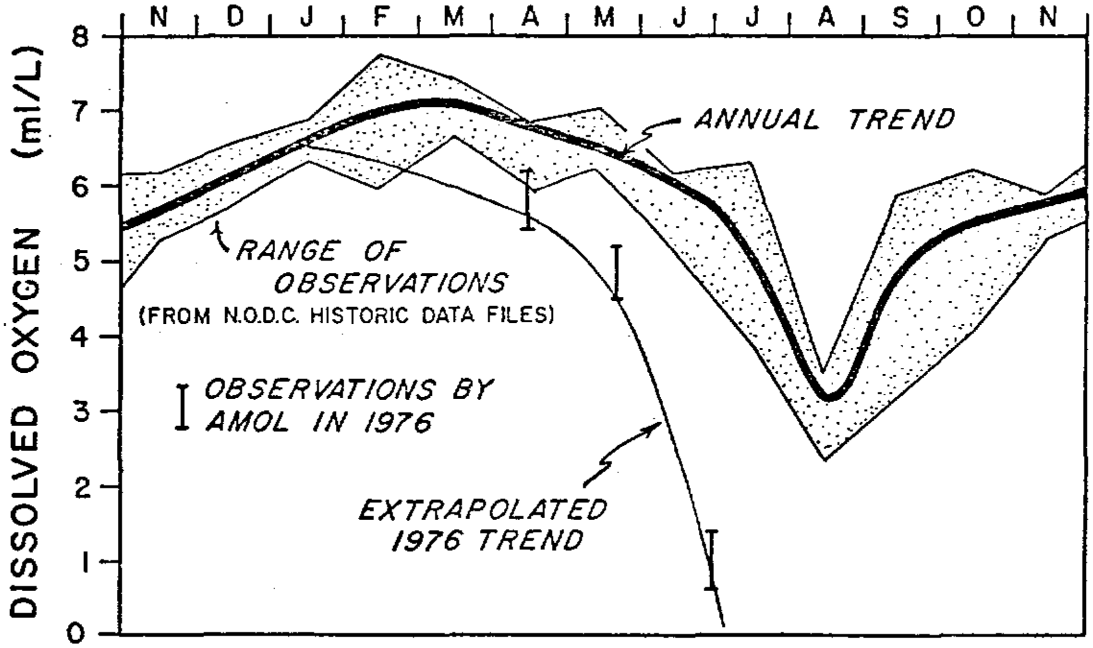

Figure 4. Sub-surface (> 20 m) dissolved oxygen as predicted and measured in 1976 in comparison with historic record at 39°-40°N, 73°-74°W.

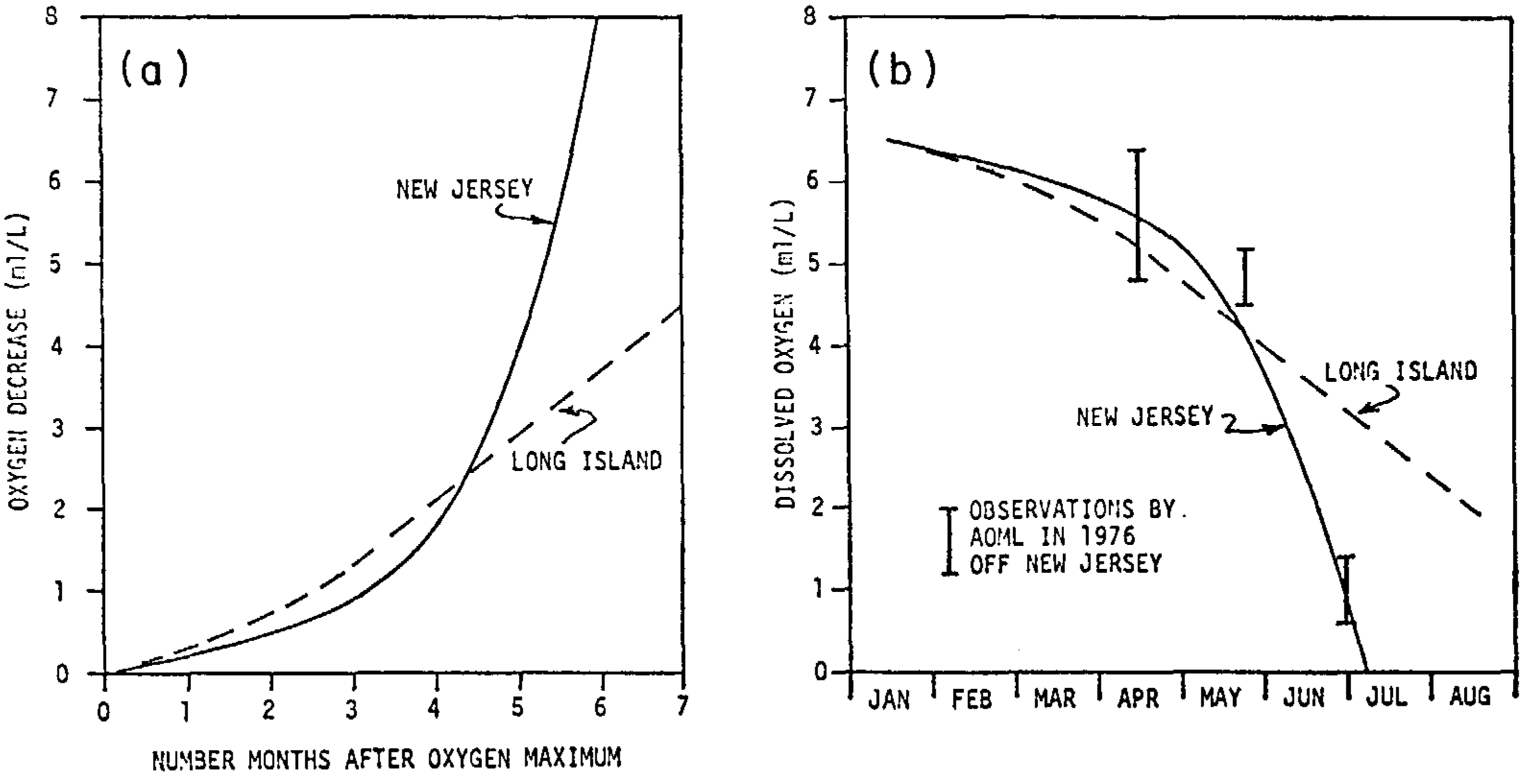

Figure 5. Comparison of trends of bottom oxygen off New Jersey and off Long Island.

a) Historical trends based on NODC archived data and extended for prolonged period of stratification.

b) Predicted trends for 1976 with observed conditions off New Jersey.

APPENDIX II

AOML COMMENTS ON MEAN RESIDENCE TIME OF BOTTOM WATER IN THE MIDDLE ATLANTIC BIGHT

During the IDOE-sponsored workshop entitled "Anoxia on the Middle-Shelf During the Summer of 1976" (1) it seemed to be a generally accepted consensus that the mean residence time of bottom water on the Middle-Atlantic Shelf was greater than two years. The reference generally cited for this residence time was W. R. Wright's 1976 paper on the limits of shelf water south of Cape Cod (2). Wrights paper describes a water budget over the shelf using characteristic salinity values for shelf and outer shelf water to calculate the amount of slope water necessary for dilution of river inputs to the shelf salinities. Using these numbers and the volume of shelf water, Wright extimates a mean residence time of shelf water of three to four years. He concludes that the exchange process can be effected by bubbles of slope water about 50 meters thick and 400 km^2 in area moving across the shelf in the area south of Vineyard and Nantucket Sounds about once every fortnight to maintain the balance. Wright then considers Stommel's Gulf Stream data and postulates that:

(1) 2400 km^3 of slope water is going onto the shelf, and (2) that 300 km^3 of this water exits past Cape Hatteras, leaving a balance of 2, 000 km^3 of water that must exit across the shelf. This is basically a budget calculation whose result is sensitive to the assumption of a base salinity for slope water, and that all reduction of salinity over the shelf is attributable to local river discharges.

Perhaps a more pertinent paper is one by Beardsley, Boicourt and Hansen (3) which was presented at the 1975 ASLO Symposium on the New York Bight. This paper indicates that the long-shore advection which trends southwest through the Bight probably eclipses the cross-shelf transport considered by Wright. Using data sets available from current meter moorings throughout the Bight, the authors calculate a volume transport through the area of between 5,300 and 8,800 km^3/year at velocities between 2.7 to 7.2 cm/sec (4 cm/sec in the New York Bight). Using a shelf volume of 6,000 km^3 and a transfer of 3,000 km^3 yields a residence time of about three-quarters of a year for the entire Bight (from Nantucket to Cape Hatteras). A mean residence time for the area where anoxia was prevalent in summer 1976 can be arrived at by considering the velocities. Since the mean velocities between Montauk Point, L. I., and Cape May, N. J., were about 4 cm/sec and the distance between these points is about 400 km, a mean residence time for water in these areas is in the order of 100 days.

Progressive vector diagrams for current meter moorings in the northern Bight for 1975 confirm that the mean velocities during that year were approximately 4 to 5 cm/sec and trending southwest. AOML is presently considering current meter data collected during 1976 to see if this condition changed during that time due to the peculiar meteorological conditions prevalent this year.

(1) Anoxia on the Middle atlantic Shelf During the Summer of 1976, a workshop held 15 and 16 October 1976 in Washington, D. C., sponsored by NSF/IDOE. Report on Workshop prepared by Jonathan M. Sharp dated November 1976.

(2) The limits of shelf water south of Cape Cod, 1941 to 1972, W. R. Wright, Journal of Marine Research, 34 (1): 1 to 14 (February 1976).

(3) Physical Oceanography of the Middle-Atlantic Bight, R. C. Beardsley, W. C. Boicourt and D. V. Hansen, 1976. In: M.G. Gross, ed., the Middle Atlantic Shelf Bight, 1976. Journal of Limnology and Oceanography, Spe. Symposium Vol. 2:20-34.

APPENDIX III

THE PERSISTENCE AND BOUNDARIES OF THE BOTTOM WATER OXYGEN DEPLETION PROBLEM OF 1976 IN THE NEW YORK BIGHT.

Frank Steimle
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Sandy Hook Laboratory
Highlands, NJ 07732

Introduction

At all depths of the ocean, oxygen is consumed by respiration of organisms, including bacteria. The consumption is limited by the amount of organic matter which is available (except for a small amount of chemical oxidation), the rate being mostly controlled by temperature. In the open ocean this is so balanced by ventilating processes that the oxygen supply is never completely exhausted. However, in certain areas, usually semi-enclosed basins, e.g. the Black Sea and some Norwegian fjords, stagnation and anoxia occur seasonally and in some cases permanently. In shallow open seas with their much greater surface there is not usually such an opportunity for anoxia to develop, here the stagnation is often disturbed by winds. Therefore, there is usually no oxygen deficiency, but this nevertheless does occur particularly in hypertrophic areas such as an open coastal area of the New York Bight during the summer-fall of 1976.

The New York Bight is basically an exposed area in which an upwelling situation has not been identified, but might occur intermittently. Abundant nutrients, organic detritus and phytoplankton are generally available, however, from a variety of human-activity related sources, particularly highly enriched effluents from the Hudson-Raritan Estuary. Mass mortalities of marine organisms in the New York Bight, such as occurred during 1976, have been observed on at least three previous occasions (Ogren and Chess, 1968; Young, 1973 and 1974). All three of these occurrences were reported from the same area, off Manasquan Inlet, N. J., during late summer or fall. On two of three occasions diver/biologists from the National Marine Fisheries Service, Sandy Hook Laboratory, found depressed (less than 2 ppm) dissolved oxygen (D.O.) levels while investigating the reports. These three early occurrences were relatively short lived, being observed for less than a month, and were limited in distribution.

When reports were received last year (1976) from sport divers and commercial fishermen of a massive mortality of fish and invertebrates in the same areas as the previous reports, during the first week of July, the National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory investigated the reports and again found depressed oxygen levels in the areas of the reported mortalities. We then implemented a series of survey cruises to study the situation. Initially the surveys were designed to confirm the probable cause of the mortalities as insufficient D.O., then to define the extent of the D.O. depleted bottom waters, assess the impact on marine resources, investigate contributing factors and monitor the phenomenon. It soon became apparent that the mass mortalities-oxygen depletion situation was more extensive and severe than the previously documented reports.

This report presents data on the temporal and spatial distribution of bottom water D.O. levels in the N.Y. Bight, collected from a total of 63 survey cruises, in cooperation with the N.J. Dept. of Environmental Conservation, (Division of Fish, Game and Shellfish, Nacote Creek Station, Absecon, N.J.) and the Atlantic Oceanographic and Atmospheric Laboratories, Miami, Fla. These surveys were conducted during the duration of the problem, early July through November, 1976.

Methods

All bottom D.O. determinations were made from water samples collected with a sampling bottle positioned 0.5 to 1.0 meters off the sea bottom. The azide modification of the Winkler technique of D.O. determination was used throughout. The results of all surveys were compiled and segregated into weekly groups and the determinations plotted to provide a chronological sequence, based on available data, of bottom D.O. levels in the N.Y. Bight. There were no surveys during the period October 16 through November 8. The "dots" on the figures represent the location (or approximate location, within three miles) of a sampling site or data-point on which the contours were drawn.

Results

The chronological sequences of bottom D.O. distributions are presented as figures 1-15. They suggest that an oxygen depleted area was apparently well established by the time the divers and fishermen reported the mortalities and the survey cruise initiated (fig. 1). D.O. levels below the normal minimum detection limits of the Winkler method were found in an area centered approximately 25-30 km east of Barnegat Inlet during the second week of July. This anoxic area persisted off Long Beach Island (bracketed by Barnegat and Little Egg Inlets) through early October (figs. 1-12). A hazardous level of oxygen depletion (bottom waters having less than 2 ppm D.O.) covered a much larger area, which at its greatest distribution extended from just off the west-central Long Island shore to a point approximately 90 km east of the Delaware-Maryland borders and from 2-100 km off the N.J. Coast (figs. 10-11).

The passage of Hurricane Belle, Aug. 10, was insufficient to cause any significant change in the condition, with bottom D.O., immediately after the storm, having only minor offshore shift of the anoxic water mass which resumed its pre-storm distribution within a few days (Figs. 5, 6). Severe oxygen depletion (less than 1 ppm) was evident at the N. Y. Metropolitan area dump sites, approximately 20 km east-southeast off Sandy Hook, only once (Fig. 3) or possibly twice (Fig. 11), based on almost weekly sampling in this area. The thermocline apparently began to decay by the end of September, as evidenced by an increase of D. O. to near tolerable levels in most inshore areas (Figs. 12-14) and near normal bottom D. O. levels returning by mid-November (Fig. 15).

During the surveys of bottom water D. O. levels and distribution, high concentrations of hydrogen sulfide (H_2S) were detected in the anoxic area off Long Beach Island. The H_2S was noted throughout the water column beneath the thermocline, situated at approximately 20 meters deep during most of the summer. Further details of the concentrations and distributions of H_2S associated with the anoxia are included elsewhere in this workshop report (Draxler and Byrne).

Discussion and Conclusions

The probable causes of the oxygen depletion phenomenon in the bottom waters of the New York Bight are discussed in detail elsewhere (Malone; Armstrong and Chanesman) in this volume. Briefly, the environmental and biological phenomenon which appear to be correlated with the development of the anoxia are: an early warm spring which extended the duration of the normal summer water column stratification and bottom water stagnation; a period of unusual wind direction, low storm activity, combined with early high river runoff, helped strengthen this stratification; and unusual organic input from an extensive bloom of the dinoflagellate, Ceratium tripos throughout the outer and middle New York Bight Continental Shelf waters during the spring.

Although the anoxic condition was not persistent at the dump site areas, studies by Thomas et al., (1976) have found D. O. levels of less than 1 ppm north of the dumping areas during the summer of 1974, but not during 1975.

The impact of the bottom water oxygen depletion and concurrent H_2S buildup on the marine resources of the area affected are also discussed in detail elsewhere (Hamer, Steimle) in this volume. A brief summary of these impacts include the following: except for some mortalities during the first week of July and during short periods when the anoxic water mass was drawn up to the surf zone by strong west winds, most finfish were apparently able to avoid the anoxic area; the major impact has been identified as being to the benthic invertebrates, particularly, bivalves; this includes the virtual elimination of a valuable surf clam stock off central New Jersey, with the additional significant impacts on the ocean quahog, and sea scallop stocks and non-resource species (small crustaceans, polychaete worms, etc.) which are valuable forage for demersal finfish.

Whether the mortalities are the result of the anoxia or the H_2S or a synergism of both, is debatable. Both conditions are known to be lethal to most marine organisms. Theede, et al. (1969) provides a good review of the effects of anoxia-H_2S on marine organisms.

The 1976 bottom oxygen depletion-mass mortality phenomenon was apparently the result of a combination of several unusual environmental factors that accentuated the normal summer stagnation of the bottom waters off New Jersey, which developed into and persisted as, an anoxic-sulfidic water mass for several months until the fall decay of the thermocline and subsequent destratification of the water column. The reasons for its location off Long Beach Island is not understood at this time, but suggest that studies of ocean currents in that area be implemented. Man's contribution to the phenomenon is also presently not clearly defined, but future more intensive monitoring may shed some light on this aspect of the problem. Armstrong (this volume) believes there is good chance of a reoccurrence if environmental conditions similar to last year occur. Continued reoccurrences of anoxia can have a great impact on future fishery and recreational resources in the N. Y. Bight by stressing marine populations which are, for the most part, already under intensive harvesting pressure.

Acknowledgments

The data on which this report is based were collected by many researchers who had a part in investigating the phenomenon, these include, from NMFS: V. Anderson, T. Azarovitz, C. Byrne, A. Draxler, F. Farwell, C. MacKenzie, J. Mahoney, D. Radosh, R. Reid, L. Rogers, J. Ropes, Mal. Silverman, J. Thomas, A. Thoms, T. Wilhelm, J. Ziskowski and from N.J.D.E.P., P. Hamer, P. Himchak and F. Takus. Ms. Leslie Rogers prepared the figures.

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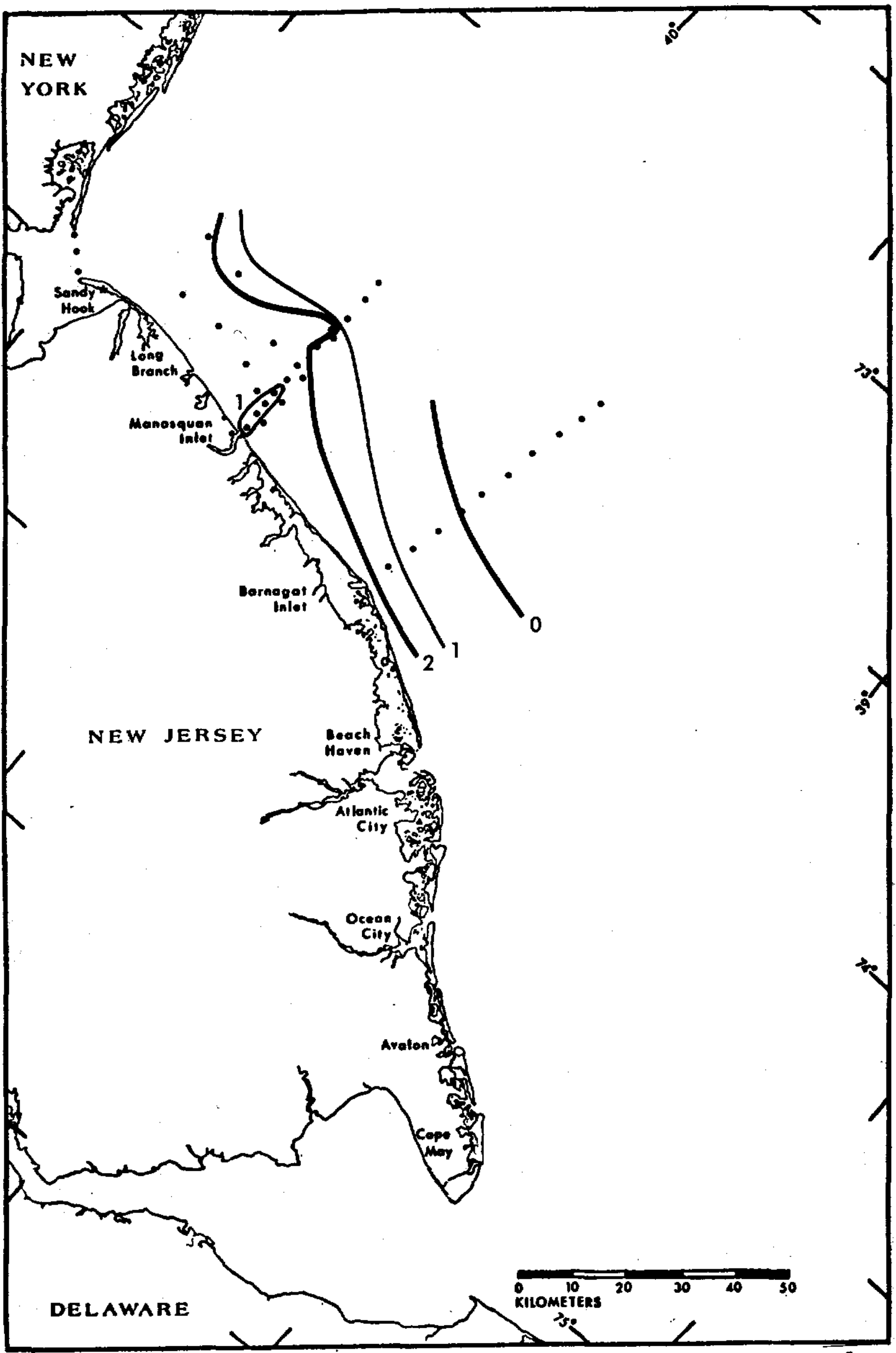
Table of Figures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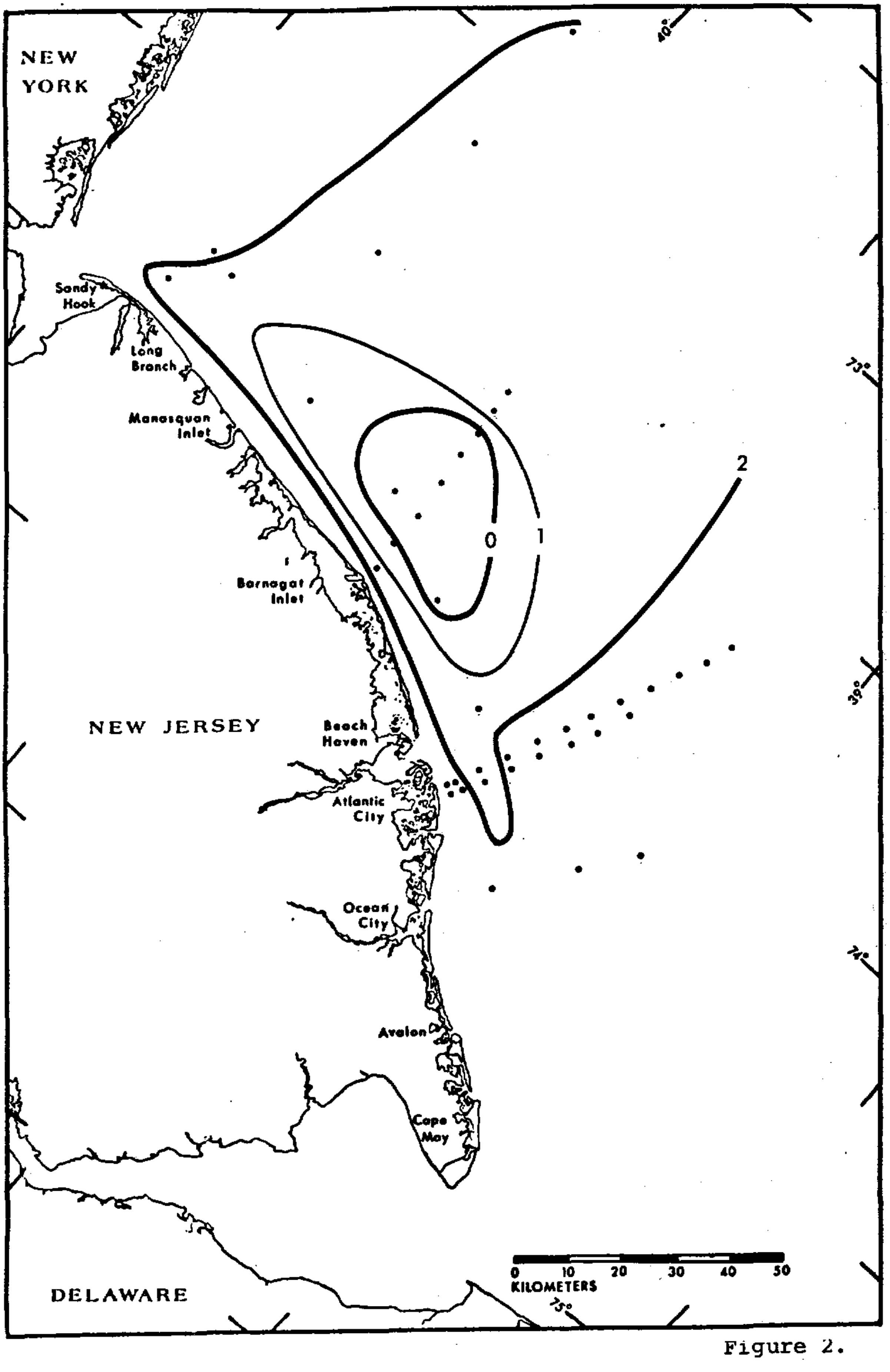
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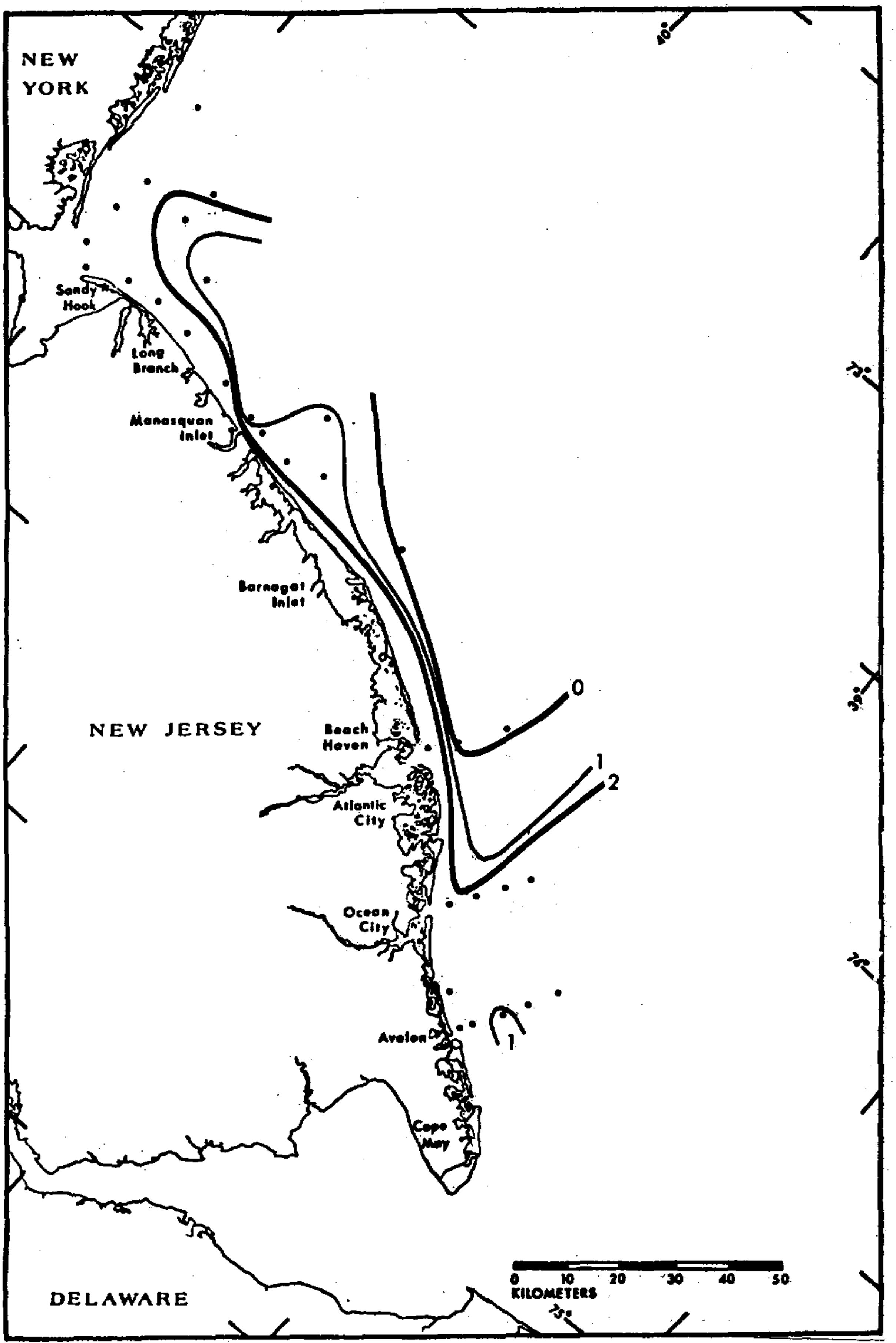
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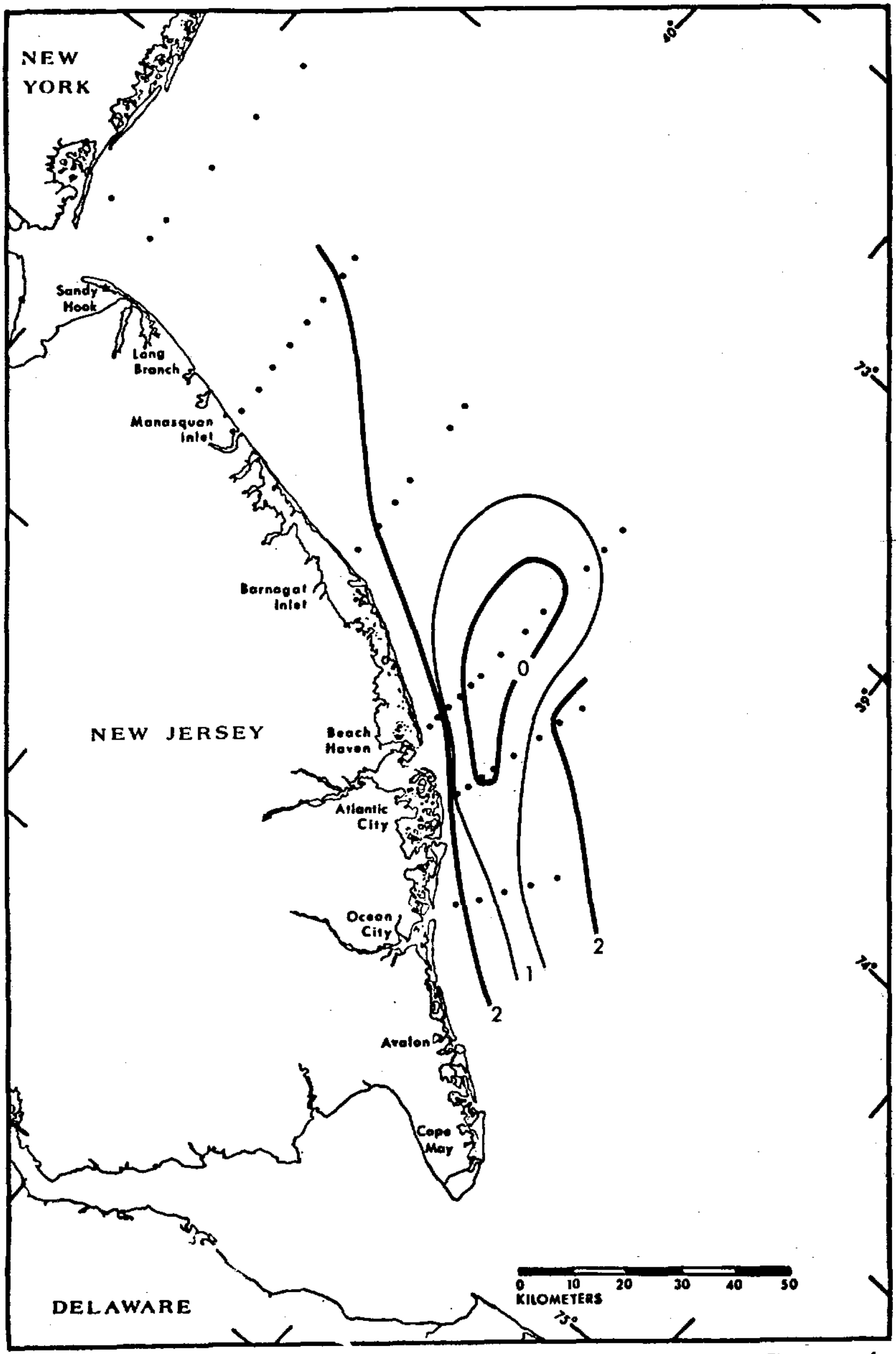
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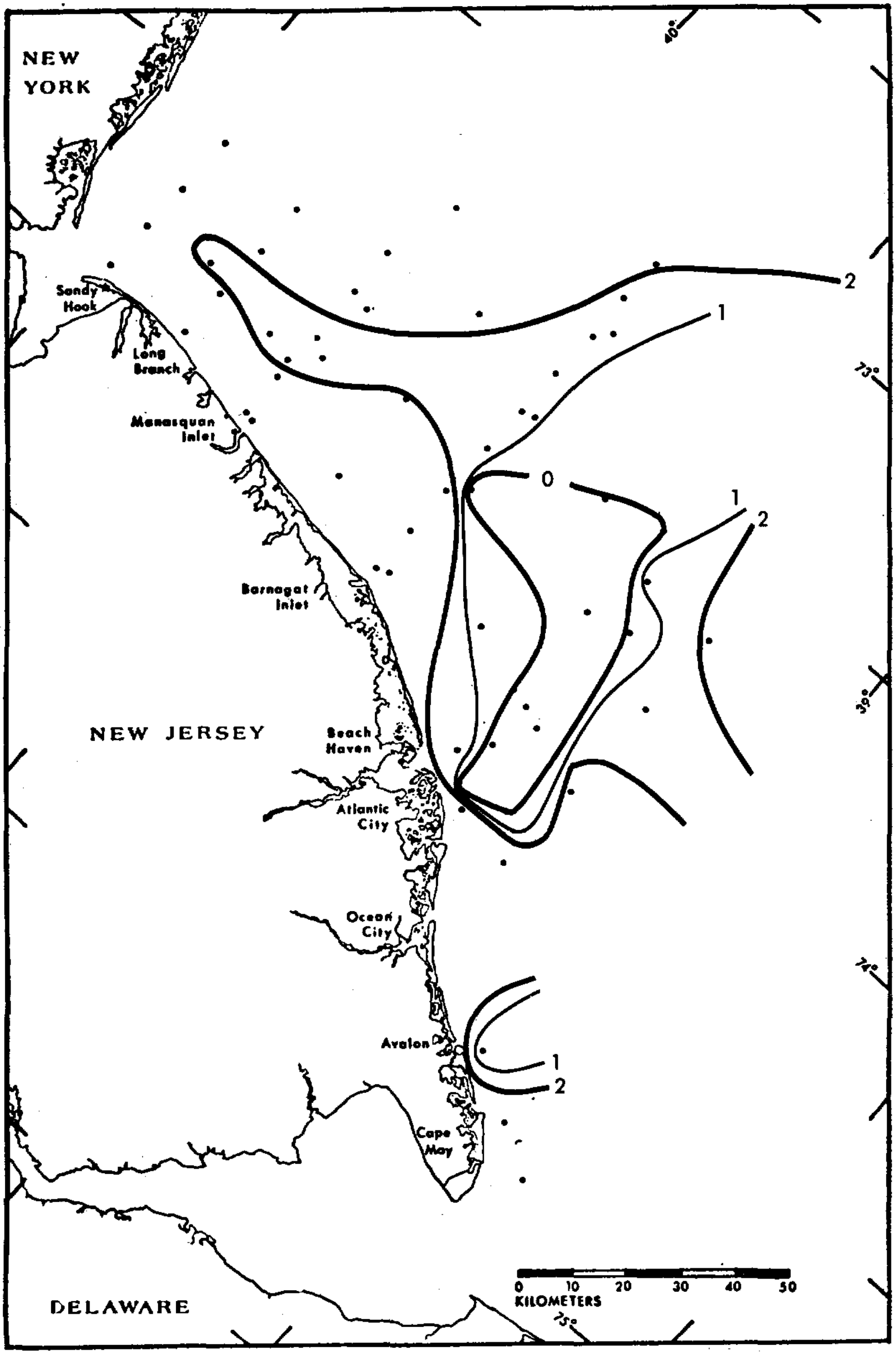
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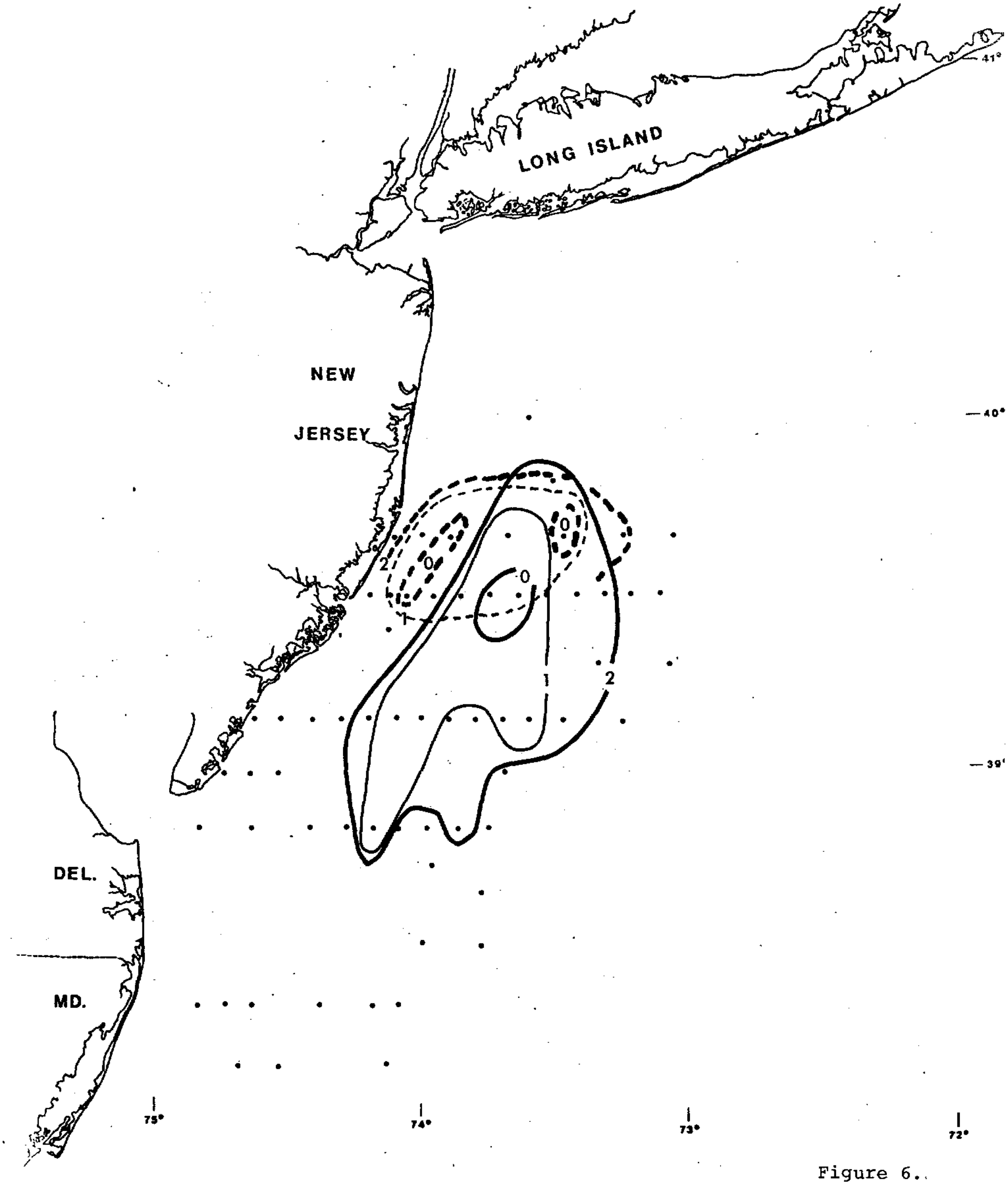

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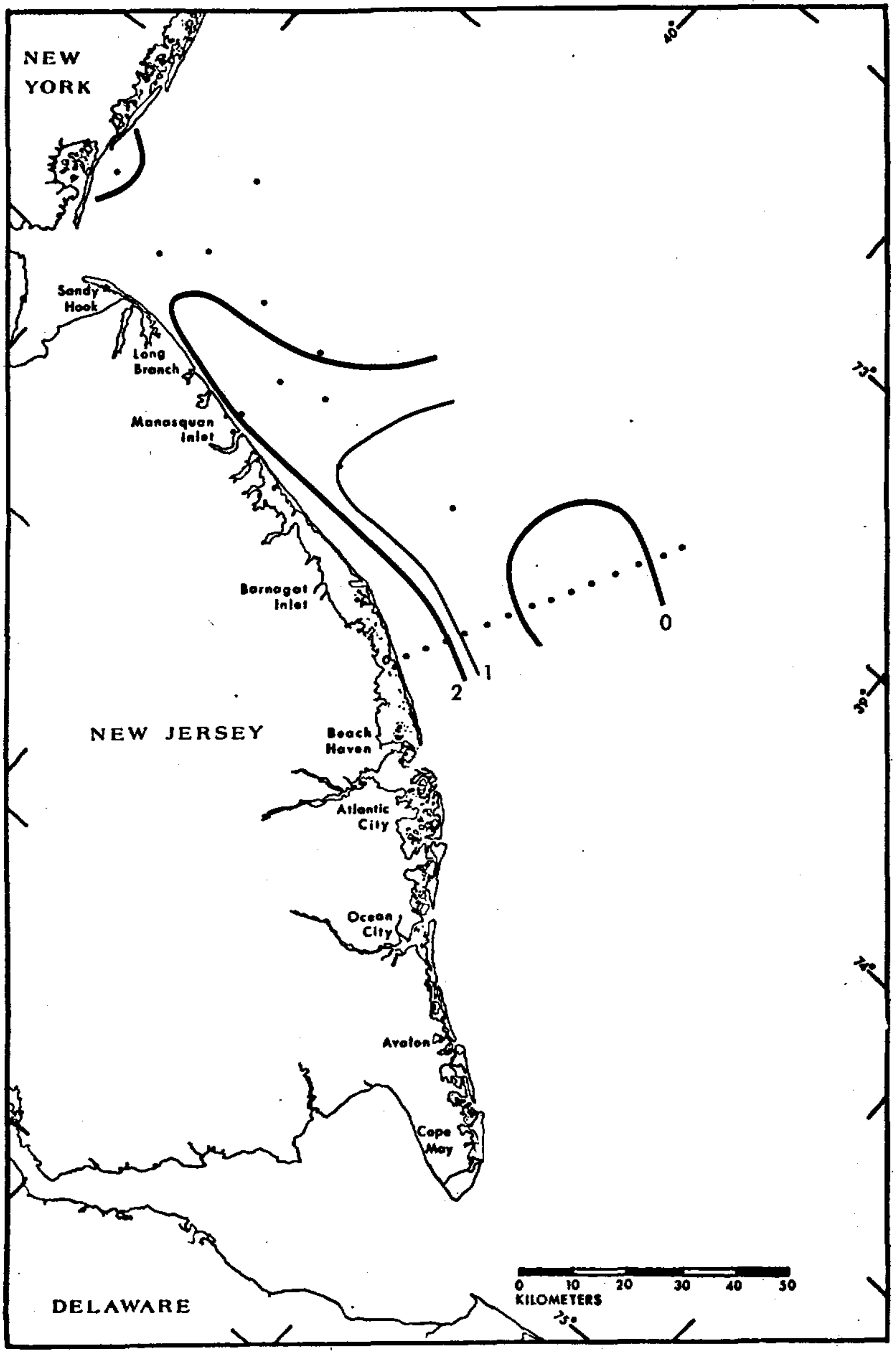
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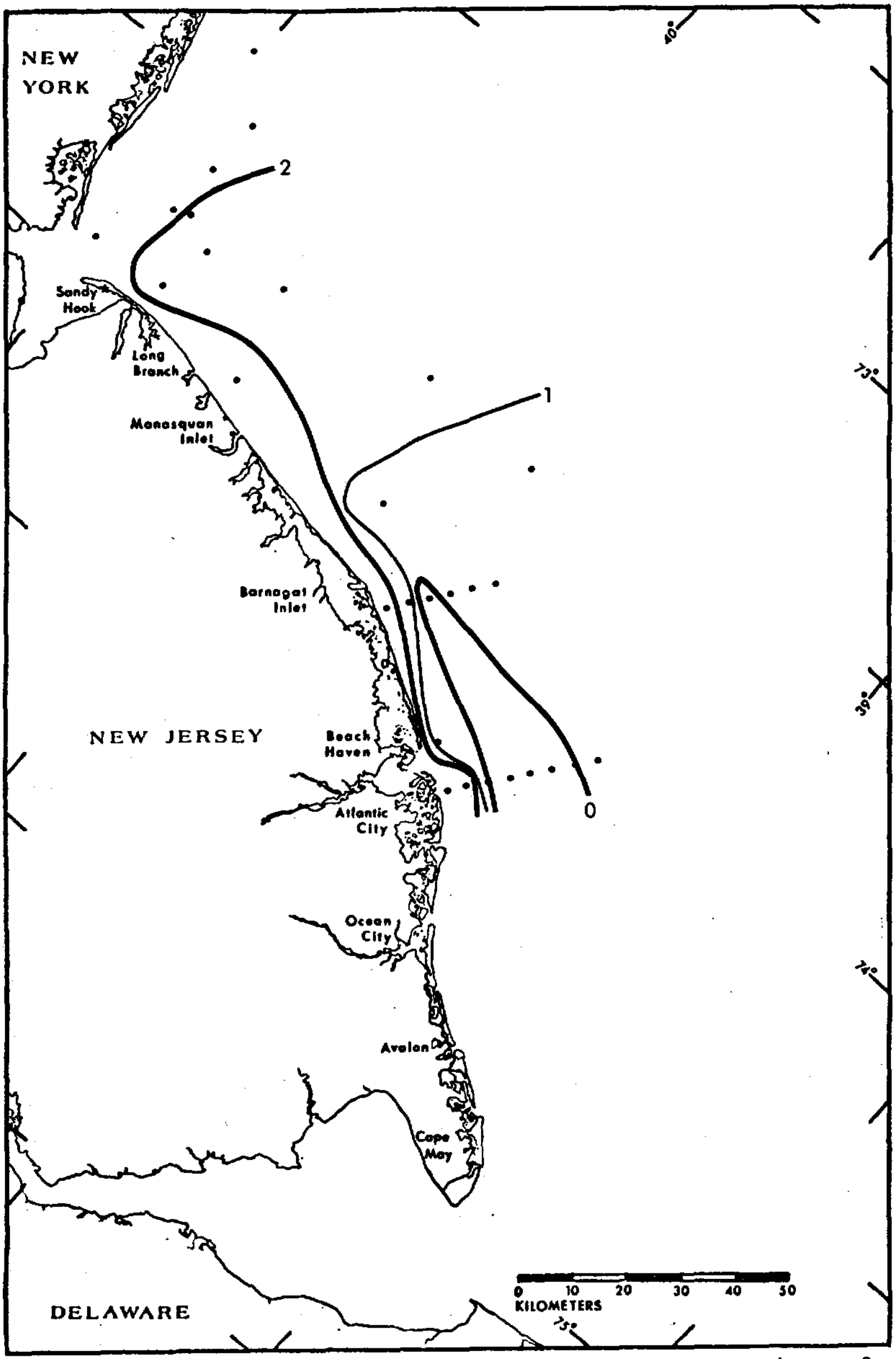
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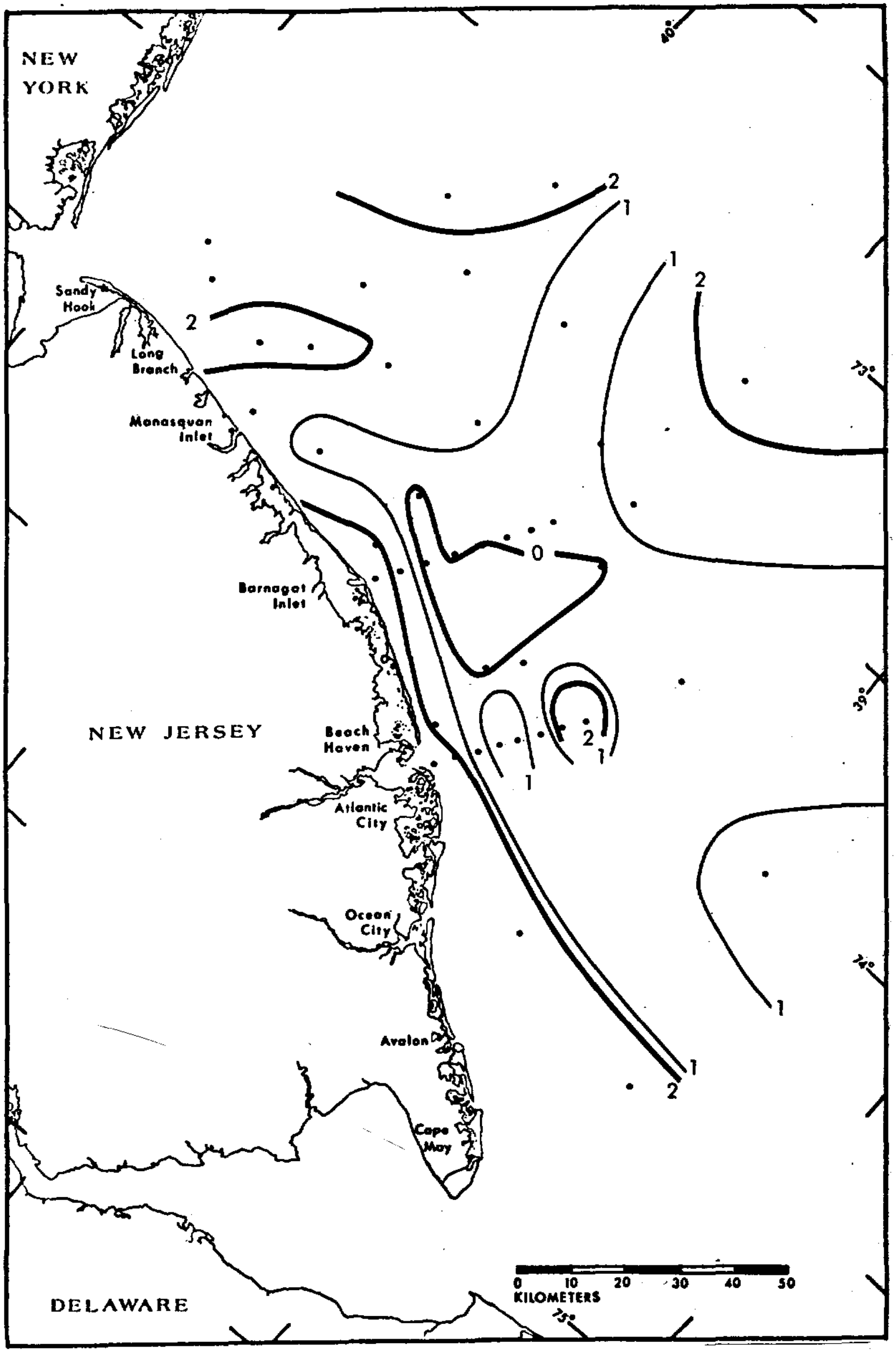
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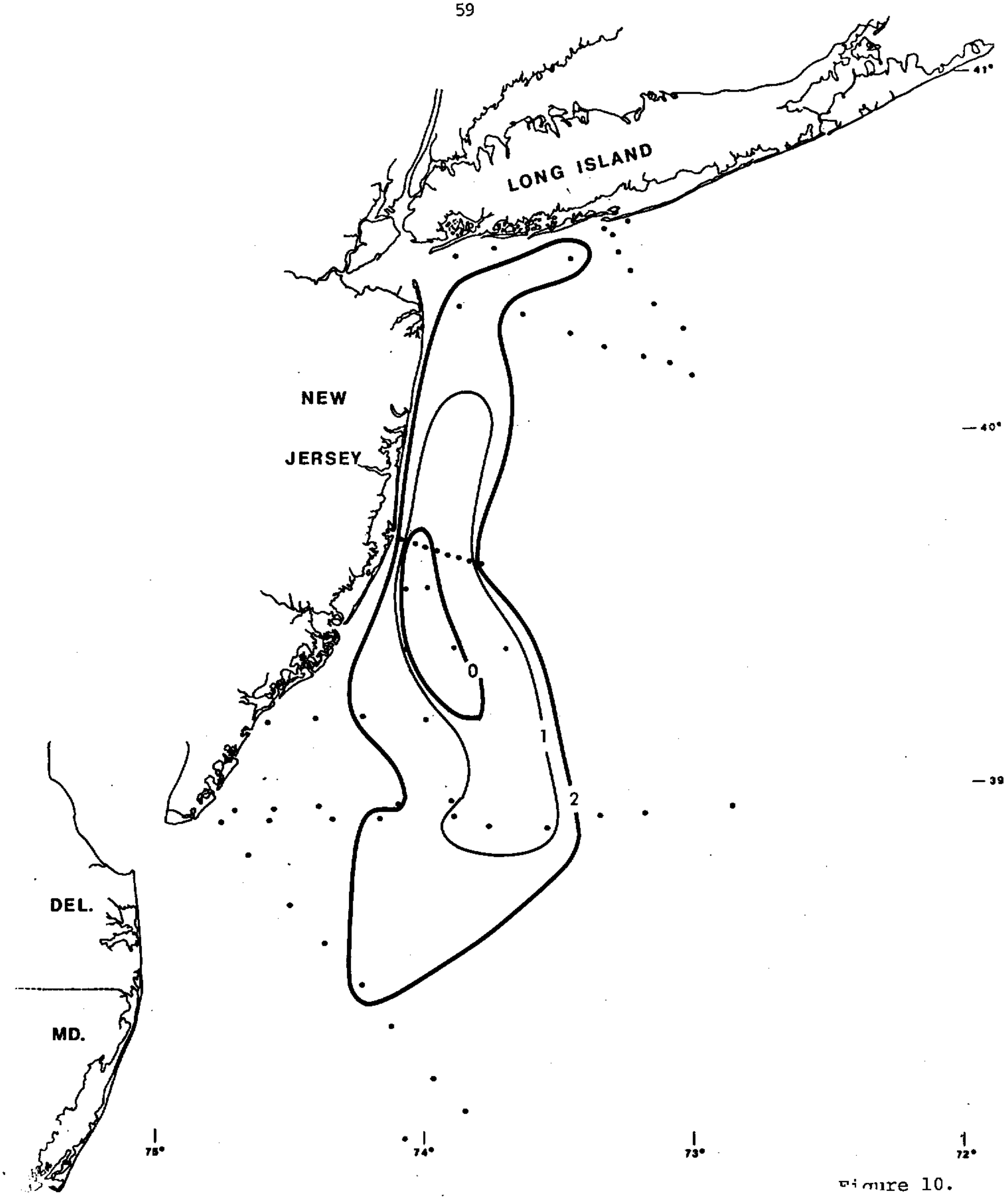

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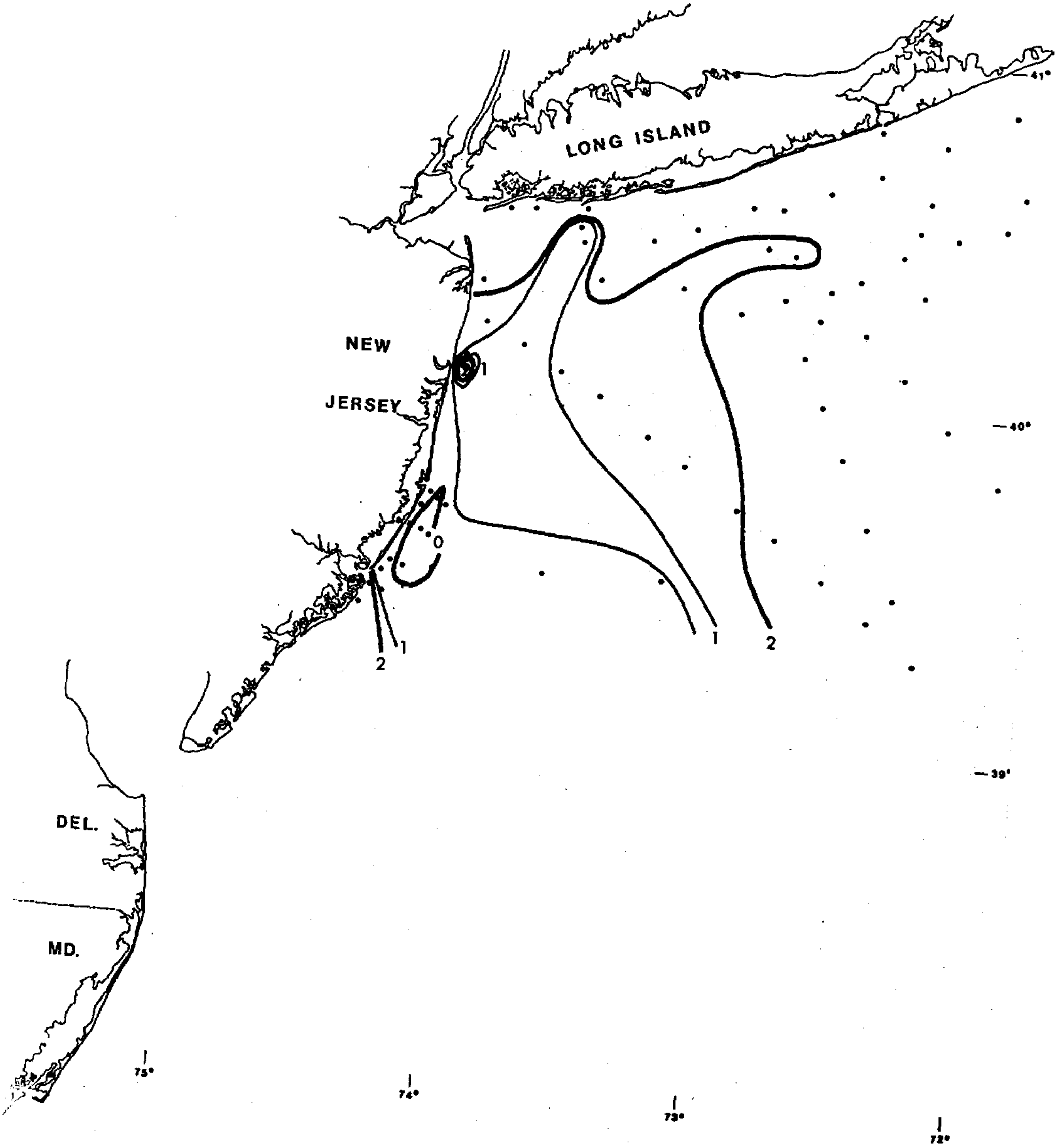

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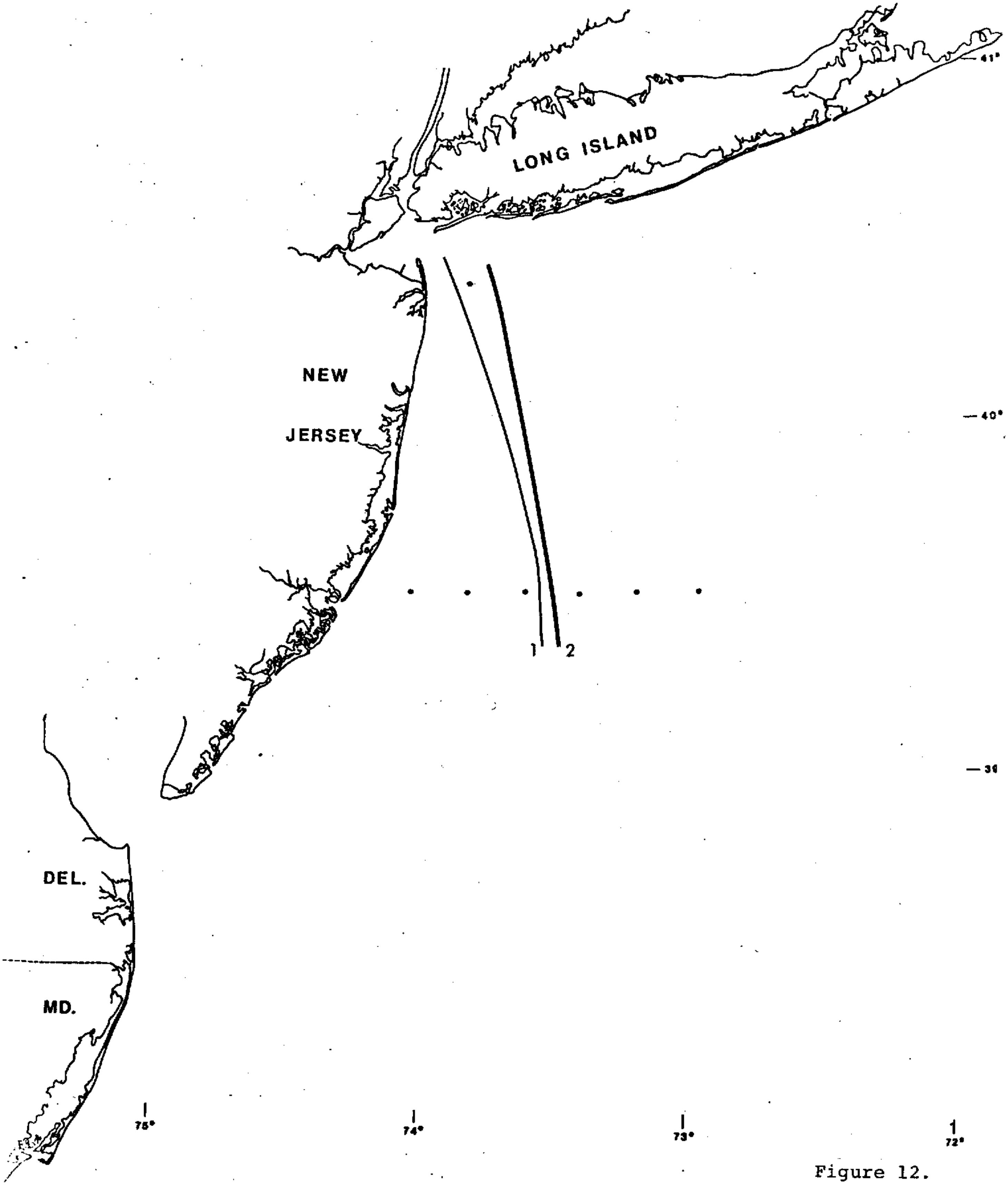

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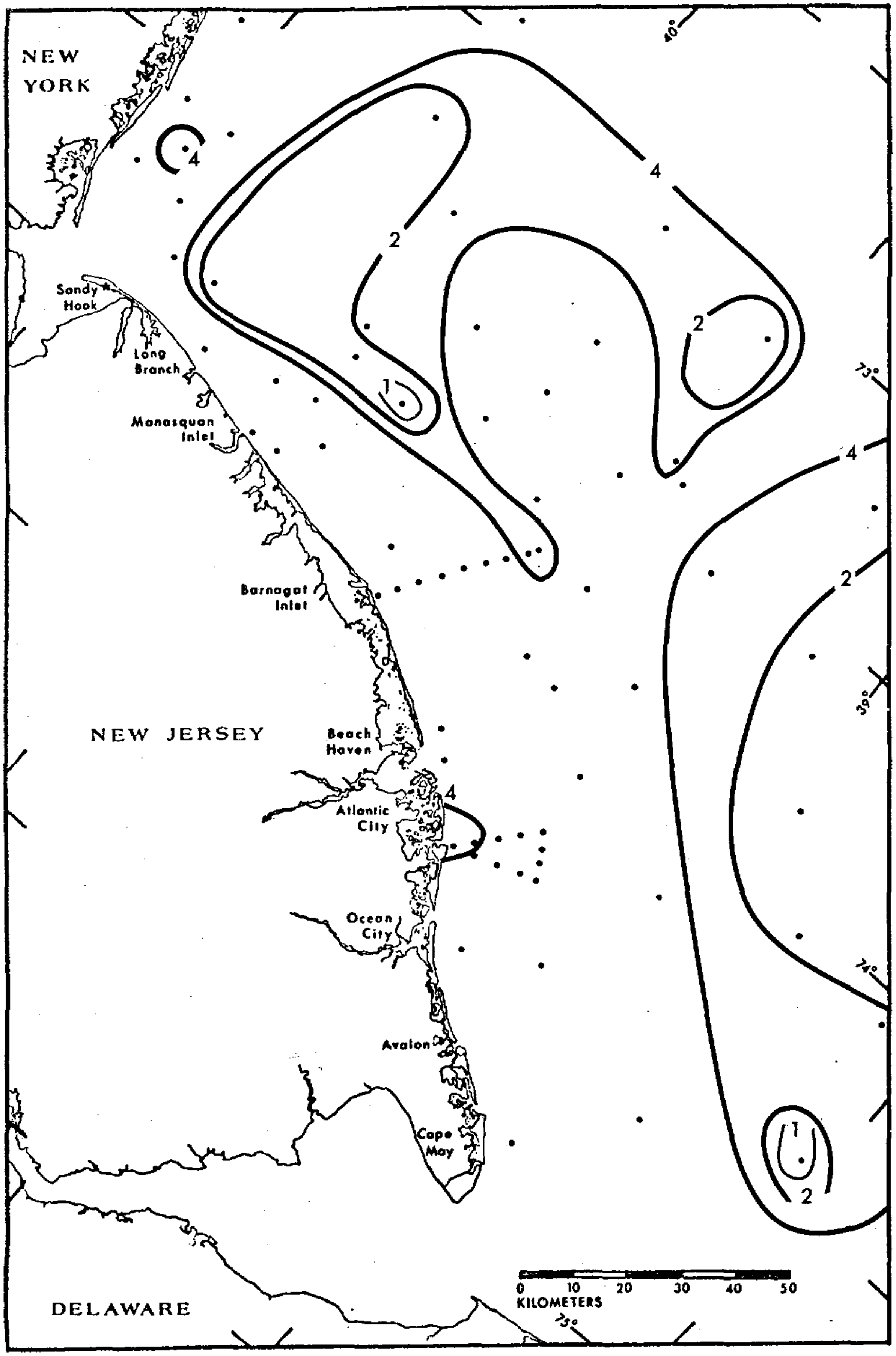
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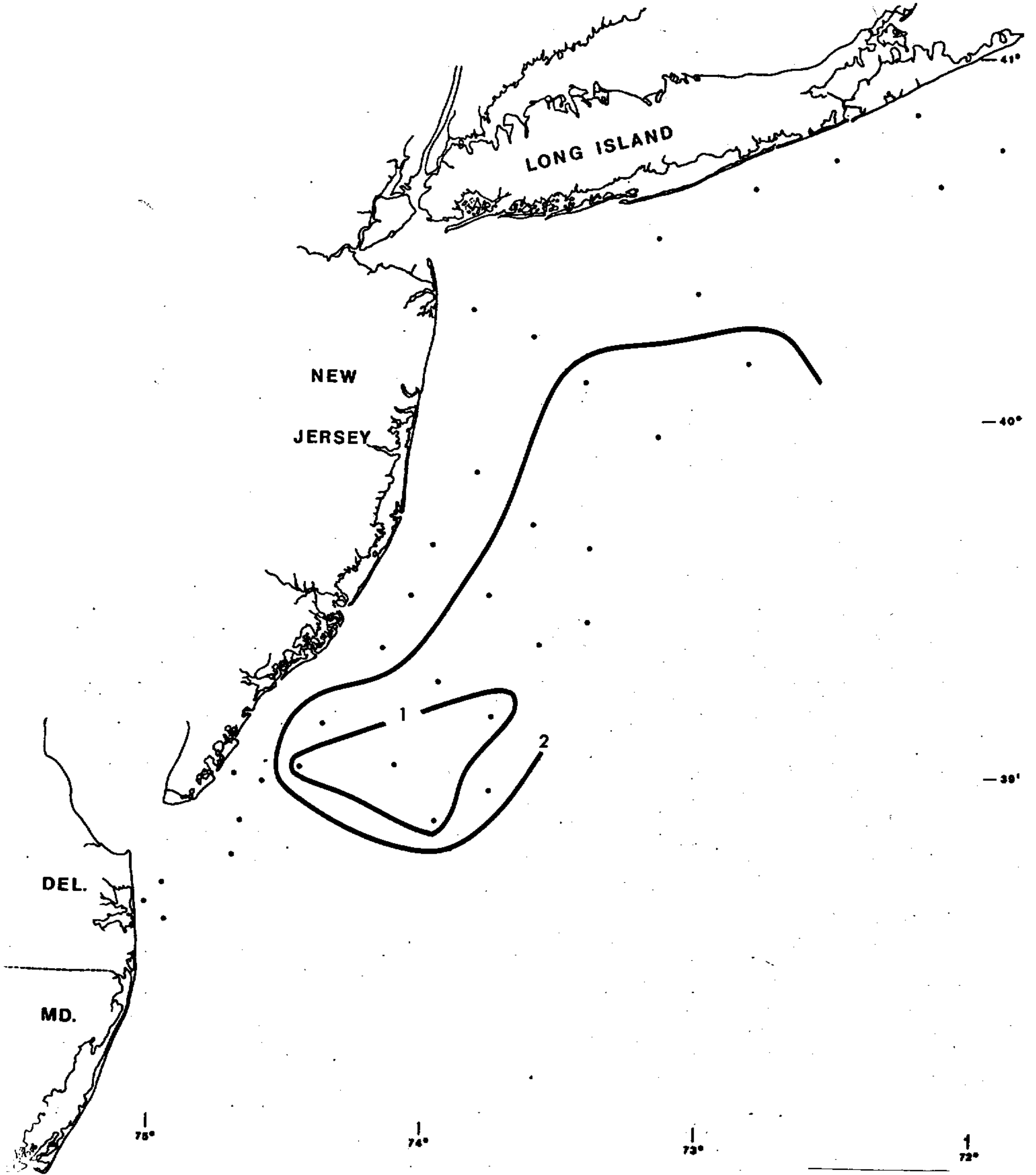

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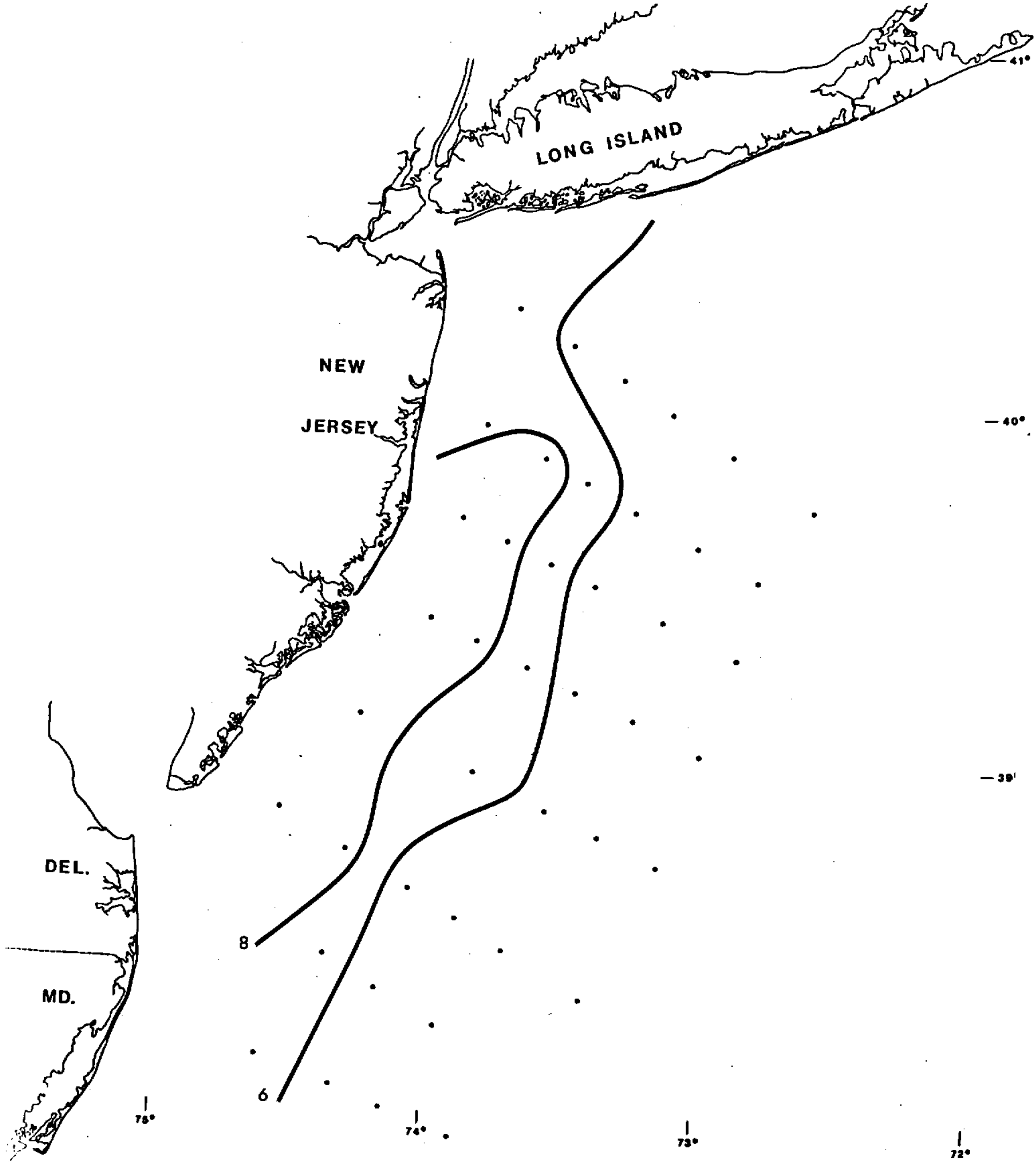


Figure 15.

APPENDIX IV

LISTING OF CHEMICAL DATA PERTINENT TO MIDDLE-ATLANTIC BIGHT ANOXIA PROBLEMS AS IDENTIFIED AT THE CHEMICAL OCEANOGRAPHY WORKSHOP

22 NOVEMBER 1976, SANDY HOOK, NEW JERSEY.

NOAA

AOML/Miami/MESA Data Base

1. Data available and status.

Nutrients (NO_3^-, NO_2^-, $SiO_4^=$, $PO_4^{\equiv}$), dissolved oxygen, trace metals at selected stations (Fe, Mn, Cu, Cd, Zn, Cr), temperature and salinity for cruises listed below. All samples have been analyzed and data reduction is in the status noted for each cruise.

PhOL-AOML

Status of expended Water Column Characterization (XWCC) Cruise Data Sets as of 15 October 1976

XWCC Cruise #	Dates	Ship	Status
1	1/15-19/75	ADVANCE II	MESA Data Report No. 22
2	3/01-06/75	RESEARCHER	Data Report-draft in Boulder & NJ
3	3/31-4/16/75	RESEARCHER	Data Report-draft in Boulder & NJ
4	5/05-9/75	KELEZ	Data Report-draft in Boulder & NJ
5	6/08-15/75	KELEZ	Data Report-draft in Boulder & NJ
6	9/29-10/4/75	KELEZ	Data Report Draft in internal review

cont.

XWCC Cruise #	Dates	Ship	Status
7	12/3-9/75	KELEZ	Data being processed
8	4/12-16/76	KELEZ	Data being processed
9	5/17-24/76	KELEZ	Data being processed
10	6/28-7/1/76	KELEZ	Data being processed
11	9/8-27/76	RESEARCHER	Data being processed

Trace metal data is available only for XWCC cruises 2, 8, 9, 10 and 11.

2. Data quality.

Nutrient data - fair to good, almost all analyses were done on frozen samples and, up to XWCC #11, non-aged polyethylene bottles were used.

Dissolved oxygen data - good to excellent; duplicate samples usually run with excellent agreement. Some isolated standard problems, but questionable data are dropped for section plotting and flagged in data reports.

Trace Metals - data are excellent for XWCC cruises 2 and 11. However, data for cruises 8, 9, and 10 show evidence of severe contamination.

Temperature and Salinity - data are good to excellent.

NMFS/Sandy Hook

1. Data available.

   a. New York Bight Apex

      August 1973 - August 1975. Temperature, salinity, D. O. - bottom water from March 1974 - August 1975. Temperature, Salinity, D. O. - bottom 20-50 c. (See New York Bight Symposium L. & O. Volume).

   b. Lower New York Bay

      November 1973 - March 1975. Primary productivity, nutrients, etc. (see paper Proceedings 4th Hudson River Symposium HRES.)

   c. Seabed O_2 Uptake Data

      March 1974 - August 1975. (see New York Bight Symposium L. & O. Volume.) (See Proceedings 4th Hudson River Symposium.)

   d. Sludge Tracking and Acoustical Exp.

      July 9 - 17, 1976. D. O. Water column O_2 uptake.

Between 24 August and 9 September 1976, members of the NOAA/NMFS Sandy Hook Laboratory accomplished a cruise on the FRS ALBATROSS IV in response to anoxic conditions off the New Jersey coast. The area sampled included the continental shelf off New Jersey and Delaware (see attached map of station locations). Specifically, 37 stations were sampled from New York Harbor to the Delaware-Maryland line, west of the Hudson Shelf Valley, but from the coast out to the 100 m depth contour. Stations were sampled for phytoplankton productivity (net, nano-, and dissolved organic matter released), phytoplankton speciation (numbers, diversity, and morphology), nutrients (phosphate, nitrate nitrite, silicate, and ammonia), plant pigments (chlorophyll a, b, c, phaeophytin, carotenoids, particulate organic carbon and nitrogen), alkalinity, pH, salinity, and temperature (via XBT and reversing thermometers), photosynthetically active radiation, hydrogen sulfide concentration, bacterial counts in water and sediment, and generation of ammonia and carbon dioxide by the sea bed. Samples for benthic macrofauna were also taken at select stations. These data are presently being analyzed and will be part of the computer data bank at Sandy Hook Laboratory at Highlands, New Jersey.

2. Data Quality

No statement.

3. Contact.

Dr. Jim Thomas
NOAA/National Marine Fisheries Service
Sandy Hook Laboratory
Highlands, New Jersey 07732

MESA Biological Program

1. Data Available

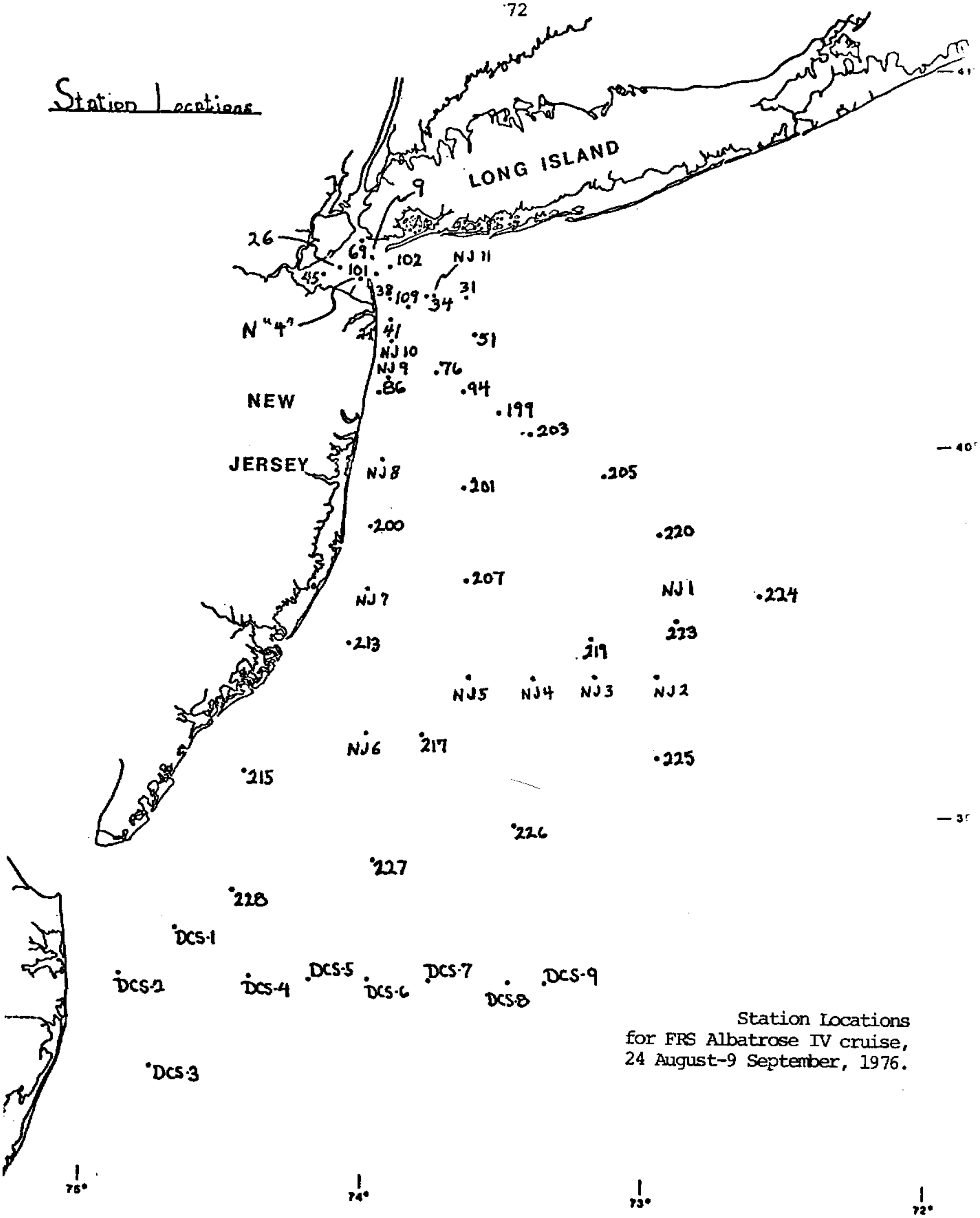
Description of data available through MESA New York Bight Biological Program. Table numbers refer to tables in NOAA/ERL/MESA technical report. Data are also available from NODC as tape or computer printout. Data cover September 1973 to August 1974 and June 1975 to May 1976.

TABLE	VARIABLE	UNITS	DESCRIPTION
I	Z	Meters	Sample depth
	T°C	Centigrade	Temperature
	S°/oo	ppt	Salinity
	DO	ppm	Dissolved oxygen
	NO_3	uM	Nitrate-nitrogen
	NH_3	uM	Ammonia-nitrogen
	PO_4	uM	Phosphate-phosphorus
	SiO_4	uM	Silicate-silicon
	N:P	None	Atomic ratio $(NO_3+NH_3)/PO_4$

TABLE	VARIABLE	UNITS	DESCRIPTION
II	Z	Meters	Sample depth
	TURB.	FTU	Turbidity
	TMS	mg liter^{-1}	Total microseston
	% OMS	Percent	Proportion of TMS which is organic
	POC	mg liter^{-1}	Particulate organic carbon
	CHL	ug liter^{-1}	Chlorophyll a
	% PHYTO-C	Percent	Proportion of POC which is phytoplankton
	PHAEO	ug liter^{-1}	Phaeopigments
III	Z_{wc}	Meters	Water column depth
	K_d	Meters^{-1}	Secchi disc extinction coefficient
	K_p	Meters^{-1}	Photometer extinction coefficient
	TMS	g meter^{-2}	Total microseston
	% OMS	Percent	Proportion of TMS which is organic
	POC	g meter^{-2}	Particulate organic carbon
	CHL	mg meter^{-2}	Chlorophyll a
	PHYTO-C	g meter^{-2}	Phytoplankton bound carbon
	PROD	mgC day^{-1}m^{-2}	Primary productivity
IV	% LIGHT	Percent	% incident light
	PHOTO CAP	ugC hr^{-1} liter^{-1}	Photosynthetic capacity
	ASSIM NO.	ugC hr^{-1}guChl	
	I	g-cal cm^{-2} day^{-1}	Incident sunlight energy
	% LD	Meters	Depths corresponding to % LIGHT
	PROD	ugC day^{-1} ugChl	Primary productivity
	ASSIM RATIO	ugC day^{-1} ugChl	Assimilation ratio
VI	% LIGHT	Percent	% incident light
	NANO		Nanoplankton (20 u)
	NET		Netplankton (20 u)
	% LD	Meters	Depths corresponding to % LIGHT

TABLE	VARIABLE	UNITS	DESCRIPTION
VII	P_{max}	None	Net:nano ratio of maximum PHOTO CAP
	ASSIM NO	None	Net: nano ratio of maximum ASSIM NO
	CHL N^{-2}	None	Net: nano ratio of water column CHL
	PROD N^{-2}	None	Net:nano ratio of water column PROD
	ASSIM RATIO	None	Net:nano ratio of water column ASSIM RATIO
VIII	TAXONOMIC GROUP	Numbers liter^{-1}	Density of cells
IX	TAXONOMIC GROUP	Numbers m^{-3}	Density of individuals
X	NT	mg m^{-3}	Dry weight
	WT/ORG	mg organism^{-1}	Weight/individual

Station Locations



Station Locations
for FRS Albatrose IV cruise,
24 August-9 September, 1976.

2. Data Quality

Data quality and collection and measurement techniques used are included in NOAA/ERL/MESA reports. All data are of a standard accepted for the techniques used.

3. Contact

Dr. Chris Garside
Bidelow Laboratory of Ocean Science
West Boothbay Harbor
Maine 04575
(207) 633-2173/5
NODC

MESA/STAX-II/Stony Brook

1. Data Available Pertinent to the Anoxia Problem

During the period July 11-16, 1976, 16 stations were occupied in a concentrated area of the New York Bight Apex. This work was part of the STAX-II study. The following water column variables were measured: T,S, O_2 (Winkler), the nutrients (NH_4+, PO_4^{3-}, Si $(OH)_4$, NO_2^-, NO_3^- (Autoanalyzer), POC and PON (CHN analyzer), suspended solids (gravimetric analysis) and the suspended metals Fe, Mn, Hg, Cd, Cu, Ni, Pb, Cr, and Ag (atomic absorption and X-ray fluorescence). Additionally, concentrations of *Ceratium tripos* were determined from the number of organisms collected on filters. The water column data showed a well-developed oxygen minimum (1.5-2.0 ml/l) which occurred at a depth of 15 m. The POC and PON maximum occurred a few meters above the thermocline. Correlations of *Ceratium* count with POC are now being made.

Previous data bases in the Bight apex include our transect study (Duedall et al; Parker et al/L & O Symposium Volume/; and Parker /thesis/) and studies related to dumping experiments (Duedall et al, 1975-ECNS; Duedall, et al. 1976- Short-term Water Column Perturbations, *Journal of Water Pollution* (In Press).

2. *Data Quality*

   No statement.

3. *Contact*.

   Dr. Iver W. Duedall
   Marine Sciences Research Center
   S.U.N.Y.
   Stony Brook, New York
   (516) 246-3367

ERDA

Brookhaven National Laboratory

1\. and 2. Data Available, Status and Reliability

January 1975 - KNORR cruise off Long Island, Shinecock Transect.

What: Temperature, salinity, NO_3, NO_2, SiO_4, PO_4, NH_4.

Status: Rough compilation (handwritten).

Reliability: Not very good; other is good.

March 1975 - ATLANTIS II cruise off Long Island, Shinecock Transect.

What: Temperature, salinity, NO_3, NO_2, NH_4, SiO_4, PO_4, O_2, PN, Pc, PCB's, zooplankton, chlorophyll, phytoplankton species, ^{14}C particle counts (fluorescent and non-fluorescent).

Status: Data being worked up; data report available; manuscript submitted to Journal.

Reliability: Very good.

March 1976 - KELEZ cruise - joint with MESA - Nutrients from Stony Brook.

April 1976 - EASTWARD cruise - Shinecock Transect.

What: Temperature, salinity, NO_3, NO_2, NH_4, SiO_4, PO_4^-, PN, ^{15}N, ^{14}C, phytoplankton species, chlorophyll.

Status: Data being worked up; data report available approximately in the spring.

Reliability: Very good.

May 1976 - EASTWARD cruise - Surface maps from Long Island - Georges Bank.

What: NO_3, NO_2, SiO_4, NH_4, chlorophyll, PO_4.

Status: Data being worked up.

Reliability: Good.

June 1976 - KELEZ cruise - off Long Island - joint with AOML.

What: NO_3, SiO_4, NH_4.

Status:

Reliability: Good.

September 1976 - RESEARCHER cruise - New York Bight (New Jersey and Long Island) - joint with AOML.

What: NO_3, NO_2, NH_4, UREA, SiO_4, PO_4, primary amines, bacterial uptake, zooplankton biomass.

Status: Data not edited nor corrected yet.

Reliability: Some nutrients were frozen - NO_3 and NH_4 run fresh - other data good.

3. <u>Contact</u>

Dr. Terry Whitledge
Ocean Sciences Division
Brookhaven National Laboratory
Upton, L. I., N. Y. 11973
(516) 345-2945

STATE OF NEW JERSEY

Department of Environmental Protection

Various contacts from the State of New Jersey/DEP have data sets available. These are listed below. In each case the contact address is given followed by the data summary provided by the contact.

John Ruggero/New Jersey/DEP
P. O. Box 2809
Trenton, N. J. 08625
(609) 292-1576

Will also be available through Paul White.

17 Stations - between Cape May and Sandy Hook, 8 of which are north of Barnegat. All are one to two miles offshore. Sampled at surface. Sampled quarterly since late 1974. Available - Cr, Cw, An, Pl, Cd, Hg, NH_3, NO_3, TKN, PO_4.

Summaries available--ranges of observations by station in two-page typewritten summary.

Raw data available--all in machine-readable format: Cards in fixed format December 1, 1976.
Printout available: Mid-December 1976.
STORET: January 1977.

Nitrate data lack sensitivity. NH_3 by EPA method.

Also available: 25 bay stations. Approximately 75 fresh water sites for similar parameters.

CONCENTRATION OF METALS IN ATLANTIC OCEAN OFF NEW JERSEY 1975-1976

STATION LOCATION	CHROMIUM		COPPER		ZINC		LEAD		CADMIUM		MERCURY	
	Range (mg/l)	Number of Samples	Range (mg/l)	Number of Samples	Range (mg/l)	Number of Samples	Range (mg/l)	Number of Samples	Range (mg/l)	Number of Samples	Range (mg/l)	Number of Samples
A3A SANDY HOOK	ND-.058	5	ND	5	ND	5	.003-.006	5	ND-.001	5	ND	5
A13A LONG BRANCH	ND-.052	6	ND	6	ND-.11	6	.003-.008	6	ND-.003	6	ND	6
A18A ASBURY PARK	ND-.052	6	ND	6	ND	6	ND-.007	6	ND-.004	6	ND-1.0	6
A21A BELMAR	ND-.044	6	ND	6	ND-.51	6	.003-.007	6	ND-.002	6	ND	6
A27A POINT PLEASANT	ND-.037	5	ND	5	ND	5	.002-.007	5	ND-.002	5	ND	5
A34A ORTLEY BEACH	ND-.04	5	ND-.186	5	ND	5	ND-.006	5	ND-.01	5	ND	5
A41A ISLAND BEACH ST.PK.	.011-.057	5	ND-.103	5	ND-.06	5	ND-.006	5	ND-.01	5	ND	5
A50A HARVEY CEDARS	.01-.063	5	ND	5	ND-.025	5	ND-.005	5	ND-.011	5	ND-5.4	5
A59A BRANT BEACH	ND-.063	5	ND-.048	5	ND-.025	5	ND-.012	5	ND-.002	5	ND	5
A65A BEACH HAVEN INLET	ND-.046	5	ND	5	ND	5	ND-.006	5	ND-.001	5	ND	5
A71A BRIGANTINE	ND-.073	5	ND-.069	5	ND	5	ND-.005	5	ND-.001	5	ND-1.0	5
A77A ATLANTIC CITY	ND-.01	7	ND-.024	7	ND-.81	7	ND-.017	7	ND-.006	7	ND-3.2	7
A84A OCEAN CITY	ND-.023	7	ND-.058	7	ND-.075	7	ND-.006	7	ND-.007	7	ND-3.6	7
A90A SEA ISLE CITY	ND-.027	7	ND-.024	7	ND-.04	7	ND-.006	7	ND-.007	7	ND-1.0	7
A96A STONE HARBOR	ND-.016	7	ND-.058	7	ND-1.5	7	.002-.008	7	ND-.004	7	ND-17.0	7
A102A WILDWOOD	ND-.1	7	ND	7	ND-.88	7	ND-.026	7	ND-.002	7	ND-1.4	7
A108A CAPE MAY	ND-.085	7	ND-.055	7	ND-2.6	7	.002-.028	7	ND-.006	7	ND-7.0	7

For further information contact:
N.J. Division of Water Resources
P.O. Box 2809
Trenton, N.J. 08625

*ND=NOT-DETECTABLE
Station locations are one mile east of land reference

Paul White/New Jersey/DEP
805 Labor and Industry Building
Trenton, N. J. 08625
(609) 292-2907

The New Jersey DEP conducted roughly 28 one-day ocean transects during the period July 8 to mid-October. The primary purpose of the transects was to monitor the size and development of the low-oxygen region. The transects ranged in length from 8 to 30 miles, the majority being approximately 20 miles in length. Stations were at two-mile intervals and samples were taken at the surface, thermocline and bottom (using a weighted bottle for the bottom samples).

The following were done at each sample point: Dissolved oxygen, temperature and Ph. Nutrient samples and Ceratium samples were taken at several stations on each transect. The nutrient analyses were for: TKN, nitrate, nitrite, ammonia, total phosphate and ortho-phosphate; both filtered and unfiltered analyses were done for each nutrient.

The nutrient analyses have not been completed for the latter part of the summer. Except for this nutrient data, our results are typed and compiled in one report.

I have not been involved in the analyses and cannot comment on accuracy at this time.

Frank Takocs/New Jersey/DEP
Robert Kotch/New Jersey/DEP
Division of Water Resources
Biological/Technical Support Unit
Box 2809
Trenton, N. J. 08625
(609) 292-7754

The Biological/Technical Support Unit of the Division of Water Resources, NJDEP, was charged with monitoring the coastal beaches and surf, with emphasis on bather safety. Twenty-eight stations from Cape May to North Beach, Sandy Hook, were sampled (173 samples) from July 6 to September 7, 1976, for bacteriological, biological, physical and chemical parameters. The data have been compiled and tabulated by station.

Hydrogen Sulfide Observations from R.V. *Albatross* IV and C.G.C. *Pt. Francis* Cruises

(26 Aug.-9 Sept., 21 Sept. 1976)

A. Draxler and C. J. Byrne
National Marine Fisheries Service
Sandy Hook Laboratory
Highlands, New Jersey 07732

Introduction

Hydrogen sulfide has been shown to be toxic to a wide variety of aquatic organisms (Water Quality Criteria, 1963; Theede et al., 1969). Its occurrence in the sea is usually limited to relatively isolated water masses such as the lower depths of the Black Sea, various fjords, bays and inlets where concentrations reach 300 µg-at/l or more (Caspers, 1957; Richards et al., 1965). Vertical stratification results in reduced mixing and therefore replenishment of oxygen; this along with the degradation of plankton production, combine to produce anoxia in the bottom waters. Richards et al. (1965) have proposed a model for the biochemical oxidation of organic material. After the dissolved oxygen has been reduced, nitrite and nitrate serve as oxidants, then sulfate reduction to sulfide can take place. The concentration of sulfide is controlled by the rate at which it diffuses away from its place of formation into aerated water where it is oxidized. In Lake Nitinat Richards et al. have shown this process to be describable by a one-dinensional model.

There are, however, instances, notably off the west coast of Africa (near Walvis Bay), where conditions conspire on a relatively open continental shelf to exhaust dissolved oxygen supplies and produce sulfide. Here there is an area (at least 15,000 km^2) extending from 8 out to 65 km from shore that is devoid of bottom life including demersal fish. The concentration of sulfide has not been measured but olfactory examination indicates that the organic rich sediment of the area is capable of producing hydrogen sulfide throughout the year by virtue of presence of Desulphovibrio sp. (Copenhagen, 1953).

During the summer of 1976, personnel from the National Marine Fisheries Service made approximately 40 cruises in the New York Bight ranging in length from one to 15 days making a wide variety of chemical and biological measurements. Temperature, salinity, and dissolved oxygen concentrations were measured on most cruises. Sulfide concentration was determined on four. On the first two of these (20-22 July and 6-17 August) the main objective was to census demersal finfish and shellfish. The third (26 August-9 September) concentrated on benthic and water column respiration, primary productivity, bacteriology, and chemistry. The last (21 September) occupied 4 stations across the anoxic area in order to collect samples for heavy metals and bacteriological examination.

Methods

Station locations for the third and fourth cruises are shown in Figure 1. Water was collected in 10 liter PVC Niskin bottles from which samples for oxygen and sulfide analyses were routinely drawn first. Oxygen was measured by the azide modification of the Winkler procedure (Standard Methods, 1975) using PAO (Hach Chemical Co., Ames, Iowa) in place of thiosulfate and amylose in place of starch. Sulfide determinations were based on the formation of Lauth's violet (Strickland and Parsons, 1972).

Temperatures on the cruises were measured with reversing thermometers and XBT's and salinities were determined on an induction salinometer.

Results

Temperature, salinity, sulfide and dissolved oxygen data for the third and fourth cruises are listed in Table 1. The values reported are those for which the F-ratio showed significant differences (at the 99% level) from the blanks and the overlying waters.

Discussion

The highest concentrations of sulfide were observed in the anoxic area at stations 213, 217 and NJ5. There were traces at marginal stations where some oxygen was present as well as in the sewage sludge disposal area (Sta. 34) and Raritan Bay (Sta. 45). Data which we will present elsewhere, show that nitrite and nitrate were undetectable, ammonium was plentiful, and the apparent pH was depressed where sulfide concentrations were high. It is interesting to note that between 8 September and 21 September the oxygen concentration at station 219 decreased dramatically but sulfide had not begun to be produced. (The oxygen concentration may have been lower than we report since the samples remained in the alkaline state for 24 hours before titration. This is longer than recommended in Standard Methods (1975.)

References

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Richards, F.A., J.D. Cline, W.W. Broenkow and L.P. Atkinson. 1965. Some consequences of the decomposition of organic intake in Lake Nitinat, an anoxic fjord. Limnol. Oceanogr. 10 (suppl.): R185-R201.

Standard Methods for the Examination of Water and Waste Water. 1975. Edited by M.C. Rand, A.E. Greenberg and M.J. Taras. Am. Pub. Health Asso., Washington, D. C. Pages 443-447.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis, 2nd ed. Fish. Res. Board Can., Bull. 167:41-44.

Theede, H., A. Ponat, K. Hiroki and C. Schlieper. 1969. Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulfide. Mar. Biol. (Berl.)2:325-337.

Water Quality Criteria. 1968. Report of the National Technical Advisory Committee to the Secretary of the Interior. Federal Water Pollution Control Administration, Washington, D. C., 234 pages.

TABLE 1

Station	Date	Depth (m)	Temp. °C	Sal. (ppt)	Sulfide ug-at/l	Dis. O_2 (mg/l)
51	760827	1.0	22.40	30.41	<0.2	7.68
51	760827	1.8	22.45	30.40	<0.2	7.60
51	760827	2.8	22.40	30.41	<0.2	7.60
51	760827	7.2	22.40	30.42	<0.2	7.53
51	760827	11.5	19.55	31.83	<0.2	8.04
51	760827	14.0	18.4	31.96	<0.2	7.75
51	760827	17.0	18.3	31.32	<0.2	7.86
51	760827	21.0	14.5		<0.2	4.89
51	760827	23.0	14.4	31.97	<0.2	5.08
109	760828	1.0	20.90	28.54	<0.2	5.68
109	760828	4,0	20.44	28.74	<0.2	5.44
109	760828	6.5	20.28	28.77	<0.2	5.22
109	760828	11.5	20.04	29.48	<0.2	5.94
109	760828	14.0	19.43	30.73	<0.2	5.56
109	760828	21.0	14.83	31.59	<0.2	2.43
45	760830	1.0	22.41	24.39	<0.2	3.91
45	760830	2.0	22.5	24.40	-	3.92
45	760830	3.4	22.6	24.44	0.28	3.84
45	760830	6.0	22.6	24.41	0.32	3.95
69	760830	1.0	21.26	25.73	<0.2	4.95
69	760830	2.8	21.2	25.73	<0.2	5.02
69	760830	4.0	21.23	25.69	<0.2	5.00
69	760830	5.4	21.31	25.65	<0.2	4.90
69	760830	8.0	20.93	26.20	<0.2	5.09
69	760830	11.0	20.94	27.42	<0.2	5.39
101	760831	1.0	20.53	25.75	<0.1	5.09
101	760831	2.5	20.54	25.73	<0.1	5.07
101	760831	5.0	20.58	25.78	<0.1	5.10
101	760831	6.0		25.77	<0.1	5.06
101	760831	11.0	20.78	25.76	<0.1	5.09
102	760831	1.0	19.39	28.66	<0.1	5.81
102	760831	3.4	18.28	29.81	<0.1	5.18
102	760831	5.0	18.09	30.13	<0.1	4.90
102	760831	7.2	15.61	31.31	<0.1	3.03
102	760831	9.0	14.96	31.51	<0.1	2.67
102	760831	13.0	15.07	30.12	<0.1	4.84
41	760901	1.0	19.51	30.30	<0.1	8.12
41	760901	2.4	19.51	30.30	<0.1	8.05
41	760901	4.2	19.60	30.53	<0.1	7.91
41	760901	6.2	11.19	31.14	<0.1	7.47
41	760901	9.0	18.48	31.17	<0.1	4.62
41	760901	15.0	12.50	31.99	0.15	1.38
41	760901	20.0	11.58	32.19	0.23	1.19
34	760901	1.0	19.86	29.76	<0.1	9.48
34	760901	4.0	19.86	29.77	<0.1	9.49
34	760901	6.0	20.04	29.76	<0.1	9.39
34	760901	10.0	19.79	30.40	<0.1	7.43
34	760901	18.0	15.10	32.01	<0.1	6.06
34	760901	26.0	10.96	32.22	<0.1	3.16
34	760901	36.0	9.48	32.29	0.12	1.99
76	760902	1.0	20.4	31.10	<0.1	7.32
76	760902	4.8	20.6	31.10	<0.1	7.32
76	760902	9.6	20.6	31.17	<0.1	7.29
76	760902	16.0	15.6	31.91	<0.1	6.16
76	760902	23.0	12.2	32.18	<0.1	3.94
76	760902	30.0	7.94	32.39	<0.1	3.20
76	760902	40.0	7.7	32.56	<0.1	2.07
76	760902	50.0	7.77	32.65	0.14	1.79
200	760903	1.0	20.43	31.44	<0.1	6.79
200	760903	4.0	20.4	31.45	<0.1	6.74
200	760903	11.0	17.56	31.43	<0.1	4.14
200	760903	14.0	12.9	31.78	<0.1	0.33
200	760903	17.0	12.77	31.76	<0.1	0.18
200	760903	21.0	12.69	31.75	<0.1	0.31
201	760903	1.0	20.59	31.38	<0.1	7.54
201	760903	3.0	20.6	31.37	<0.1	7.59

TABLE 1 (continued)

Station	Date	Depth (m)	Temp. °C	Sal. (ppt)	Sulfide ug-at/l	Dis. O_2 (mg/l)
201	760903	8.0	20.30	31.37	<0.1	7.58
201	760903	18.0	19.0	31.79	<0.1	6.93
201	760903	23.0	11.07	31.90	<0.1	4.51
201	760903	28.0	13.28	32,24	<0.1	2.39
201	760903	33.0	11.98	32.21	<0.1	2.33
86	760902	1.0	19.57	30.92	<0.1	7.19
86	760902	4.0	12.77	30.97	<0.1	7.06
86	760902	8.0	19.72	31.00	<0.1	6.59
86	76092	12.0	15.10	31.73	0.10	3.30
86	760902	18.0	13.63	31.91	0.25	3.21
207	760904	1.0	21.01	31.27	<0.1	7.00
207	760904	5.0	20.91	31.26	<0.1	6.89
207	760904	11.0	20.91	31.30	<0.1	6.96
207	760904	20.0	14.0	31.81	<0.1	2.28
207	760904	25.0	11.06	32.06	<0.1	0.98
207	760904	31.0	7.67	32.05	0.18	0.81
213	760904	1.0	20.98	31,99	<0.1	6.98
213	760904	4,0	21.40	31.98	<0.1	6.95
213	760904	9.0	20.98	31.99	<0.1	6.91
213	760904	15.0	20.58	31.95	<0.1	5.18
213	760904	18.0	14.8	32.06	6.64	0.00
213	760904	21,0	14.39		18.03	0.00
217	760905	1.0	21.59	32.18	<0.1	7.22
217	760905	4.0	21.57	32.18	<0.1	7.08
217	760905	12,0	21,6	32.19	<0.1	7.10
217	760905	20.0	11.96	32.57	9.80	0.0
217	760905	27.0	11.81	32.54	9.74	0.0
217	760905	31.0	11.84	32.54	10.34	0.01
217	760905	35.0	11.78	32.54	10.99	0.05
215	760906	1.0	20.37	32.11	<0.07	7.18
215	760906	4.0	20.36	32.12	<0.07	7.14
215	760906	7.0	20.4	32.10	<0.07	7.17
215	760906	14.0	18.53	32.21	<0.07	5.37
215	760906	17.0	15.89	32.23	<0.07	4.50
215	760906	20.0	11.91	32.24	<0.07	4.34
228	760906	1.0	20.94	31.73	<0.07	7.17
228	760906	4.0	20.32	31.73	<0.07	7.29
228	760906	6.0	20.32	31.73	<0.07	7.24
228	760906	11.0	20.29	31.91	<0.07	7.14
228	760906	16.0	15.07	32.50	<0.07	3.73
228	760906	22.0	15.06	32.47	<0.07	3.67
226	760907	1.0	21.54	32.13	<0.07	7.22
226	760907	6.0	21.02	32.11	<0.07	7.23
226	760907	18.0	21.58	32.12	<0.07	7.27
226	760907	26.0	14.75	32.44	<0.07	2.98
226	760907	40.0	8.55	32.85	<0.07	0.62
226	760907	47.0	7.89	32.88	<0.07	0.49
226	760907	55.0	8.40	32.87	<0.07	0.54
227	760907	1.0	21.73	32.13	<0.07	7.21
227	760907	8.0	21.17	32.14	<0.07	7.18
227	760907	16.0	21.1	32.12	<0.07	7.25
227	760907	28.0	13.39	32.58	<0.07	2.86
227	760907	36.0	11.80	32.59	0.08	1.13
227	760907	40.0	9.24	32.52	0.08	1.65
219	760908	1.0	19.99	32.06	<0.07	7.51
219	760908	5.0	19.98	32.06	<0.07	7.40
219	760908	11.0	19.9	32.12	<0.07	7.45
219	760908	19.0	18.78	32.33	<0.07	7.13
219	760908	25.0	14.7	32.47	<0.07	6.40
219	760908	29.0	13.00	32.55	<0.07	4.99
219	760908	34.0	10.9	32.66	<0.07	4.50
219	760908	41.0	9.9	32.52	<0.07	5.18
205	760908	1.0	20.84	31.59	<0.07	7.42
205	760908	6.0	20.37	31.63	<0.07	7.37
205	760908	14.0	20.37		<0.07	7.44
205	760908	21.0	20.88	31.61	<0.07	7.41

TABLE 1 (continued)

Station	Date	Depth (m)	Temp. °C	Sal. (ppt)	Sulfide ug-at/l	Dis. O_2 (mg/l)
205	760908	30.0	20.27	31.68	<0.07	7.40
205	760908	46.0	14.40	32.35	<0.07	4.56
205	760908	62.0	7.98	32.62	<0.07	1.34
205	760908	80.0	8.02	32.90	<0.07	1.98
DCS 1	760906		7.69	32.91	0.20	3.46
DCS 2	760906				0.11	
DCS 3	760906				<0.07	
DCS 4	760906				<0.07	
DCS 5	760906				<0.07	
DCS 6	760907				0.09	
DCS 8	760907				<0.07	
NJ 5	760909				8.89	
NJ 7	760909				0.79	
NJ 8	760909				0.12	
NJ14	760921	1.0	20.5	31.6	<0.07	11.3
213	760921	1.0	21.0	31.9	<0.07	10.2
213	760921	15.0	15.3	31.9	0.37	2.7
213	760921	20.0	14.9	31.9	5.79	0.2
NJ13	760921	1.0	21.2	31.4	<0.07	11.1
NJ13	760921	20.5	20.8	31.8	<0.07	8.4
NJ13	760921	31.0	11.4	32.2	0.12	0.6
219	760921	1.0	21.2	31.7	<0.07	10.9
219	760921	18.0	16.8	31.6	<0.07	9.8
219	760921	43.0	9.8	32.3	<0.07	0.4

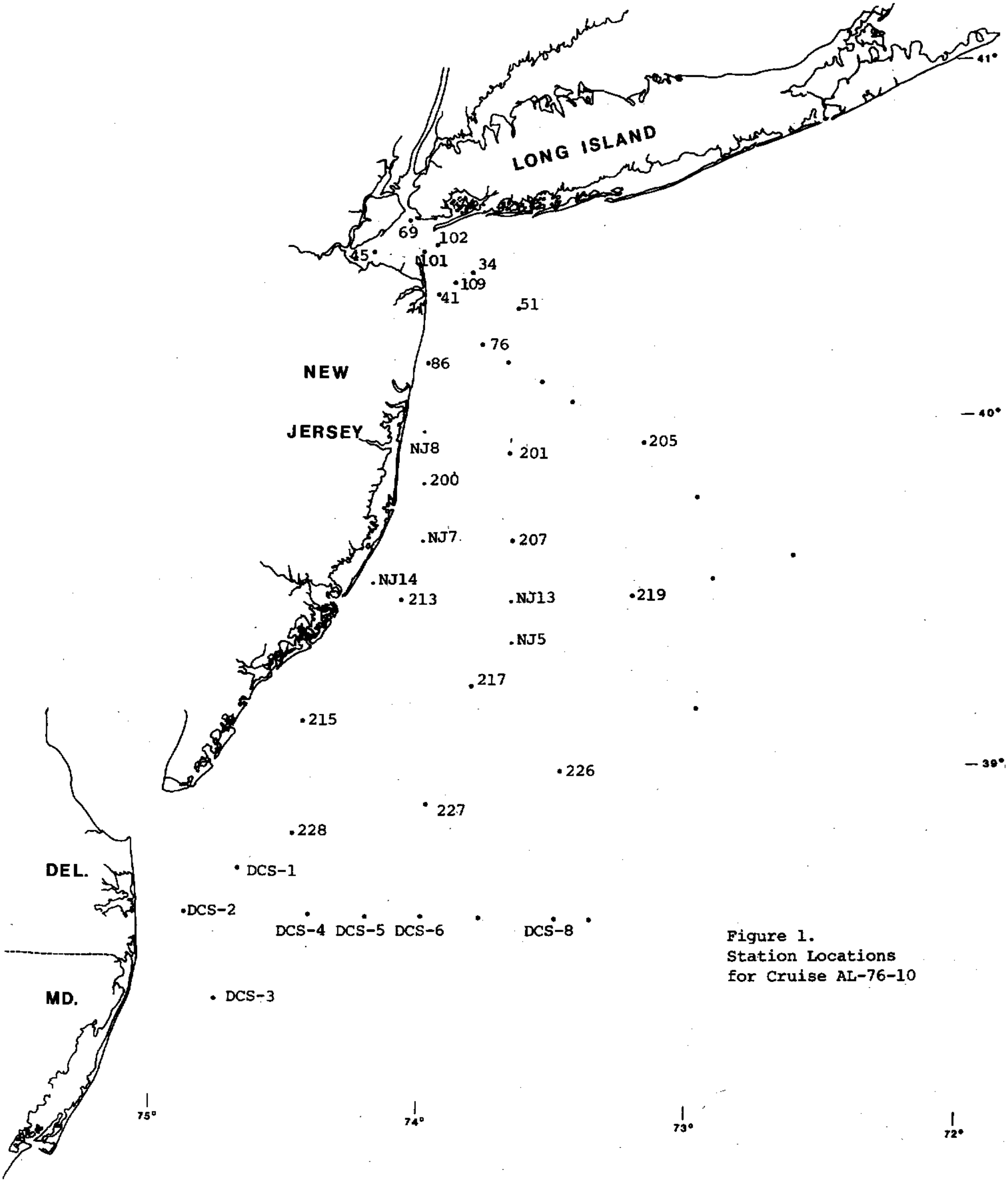

Figure 1.
Station Locations
for Cruise AL-76-10

SEDIMENT WORKSHOP -- SUMMARY REPORT

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1.0 SUMMARY REPORT (Dennis Weiss, Rapporteur)

The sediment workshop met on November 19, 1976 at the City Institute of Marine and Atmospheric Sciences, Wave Hill, Riverdale, New York. The participants (see attached list) discussed the possible role of bottom sediments in the 1976 New York Bight anoxia event. It was noted that the overall sediment type in the area of concern is clean, fine-grained sands with less than 3% fines (the fines being smaller than 63 microns in size). The fine fraction is composed of more silt than clay. The workshop members agreed that the sediments themselves (mineralogic constituents) did not contribute to the start and maintenance of the anoxia. It is of course possible that metals chelated onto the clay minerals or the organic fractions were somehow released. It was pointed out, however, that data do not exist as to the trace metals associated with the fine fraction or sediments which could contribute highly toxic substances into the aquatic environment. (Unfortunately two invited scientists, Drs. A. Cok and W. Harris could not attend the workshop. It is quite possible that they may have provided additional insight into the problem).

Another sediment related source for the anoxia that was discussed was the decay of any organic-rich sediment that may have led to the event in question. It was noted that extremely high ammonia concentrations were measured in the area affected by the anoxia along with a coincident of anoxic bottom water conditions. This has been noted in other areas to be related to a benthic demand for oxygen by marine sediments. Unfortunately, the sediments, as noted above, in the affected area are not organic-rich and would not necessarily contribute to the high ammonia levels as measured in the water column.

As a result of the discussion of the workshop's participants in light of the lack of available information about the sediments in the area affected by the anoxia, the following was recommended:

1. A detailed sedimentologic and mineralogic map be prepared for the area.

2. A study of the metal concentrations in the area of the New York Bight and the contiguous shelf. This is needed in order to determine what role(s) metals play in such anoxic events.

3. A study of the interaction of the clay minerals and the organic sediment fraction with the heavy metals.

4. An assessment of the role and interaction of the microflora and microfauna within the sediments and water column in the development of anoxic conditions.

5. Monitor (or model) the movement of bottom sediment from the New York dump site during periods of similar runoff, current, tidal, and wind conditions as existed prior to and during the anoxic event of 1976.

6. Mount a continuous monitoring program of the waters and sediment in and around the New York Bight dumping grounds and the contiguous Atlantic Ocean continental shelf in order to posibly predict and prevent another anoxic event.

APPENDIX I

STATEMENT ON DISTRIBUTION OF SEDIMENT TYPES

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With a very few areally-minor exceptions, the sediments underlying the anoxic area off the Jersey shore are clean sands which contain low percentages of silts much less clays. The nearest source of fine-grained sediments is the Hudson Shelf Channel. I (PEB) have recently compiled a map of the distribution of percent "fines" (defined as weight percent less than 63 µm) over the area from 38°30' to 41°N latidude and from 69°20' to 74°30'W longitude containing over a thousand data points compiled from John Schlee (U.S.G.S. at Woods Hole) and our own data (Geochemistry, Lamont-Doherty Geological Observatory). This chart is not in a form to be reprinted here but the general features of it are shown in Figure 5 which is taken from Biscaye and Olsen ("Suspended Particulate Concentrations and Compositions in the New York Bight" pp. 124-137, In: M. G. Gross, Ed. 1976, American Society of Limnology and Oceanography Special Symposium, No. 2, The Middle Atlantic Continental Shelf and New York Bight, 441 pp.). With the exception of a few narrow troughs less than a mile offshore of Barnegat and Manasquan

Inlets found by us during August and October 1976 to contain fine-grained, stinking muds, the shelf off New Jersey is covered by sands containing $<3\%$ fines (63 µm).

It is therefore difficult to imagine that some characteristic of the sediments themselves (as opposed to possibly the benthos that live in or on them) contributed in any way to the initiation and localization of the anoxia during the summer of 1976. One might think that possibly the decay of organic-rich sediments or that possibly unusually high levels of trace elements may have played some role in triggering, if not maintaining, the anoxia. Sediments with these characteristics, however, just do not exist within the problem area.

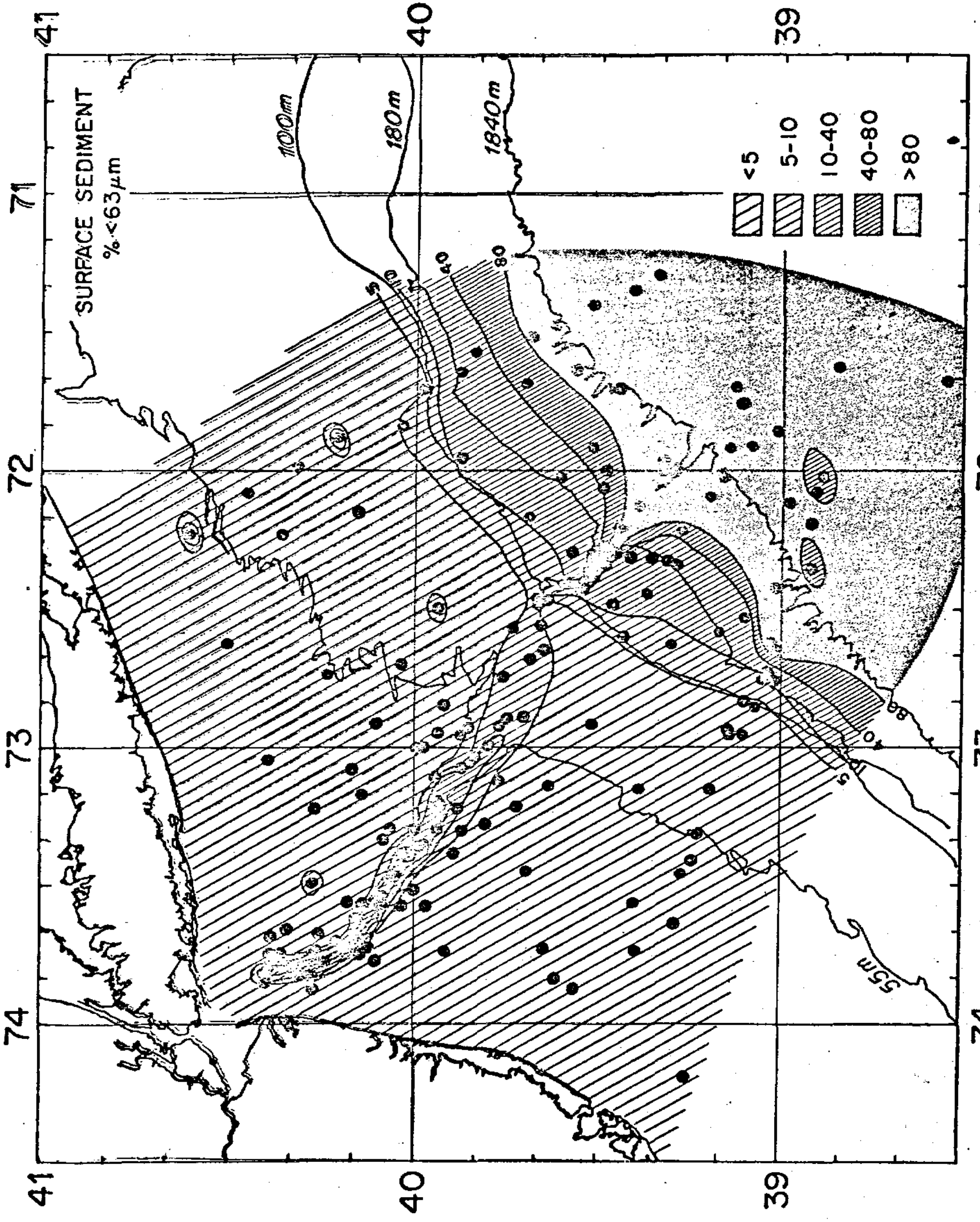

Fig. 5. Distribution of percent fines (< 63 μm) in surface bottom sediments. With the exception of the Hudson Shelf Channel, shelf sediments in the study area contain little fine-grained material. To the east of the study area a large area of the shelf is covered with fine-grained sediment as shown by Schlee (1975); beyond the shelf break, sediments of the upper continental slope and Hudson Canyon

BENTHIC WORKSHOP --

SUMMARY REPORT

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1.0 Introduction

The purposes of this workshop, as defined by the steering committee, were:

a) to compile and examine available data relating to the impact of anoxia on the benthos and the possible contributions by this ecosystem component to the problem,

b) to summarize these data and attempt to develop conclusions on impacts and contributions; and

c) with the advantage of hindsight, to discuss what data were lacking in making an accurate appraisal of the situation and to make recommendations as to future research areas, strategy and methodology of monitoring for prediction and regulatory action.

2.0 Data presentations:

David Radosh presented preliminary data based on Sandy Hook's investigation of the effects of the oxygen-deficient bottom waters on the benthic infaunal communities (Appendix Data Report No. 1). He presented evidence to suggest a moderate reduction in an area extending along most of the New Jersey coastline from within two miles of the shore out to as much as 45 miles. He also indicated a severe impact in an area south and offshore of Barnegat Inlet, N.J. This area lies within another area reported as having hazardous (1.76 mg/l) concentrations of H_2S during a groundfish survey conducted the second and third weeks in August, 1976. Certain species have been found to consistently dominate these heavily impacted stations indicating a relatively high tolerance to hypoxia and/or hydrogen sulfide. These species are also known to occur in large numbers in the organically rich Christiaensen Basin and Hudson Shelf Valley.

Frank Steimle summarized data provided via telephone by Dr. Donald Boesch, V.I.M.S., Gloucester Pt., Va., who was unable to attend. Dr. Boesch found severe reductions in fauna in two areas sampled as part of a BLM-OCS study. These areas were just north of Barnegat Inlet and southeast of Atlantic City, NJ. Generally, in both areas, the motile megabenthos was dead or absent; the sand dollar, _E. parma_ which dominated the community prior to the summer, was _totally_ absent. Select groups of infauna were most affected; many polychaetes and the bivalve, _Astarte castanea_, appeared tolerant of the condition, whereas small crustaceans, e.g., (_Tanaidaceus crustaceans_), normally abundant, were totally absent, and other bivalve species, e.g., _Spisula solidissima,_ suffered heavy mortalities.

Dr. Royal Nadeau discussed data collected by E.P.A. divers in the affected area. He indicated there was some problem with these data because of inconsistency or inaccuracy of the divers' methods in collection; the samples were inside or on the edge of the actual anoxic zone and indicated little impact.

Frank Steimle presented data collected incidentally during the resource impact assessment surveys. These data indicate severe impact on many megafaunal species (Appendix Data Report #2) throughout a wide area of the Bight through November.

Dr. James Thomas discussed some of his recent work on water column and benthic respiration. He found that benthic respiration only contributes 2-5% of the total water column respiration. Benthic oxygen uptake rates appeared to be much higher around the periphery of the anoxic area in September 1976, compared with values measured over the shelf in areas with more normal oxygen concentration, or with values measured during August, 1975, in the New York Bight Apex.

William Phoel discussed some of his observations, made while participating in a submersible habitat experiment, of the sequence of events during a period of oxygen depletion in the Baltic Sea. He observed certain groups of organisms were selectively affected by particular levels of diminishing dissolved oxygen concentrations.

3.0 Summary of data and conclusions:

Comments:

Dr. Sheldon Pratt remarked on and summarized some of the studies he had participated in or was aware of in regard to the effects of hydrogen sulfide on aquatic organisms. He reported that finfish may be able to detect and react, behaviorly, to H_2S at levels of 0.5-1.7 ppm and avoid the situation. Also, based on a section of a M.S. thesis he examined, at least one species of copepod is tolerant. He thought that pH is important in the toxicity of H_2S to organisms. Lobsters may have the ability to recover, even though they appear flaccid during an anoxic situation, if returned to oxygenated water. There are good available data on freshwater animals which may be applicable.

The anoxia-hydrogen sulfide problem had a severe impact on benthic macrofauna, including species important to fish in the coastal areas which had oxygen depletion and hydrogen sulfide buildup. Much data are still not completely analyzed or available and there is a strong need to have some input from sediment, chemical, and physical oceanography workshops to further understand the role of benthos in the situation. It would appear that the benthos did not have a large role in contributing to creating the anoxic problems. Although the surface flocculent material may be important, an estimate of the biomass created by benthic mortalities is not available, and appraisal of oxygen demands of the decaying material has not been made. Little data were presented on micro- or meiofauna, in the benthos, relative to the problem; these data may be available and should be considered in future discussions.

4.0 Recommendations:

- Once the distribution of macrofaunal impacts is known, an intensive recolonization study should be undertaken, paying particular attention to patterns of recolonization. These recolonization studies would be valuable in assessing problems other than anoxia, e.g., catastrophic mortalities resulting from oil spills. For example, CEQ/MIT assessments include "recovery" models which assume complete mortalities, and estimate recovery time based on age structure of dominant species. These assumptions are baseless because there are no data on recovery of continental shelf benthic communities.

- Laboratory studies of the tolerance levels of reduced oxygen, high H_2S levels for selected organisms (commercially valuable, community dominants, or important finfish forage species) should be initiated. This should include eggs and larval stages.

- Sublethal anoxia/H_2S-level behavioral studies would be valuable, for instance, to examine changes in breeding, spawning and feeding behavior, etc., or how changes in sediment chemistry regulate larval settling.

- Anaerobic metabolism, contaminant mobility, chemical seabed oxygen uptake should be addressed by the chemical oceanography workshop; biologists could help by examining the role of bioturbation of sediments.

- The use of "clappers" in mortality estimates for some shellfish species should be reexamined, especially for Arctica islandica.

- The role of benthos should be part of a broad integrated approach to the problem and should not be dealt with in isolation.

- The sediment workshop might examine changes in total organic carbon in the sediment - this information is selective to benthos.

- Divers or submersible surveys may be useful during any future recurrence, especially for photographic documentation, refined sampling and in situ experiments or monitoring.

- Although oceanographic monitoring may be the earliest means to detect a recurrence, monitoring of certain susceptible benthic groups, i.e., amphipods, may be very useful assessment tools.

- Increase numbers of replicate samples taken at each station, possibly using a smaller grab then the Smith-McIntyre, may provide better information on benthic community variablility.

APPENDIX I

SHORT-TERM EFFECTS ON THE BENTHIC INFAUNA RESULTING FROM OXYGEN-DEFICIENT BOTTOM WATERS OFF THE NEW JERSEY COAST, 1976; PRELIMINARY REPORT

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Introduction

As part of Sandy Hook Laboratory's investigation of the 1976 low dissolved oxygen phenomenon, several cruises were conducted to assess short-term effects on the benthic infauna. This component of the ecosystem is of importance because of the major contribution of infaunal species to the food webs of many demersal finfish and shellfish including valuable resource species. The surveys were designed to resample stations from previous benthic investigations; also included was a series of stations in areas which had not been previously studied. The resampled stations were to be used for direct comparisons of known benthic community structure prior to the phenomenon and included stations from: 1) the New York Bight MESA project quarterly cruises during 1973-74 in the New York Bight Apex (Pearce et. al. 1976a); 2) the New Jersey Coastal Benthic Survey, inshore summer samplings along the New Jersey coastline, 1972-73 (Radosh, 1976); and 3) an Offshore Coastal Survey (OCS), sampling between the 20 and 35 fathom contours during April,1975 (Pearce et. al., 1976b).

A total of 71 stations was sampled from July through November,1976 (Fig. 1). Benthic grab samples were taken in triplicate at each station with a Smith-McIntyre grab ($0.1m^2$), washed through a standard 1.0 mm geological screen, fixed in 10% formalin and transferred to 70% ethanol for storage. A subsample of the upper 1-2cm of sediment was skimmed from each grab and placed directly into the collecting jars. This was done in an attempt to prevent freshly set bivalve spats, particularly those of the surf clam, Spisula solidissima, from washing through the screen. There was concern as to what degree larvae and juveniles had survived in the impacted area.

To date, at least one of the triplicate samples at each of 33 of the stations has been processed (Fig. 2). Maximum effort was made to obtain as much immediate information as possible from the samples themselves as they were brought aboard ship. The general condition of the samples was recorded with respect to presence and relative abundance of life or recent mortalities, unusual odor e.g., putrification or hydrogen sulfide, and sediment texture and variablility, including the possible presence of reducing conditons below the surficial layers. From these observations,as well as from information obtained from groundfish and shellfish cruises, priorities were established as to which samples were to be processed first in an attempt to bracket areas which appeared to be most heavily impacted. Although processing of samples from the present study has not been completed to a point desirable for data manipulation and statistical analyses, comparisons of data with findings from earlier studies in the general area do allow prediction of major as well as specific groups of organisms one would expect to find in the New York Bight.

Table 1 gives a listing of total number of species found (S), total number of individuals (N) and relative diversity (H') (Shannon & Weaver, 1963) for each sample analyzed thus far. Table 2 compares S, N and H' values for processed 1976 OCS stations to those values from the same stations sampled over a year earlier. From these data, arbitrary criteria were established defining impacted stations as having fewer than 10 species (S) and/or fewer than 50 individuals (N). These criteria are based on comparisons of stations from this study as well as from earlier studies and represent what is believed to clearly denote an impacted community.

From Table 2 it can be noted that at some of the OCS stations, 1976 community structure was more diverse than it was in 1975. Some reasons which may account for these inconsistencies are discussed later in this report. However, annual and seasonal differences in samplings could be evident here with respect to infaunal recruitment and subsequent standing stocks. These inconsistencies could perhaps also indicate areas of slow recovery from a similar but less extensive and severe phenomenon which occurred in 1974 (Young, 1974).

The stressed behavior and extensive mortalities of the benthic megafauna (Data Summary No. 2, this workshop report) indicate that critically low levels of oxygen and/or critically high levels of hydrogen sulfide were reached for many organisms. For the most part, however, a major portion of the infaunal species appeared to be tolerant, except in an area off Long Beach Island, N. J. (Fig. 3) where part of the hypoxic cell persisted as oxygen levels in surrounding areas began to recover slowly. This area corresponds closely to a zone (Fig. 4) in which hazardous concentrations (1.76 mg/l) of hydrogen sulfide were found during a groundfish survey conducted the second and third weeks in August 1976 (NMFS, 1976). Analyses of benthic samples from stations within this zone have shown not only a severe reduction in species and relative numbers of individuals,but also indicate selective survival of the more tolerant species. Certain detritophagus organisms which inhabit the areas of deposition in the troughs of the sand waves have demonstrated a tolerance to the oxygen-deficient and, possibly, hydrogen sulfide conditions. These include the sea anemone, *Ceriantheopsis americanus*, the phoronid, *Phoronis architecta*, polychaete worms: *Spiophanes bombyx*, *Asabellides oculata*, *Ampharete arctica*, *Capitella capitata*, *Mediomastus ambiseta*, *Tharyx annulosus* and *Goniadella gracilis*, and the amphipod, *Unciola irrorata*. Although these species are considered ubiquitous throughout most of the Middle Atlantic Shelf (Pratt, 1973, Maurer et al., 1974), they are also species known as "opportunists" which actively occupy an area where conditions have been drastically altered to the point where other, less tolerant species cannot make maximum use of the available resources (Pearce and Radosh, 1976). These species are often found in high numbers with "contagious" (Fager, 1963) distributions in the organically polluted Christiaensen Basin and Hudson Shelf Valley (Fig. 5).

Because of observed oxygen-deficient bottom waters in 1976, a reduction in the benthic infauna was expected. For many animals, exposure to low dissolved oxygen (DO) concentrations is fatal (Theede et al.,1969; Reid, 1976), particularly when accompanied by the presence of hydrogen sulfide. Areas with depressed oxygen levels are often characterized by only a few tolerant species. Actual tolerance limits vary with different organisms. These limits generally tend to parallel the substrates in which the species naturally occur, i.e., inhabitants of soft substrates, which are often poorly aerated, are more resistant to low DO than those of hard and sandy ones (Theede et al., 1969).

As a whole, the area under study is one of high energy with a continuously changing ridge-swale (sand wave) topography characteristic of the Middle Atlantic inshore coastline (Swift, 1972). Textural variations across this type of bottom are represented by the coarser sediments remaining along the upper, more exposed ridges, with finer materials collecting in the troughs or swales. Observations from submersibles (pers. obs.) and bottom photographs (NOAA, 1976) reveal these sand waves to support distinct benthic assemblages which are dependent upon particular sediment types across this ridge-swale pattern (Boesch, pers. comm.) A definite problem in sampling the infauna arises here where spatial variations are quite small and yet community structure differs significantly. Also, fewer species are adapted to the high energy areas represented by the ridges of the sand waves (Pratt, 1973; Pearce and Radosh, 1976), posing still another problem in trying to assess impacts and define relative community structure. Perhaps this is what we are seeing by the inconsistencies found in the two OCS samplings mentioned earlier.

From the experiments conducted by Theede et al., (1969) it would be expected that the communities along the ridges would exhibit more stress and succumb to the hypoxia sooner than those forms found in the troughs. Theede et al., also demonstrated that tolerance limits to oxygen deficiency are dependent upon the relative activity of the organisms. Reid (1976) found the surf clam, Spisula solidissima, and the sand dollar, Echinarachnius parma, two active and dominant organisms which are in fact found mainly along the ridges, to have relatively low tolerances to depressed oxygen conditions. Also, Savage (1976) showed reduced burrowing activity in Spisula under low DO concentrations. Both the sand dollar and surf clam communities suffered extensive mortalities throughout the affected area. Black decaying sand dollar tests were often found in the grab, and surf clam mortalities reached as high as 100% at some stations (Ropes, 1976).

Many infaunal species are capable of anaerobic metabolism over extended periods of time. Dean (1964) found living polychaetes and amphipods in jars of sediment which had been sealed in storage for almost two months. The duration of tolerance to low DO/anoxia conditions is dependent on the species and often on other physical conditions, e.g., temperature, pH and the presence of hydrogen sulfide (Theede et al., 1969). Although the New Jersey Shelf is generally considered a high energy area, summer conditions tend to create an entirely different picture as the water column becomes stratified and stagnant at depth. Under certain conditions, introduction of fresh oxygenated water to the bottom layers is minimal. At the same time, however, relatively low bottom temperatures can increase low DO tolerances of many organisms well beyond what their limitations would be in warmer waters.

The ability of larval or juvenile Spisula to survive the hypoxic conditions is questionable. Young of the year of several bivalve species were extremely rare in the samples processed thus far but freshly dead juvenile clappers have been prominent. What this represents in terms of characterizing natural situations cannot be said at this time. Continued monitoring of the benthos will reveal the success and degree of recolonization over the next 6-12 months. In many cases, the particular species affected will determine the recovery rates of some areas. Certain species rely on planktonic life stages and recruitment from spawning in other areas while others recolonize by demersal larvae which spread and develop in the immediate vicinity of the parent community. If the latter is generally true and recovery slow, particularly in the case of forage species, migratory routes and feeding grounds of finfish may be altered. And, until surficial sediments stabilize from the reducing conditions which were created, an increase in populations of tolerant, opportunistic species can be expected.

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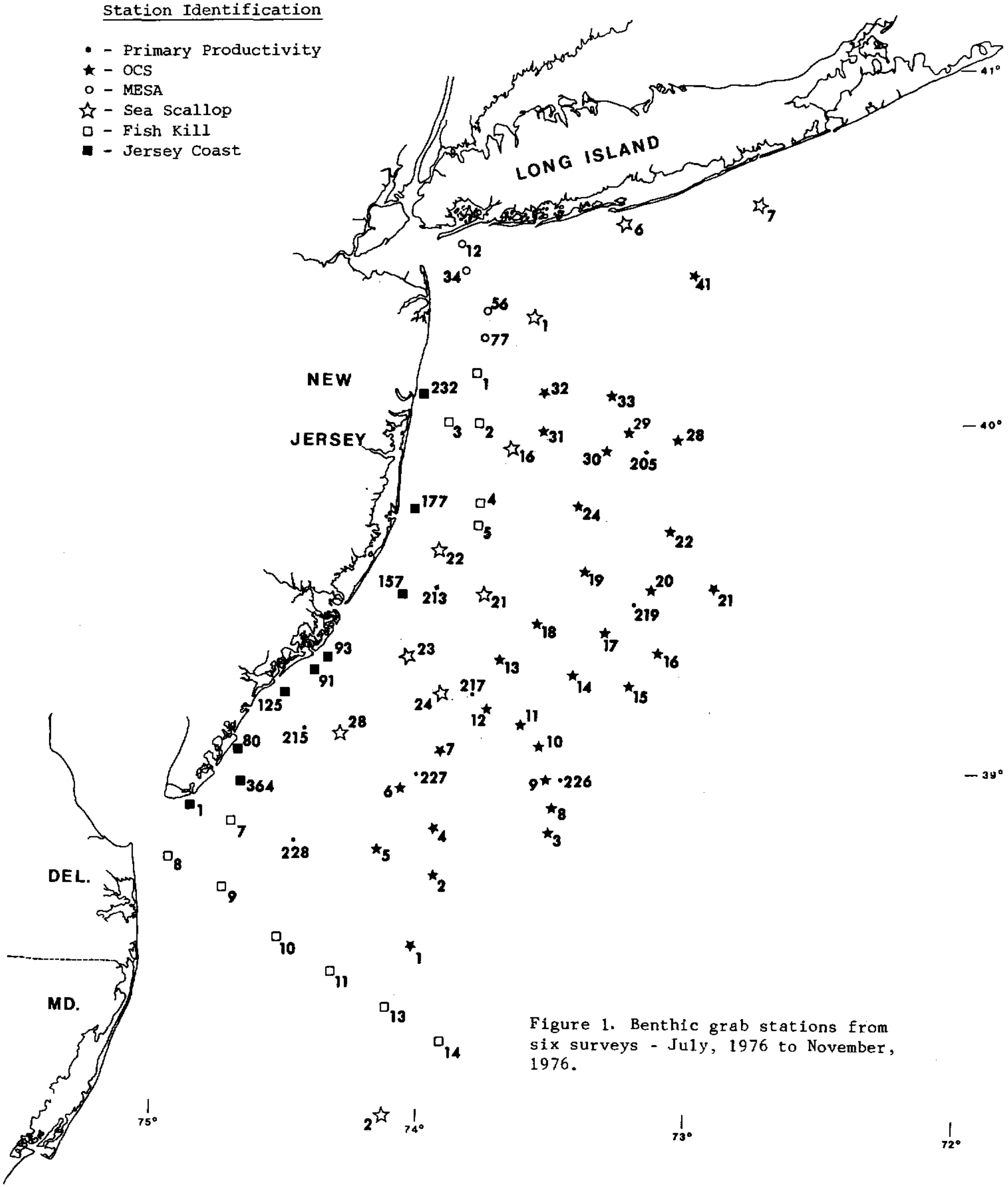

Figure 1. Benthic grab stations from six surveys - July, 1976 to November, 1976.

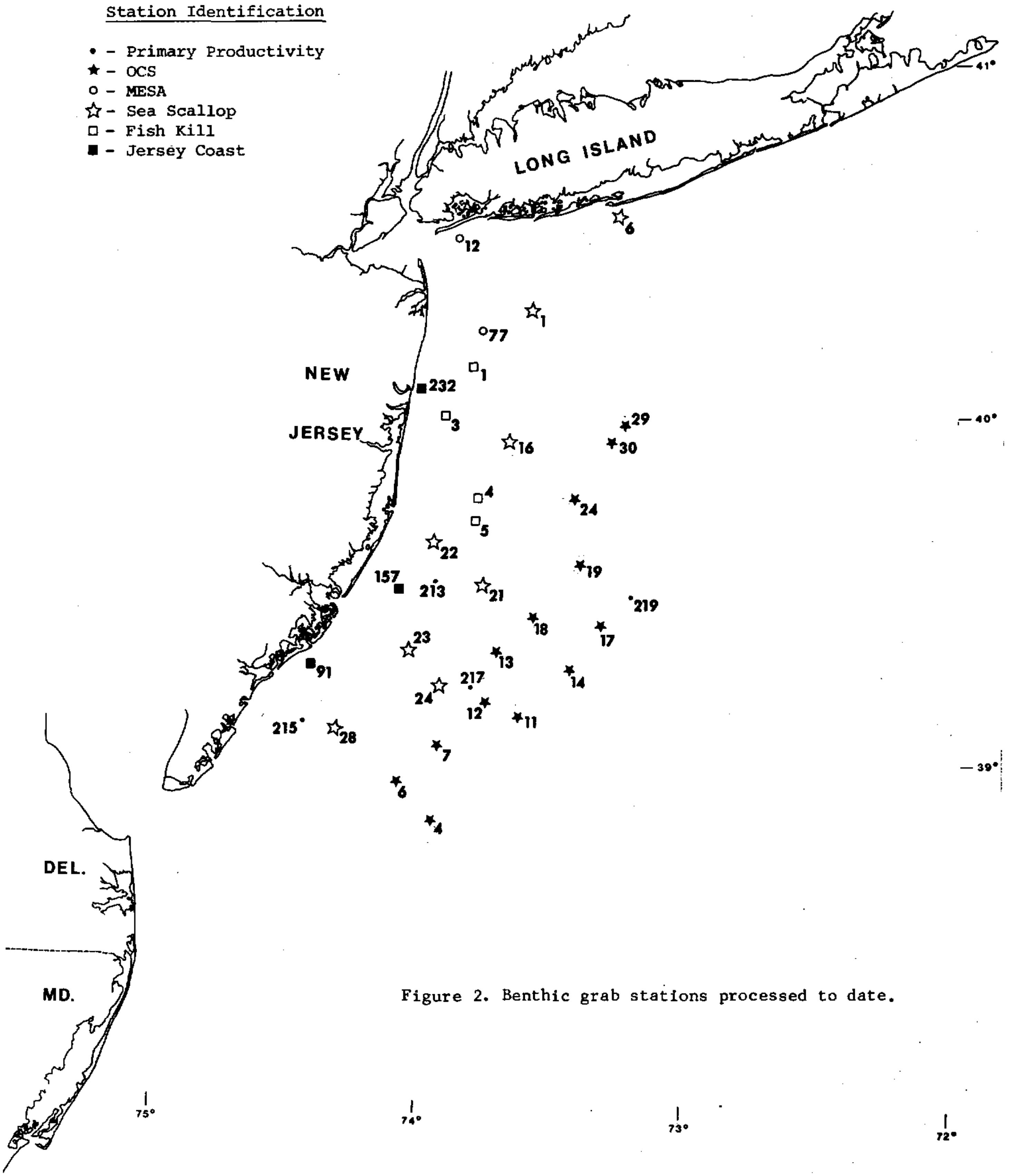

Figure 2. Benthic grab stations processed to date.

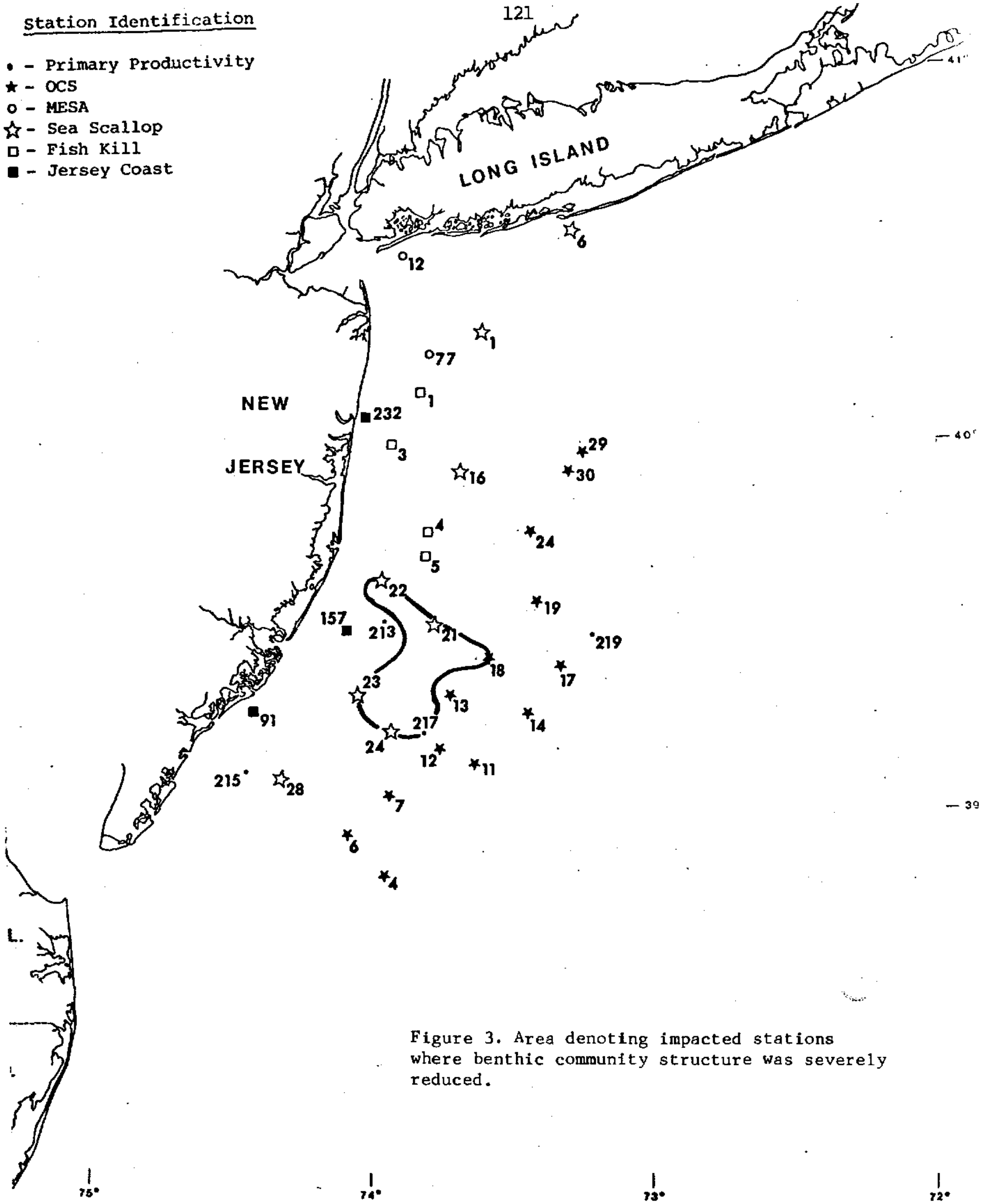

Figure 3. Area denoting impacted stations where benthic community structure was severely reduced.

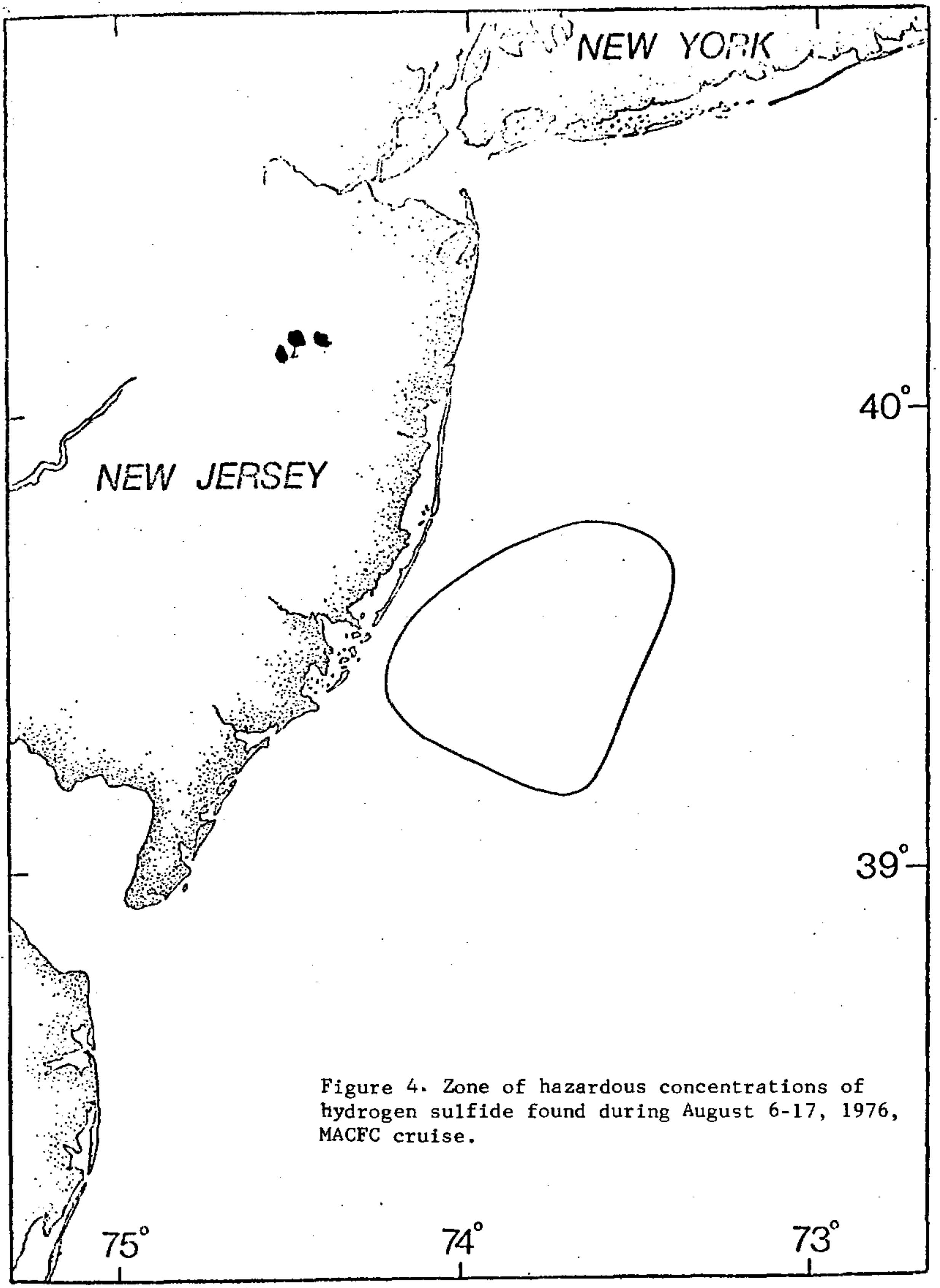

Figure 4. Zone of hazardous concentrations of hydrogen sulfide found during August 6-17, 1976, MACFC cruise.

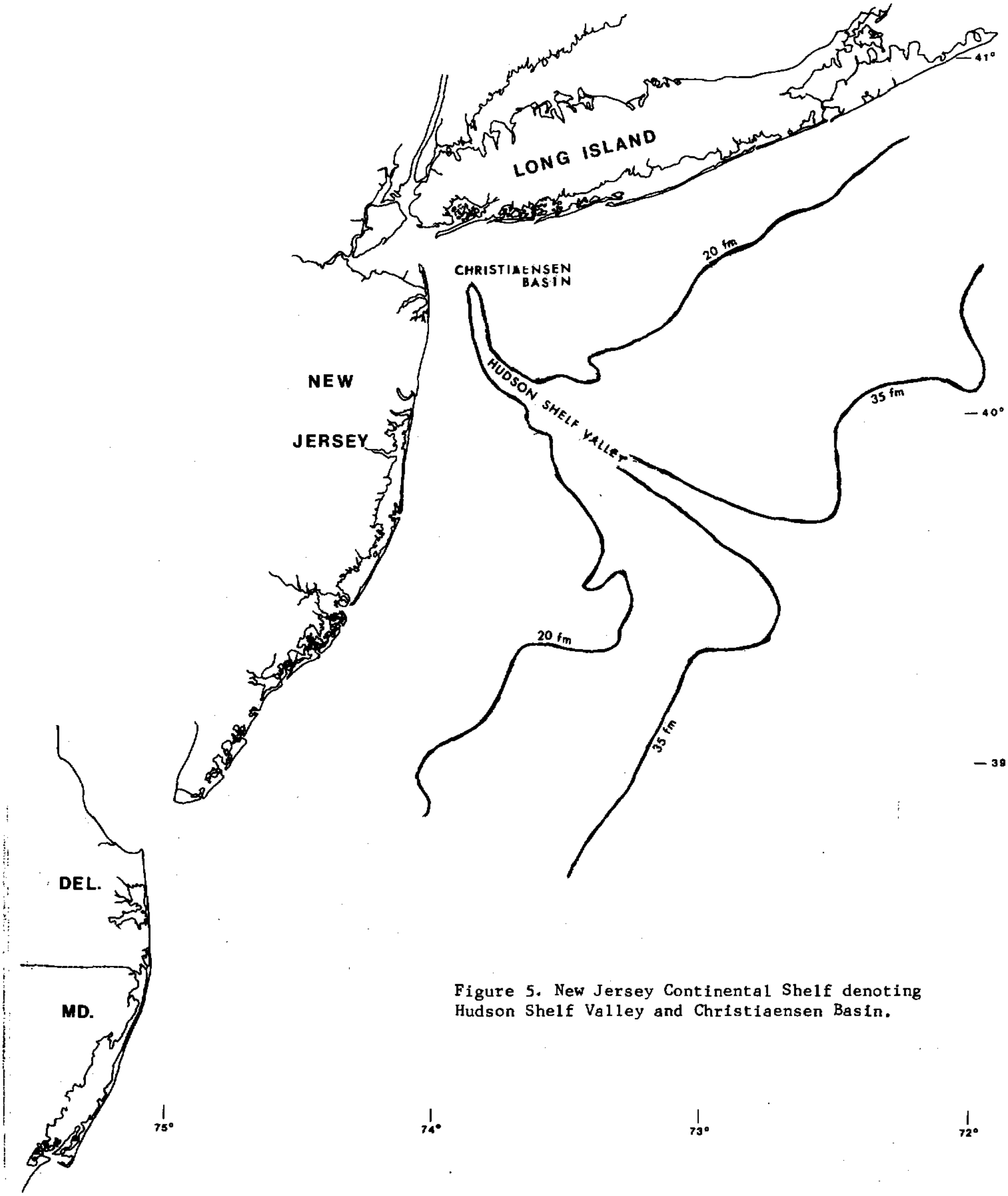

Figure 5. New Jersey Continental Shelf denoting Hudson Shelf Valley and Christiaensen Basin.

Table 1. Processed grab samples to date showing diversity (H'), total number of species (S), total number of individuals (N) and dates of collection.

Station No.	Grab	Diversity(H')	No. of Species(S)	Total Individuals(N)	Date
Primary Productivity (.)					
217	A	1.670	9	17	9/5/76
215	A	1.443	32	529	9/6/76
219	A	1.558	31	421	9/8/76
213	A	1.888	23	305	9/11/76
MESA (°)					
12	A	1.359	35	1194	7/30/76
77	A	2.399	27	530	7/30/76
77	A	3.058	56	705	8/25/76
OCS ( )					
29	A	1.603	54	1210	10/7/76
4	A	1.778	29	469	10/11/76
6	A	2.428	19	93	10/12/76
12	A	2.121	15	64	10/12/76
18	A	0.000	1	2	10/12/76
	B	1.893	11	50	10/12/76
19	A	1.312	14	210	10/12/76
24	A	1.683	15	125	10/12/76
7	A	2.728	19	37	10/13/76
30	A	3.084	53	868	10/15/76
11	A	1.459	17	543	11/11/76
13	A	1.621	24	562	11/11/76
	B	1.242	31	717	11/11/76
14	A	1.537	24	666	11/16/76
14	B	1.491	30	921	11/16/76
17	A	2.534	41	1001	11/16/76
	B	2.688	58	1058	11/16/76
Sea Scallop ( )					
1	A	2.572	19	43	10/9/76
6	A	2.357	21	179	10/10/76
16	A	1.951	13	61	10/11/76
21	A	1.189	4	33	10/12/76
	B	0.862	4	25	10/12/76
	C	1.079	5	33	10/12/76
22	A	1.030	3	10	10/12/76
	B	0.993	4	22	10/12/76
	C	1.314	5	12	10/12/76

Table 1 (cont). Processed grab samples to date showing diversity (H'), total number of species (S), total number of individuals (N) and dates of collection.

Station No.	Grab	Diversity (H')	No. of Species (S)	Total Individuals (N)	Date
Sea Scallop ( ) cont.					
23	A	0.314	4	30	10/12/76
	B	1.066	4	30	10/12/76
	C	1.190	4	22	10/12/76
24	A	1.304	7	57	10/12/76
	B	2.308	20	54	10/12/76
	C	0.925	8	63	10/12/76
28	A	2.276	20	93	10/15/17
Fish Kill ( )					
1	A	2.470	16	39	8/2/76
3	A	1.969	12	72	8/26/76
4	A	2.430	18	95	8/26/76
5	B	0.717	30	1139	11/18/76
Jersey Coast ( )					
232	B	2.327	24	136	8/2/76
	C	2.869	30	173	8/2/76
	B	2.563	20	70	8/27/76
91	A	0.910	20	608	11/18/76
157	A	1.426	11	164	11/18/76

Table 2. Comparison of (S), (N), and (H') for OCS cruises - April, 1975, versus October - November, 1976.

Station No.	Grab	1975 (S)	1976 (S)	1975 (N)	1976 (N)	1975 (H')	1976 (H')
4	A	27	29	370	469	1.344	1.778
6	A	26	19	626	93	1.355	2.428
7	A	16	19	113	37	1.928	2.728
11	A	19	17	118	543	2.176	1.459
12	A	19	15	52	64	2.451	2.121
13	A	14	24	37	562	2.279	1.621
14	A	24	24	157	666	2.312	1.537
	B	N/A	30	N/A	921	N/A	1.491
17	A	25	41	116	1001	2.502	2.534
	B	N/A	58	N/A	1085	N/A	2.688
18	A	23	1	40	2	2.752	0.000
	B	N/A	11	N/A	50	N/A	1.893
19	A	10	14	23	210	1.833	1.321
24	A	21	15	174	125	1.673	1.683
29	A	35	54	487	1210	2.266	1.603
30	A	65	53	650	868	3.409	3.084

S = Number of Species

N = Total No. of Individuals

H'= Diversity

APPENDIX II

A PRELIMINARY ASSESSMENT OF THE IMPACT OF THE 1976, N. Y. BIGHT OXYGEN DEPLETION PHENOMENON ON THE BENTHIC INVERTEBRATE MEGAFAUNA.

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Introduction

The benthic megafauna was one of the first groups of organisms observed to be affected by the anoxic phenomenon in the New York Bight during the summer-fall of 1976. The initial reports of the phenomenon came from sport divers (Steimle, 1976; Bulloch, 1976) during the July 3-5, 1976 weekend. They reported dead fish and invertebrates on and near various wrecks and other diving spots off the north-central New Jersey Coast. The invertebrate mortalities consisted mostly of rock crabs, *Cancer* sp., starfish, *Asterias forbesi*, and lobsters, *Homarus americanus*; these were found lying on the bottom around wrecks, occurring in a zone extending from Long Branch to Barnegat Inlet and from approximately 3 to 25 miles offshore. Lobsters, which are usually very secretive and territorial during the day, were observed, alive but very sluggish, lying exposed out of their holes with some reports of lobsters sharing holes. These observations of abnormal behavior patterns are good evidence of stress. The weekend prior to this, June 27, divers observed apparently healthy lobsters and crabs congregated on the highest parts of the same, or nearby wrecks, again indicative of stressful conditions in the water column at the bottom, 20-30 meters deep. Surf clams, Spisula solidissima, were also observed lying on or near the surface, a condition also considered indicative of stress, e.g., hypoxia (Savage, 1976). Similar megafauna mortalities, (beginning July 17), were also reported by sport divers on wrecks off Atlantic City.

Surveys to assess and define the extent of the effects of the phenomenon on fish and shellfish were begun within a few days of the initial diver reports, Table 1. Although resource species were the primary targets of the assessments, much data were also collected on benthic megafauna, which indicate significant effects not evident in finfish or benthic infauna assessments. Several crustaceans and shellfish, although resource species dealt with in detail in the fisheries workshop summary, are reexamined because they dominate, or are representative of impacted communities.

During July, there were six assessment surveys, Cruises A-F (Table 1) off the N. J. Coast, using a variety of equipment (Byrne and Silverman, 1976; Ropes, 1976a). These cruises sampled a total of 24 stations between Sandy Hook and Atlantic City and between 2 and 25 miles offshore. Combined cruise results indicate that the benthic megafauna in a small area, 3-6 miles east-northeast of Barnegat Inlet, was severely impacted, (greater than 50% total mortalities) (Figure 1). The surf clam, Spisula solidissima, was the most severely impacted species with 100% mortality at some stations. Other observed mortalities included the rock crabs, Cancer irroratus and C. borealis, starfish, Asterias forbesi, moon snail, Lunatia heros, mud shrimp, Axius serratus, the lobster, Homarus americanus, sea scallop, Placopecten magellanicus, the sand dollar, Echinarachnius parma, mantis shrimp, Squilla sp., polychaetes, razor clam, Ensis sp., sea cucumber, Thyone sp., ocean quahog,

Table 1. List of cruises, used to assess benthic megafauna, by dates, vessel, type of gear used, length of tow, and vessel speed.

Cruise	Date (1976)	Vessel	Type of gear used to sample benthic megafauna	Length of tow	Speed (knots)
A	July 8	R/V Rorqual	Otter trawl, 30 ft chain sweep, no liner	15 min.	3.0
B	July 9	R/V Xiphias	" " "	" "	"
C	July 13-15	Comm. Trawler- "Grande Larson"	" , 70 ft chain sweep, no liner	" "	3.0-3.5
D	July 20-22	R/V Rorqual	" , 30 ft chain sweep, no liner	" "	3.0
E	July 27	Comm. Clammer- "Harold F. Snow"	Commerical surf clam pump-dredge, 5 ft wide	5-15 "	1.0
F	July 28-30	R/V Xiphias	Otter trawl, 30 ft chain sweep, no liner	15 "	3.0
G	Aug. 6-8	Comm. Clammer- "Valerie E"	Commerical surf clam pump-dredge, 5 ft wide	4 "	1.0
H	Aug. 6-17	Atlantic Twin	Otter trawl (3/4 Yankee) 54 ft sweep	15 "	3.0-3.5
I	Sept. 9-14	Comm. Clammer- "Gail and C. M-Snow"	Commercial surf clam pump-dredge, 5 ft wide	4 "	1.0
J	Sept. 28-Oct. 15	R/V Albatros IV	Otter trawl (#36) 80 ft sweep with rollers and 1/2 inch liner	30 "	3.5
K	Oct. 6-15	Atlantic Twin	Scallop dredge, 10 ft wide	15 "	3.5
L	Oct. 7-8	Comm. Clammer- "Margret and Nancy"	Commercial surf clam pump-dredge, 5 ft wide	4 "	1.0
M	Nov. 8-17	R/V Kelez	"Digby" dredge, 2 ft wide	15 "	1.0

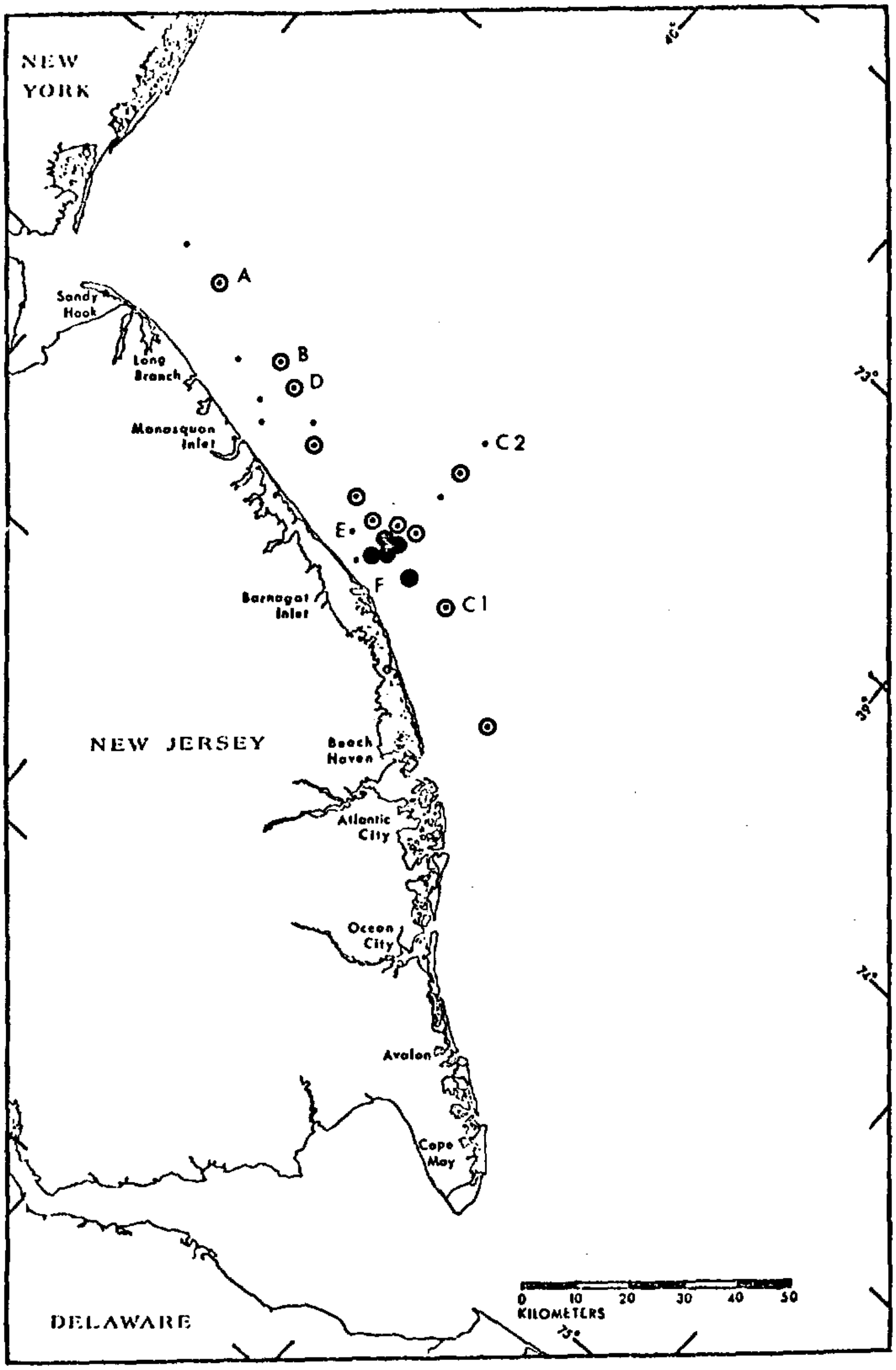

Figure 1: Summary of benthic megafauna impacts during July, 1976. Period (.) indicates a station where no mortalities were evident, "◎" indicates moderate (less than 50% total mortalities) effect, and "●" indicates severe (greater than 50% mortalities) effects.

Arctica islandica, and the burrowing anemone, Ceriantheopsis americanus. Moderate (less than 50% total mortalities) impact was found over a wider area, from Long Branch to at least Beach Haven, and between 3 and 20 miles offshore (Fig. 1), involving some of the same species. During July, many other organisms were collected, alive, in trawls, but in an obviously stressed state, i.e., burrowing organisms (polychaetes, mud shrimp, mantis shrimp, sea cucumbers, sipunculoid worms and bivalves), which are not normally collected in trawl nets. Very little impact was observed within two miles of the shore, except during two short periods of apparent upwelling near the shore, which caused some mortalities near Manasquan Inlet and Beach Haven.

Two major assessment cruises in August (cruises G and H, Table 1) sampled a wide distribution of stations (Fig. 2) from Sandy Hook to Delaware, and out to 35 miles offshore for a total of 120 stations. Severely impacted areas were found from off Barnegat Inlet to off Beach Haven Inlet (Ropes, 1976b,c; Azarovitz et al., 1976). Moderate impact was found at some stations from Barnegat to Cape May. As in July, the surf clam mortalities were the most significant, with other mortalities being found among the same species as reported above. Unattached surf clam meats were often found in the trawl netting during this month's collections.

The dredge survey of September (Cruise I - Table 1) indicated continued severe impacts, Fig. 3 (Ropes, 1976c,d). Again surf clams were most impacted, although ocean quahog mortalities were increasing. The second part of this September survey, not listed in Table 1, did not find

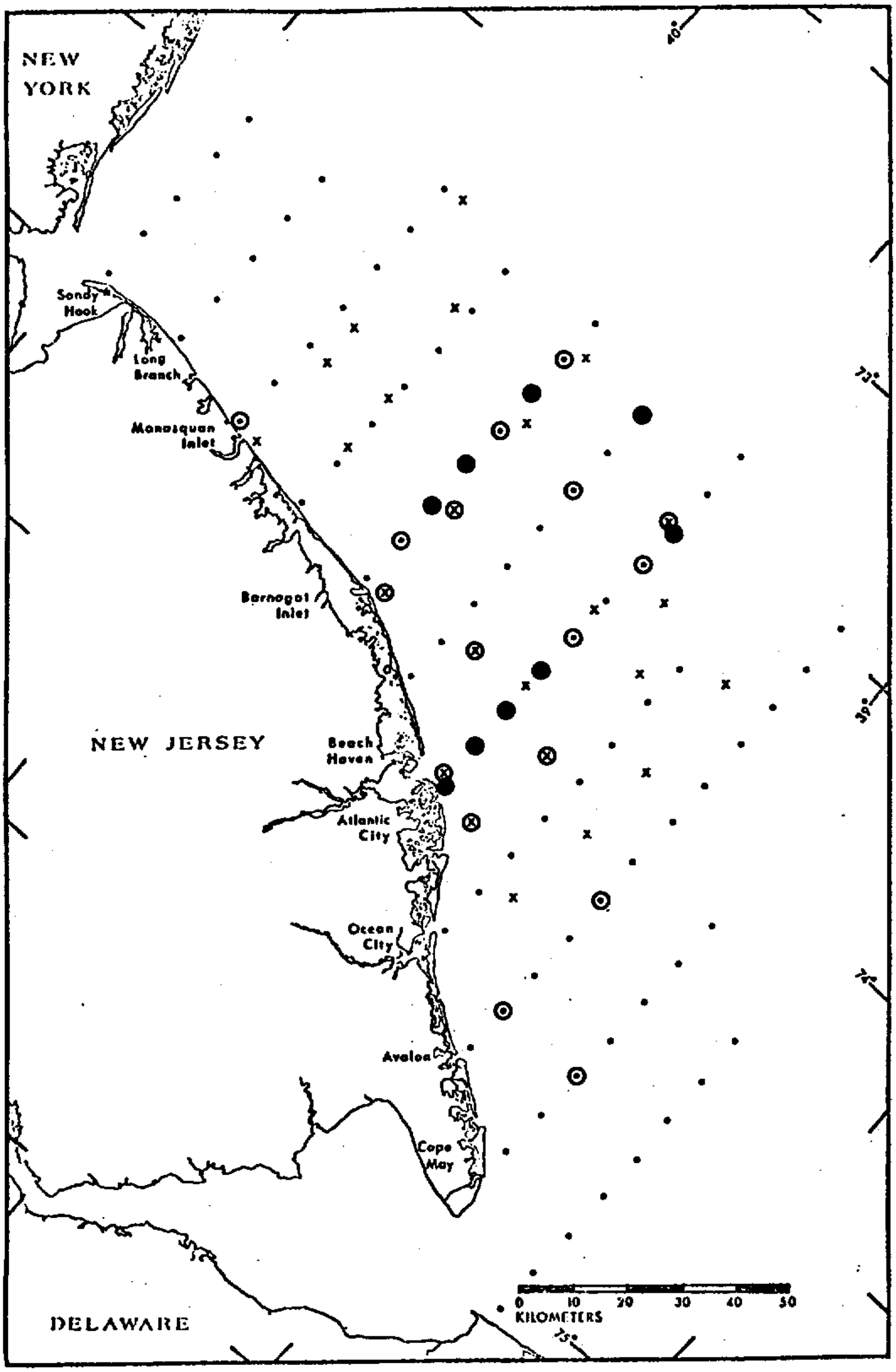

Figure 2: Summary of benthic megafauna impacts during August, 1976. "•" = uneffected stations of cruise H, "x" = uneffected stations of cruise G; "O" = moderately impacted station, "●" = severely impacted station.

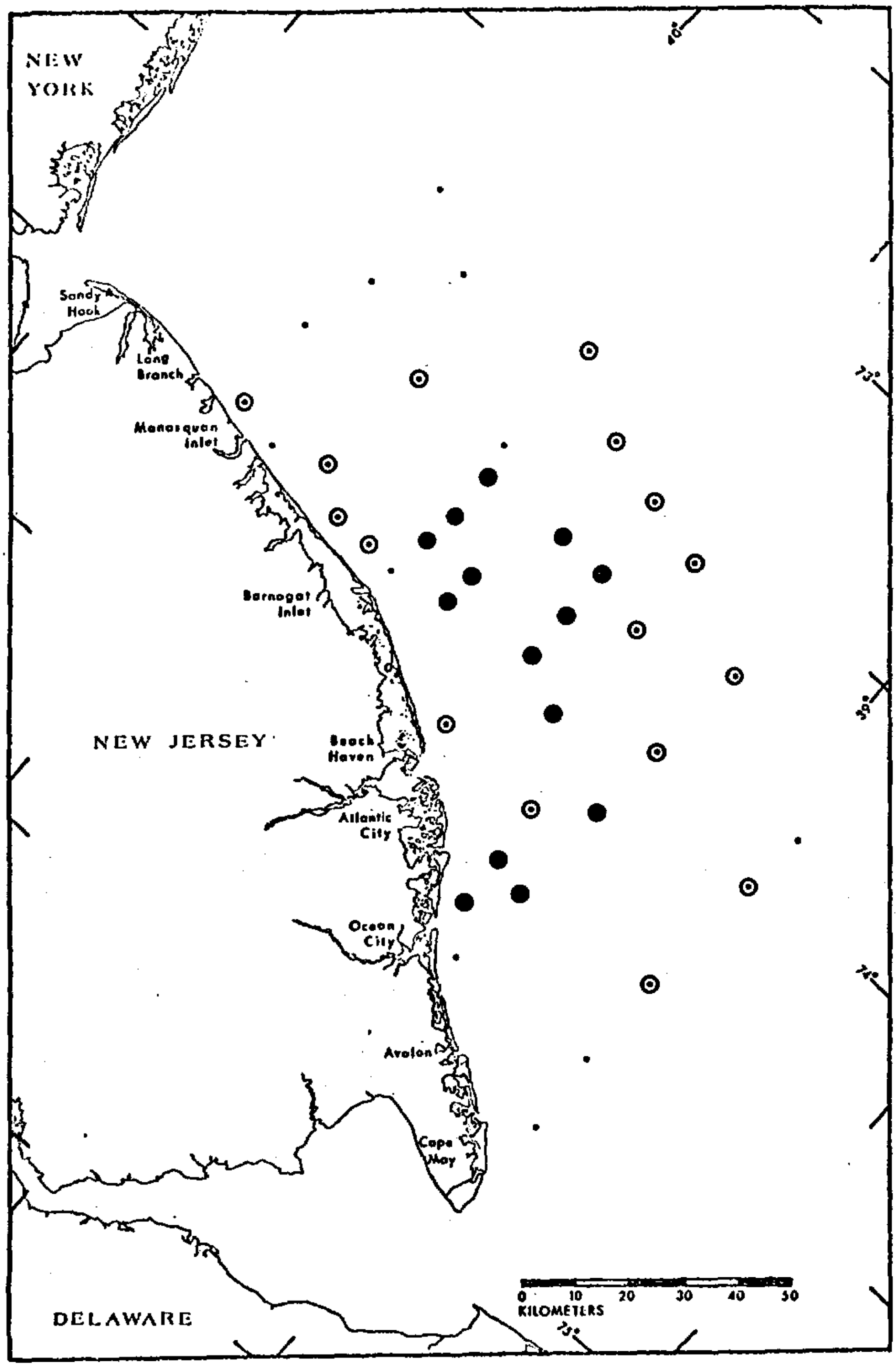

Figure 3: Benthic megafauna impacts for Cruise I, September, 1976. "•" = uneffected stations, "⊙" = moderately effected stations and "●" = severely impacted stations.

any megafauna mortalities in a survey area including the south shore of Long Island to the Hudson Shelf Valley.

The three assessment cruises of October (cruise J, K, L - Table 1) found continued scattered impacts, Fig. 4 (Ropes, 1976e; MacKenzie, 1976a; MacKenzie and Radosh, 1976; Azarovitz et al., 1976). Of significance were oxygen depleted water in that direction (Steimle, 1976). There was also an additional increase in the numbers of dead ocean quahogs and sea scallops being found, especially in a zone 20-30 miles off Barnegat to 45 miles off Cape May.

The November cruise found the impact area (Fig. 5) to extend from Manasquan Inlet to Cape May, as evidenced by mostly clapper razor clams and ocean quahogs being found (MacKenzie, 1976b; MacKenzie and Radosh, 1976). There was some evidence of recolonization of cancer crabs and starfish, collected at stations which had been previously affected.

A summary of megafauna species known to have been impacted is presented in Table 2; a complete listing of data is presented in Table 3 (as an appendix). The bivalves were particularly affected. Many of the more mobile crustaceans may have been able to avoid the situation by moving into areas of sufficient dissolved oxygen. A more detailed discussion of the impacts on species important to fisheries is presented in the Fisheries Workshop Summary.

The large amount of decaying biomass created by the mortalities could very well contribute to maintaining a depressed dissolved oxygen level in the most severely impacted areas. Whether this oxygen demand would be greater than the respiratory demand of the organisms, if they were still alive, is not known at this time.

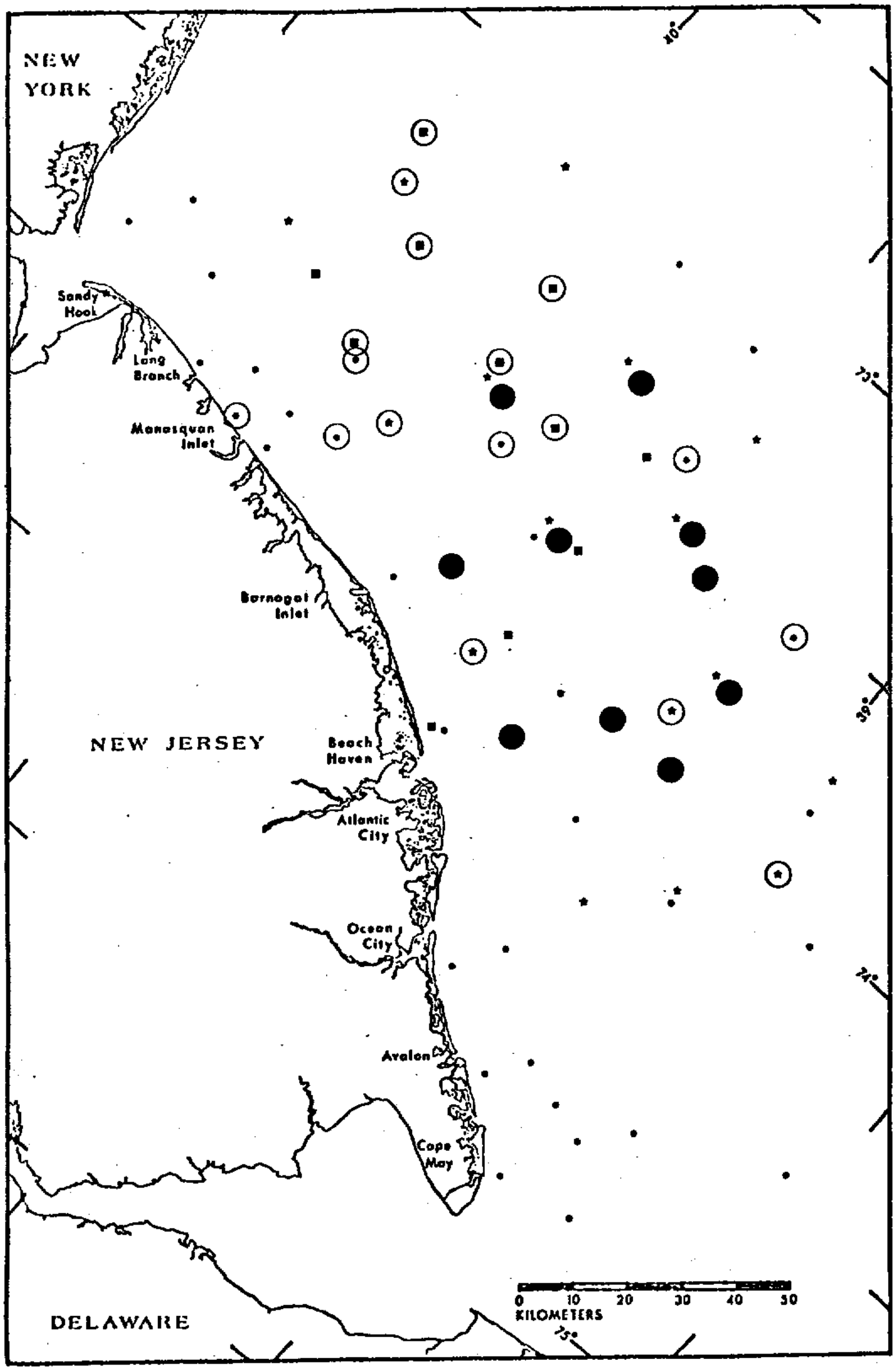

Figure 4: Summary of benthic megafauna impacts in October, 1976. "•" = uneffected ~~Cruise J~~ station, "*" =uneffected cruise K station, "■" = uneffected Cruise L stations; "○" = moderate impact, "●" = severe impact.

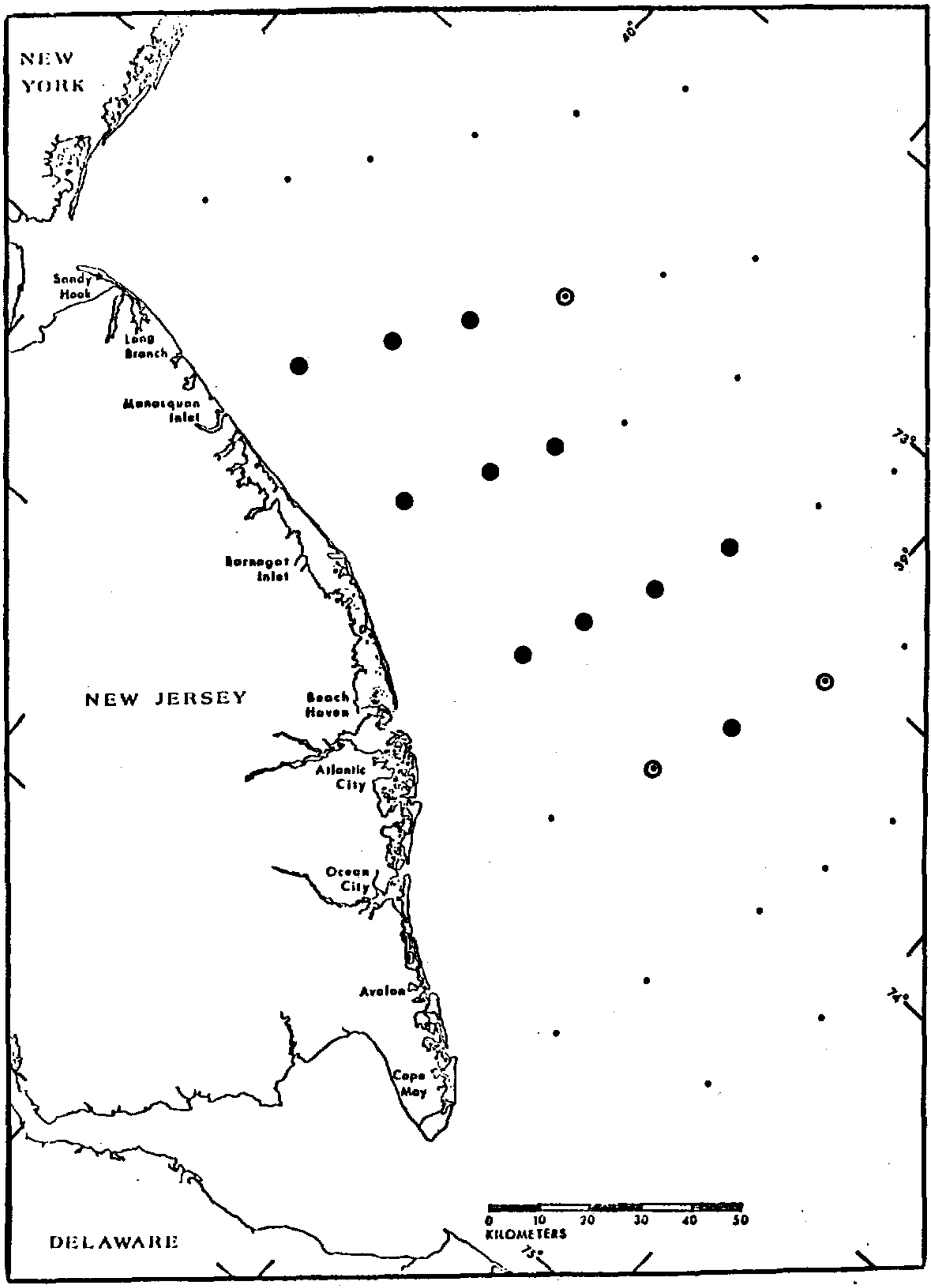

Figure 5: Benthic megafauna impacts for Cruise M, November, 1976
"•" = uneffected station, "◎" moderately impacted stations, and
"●" = severely impacted stations.

Table 2. List of benthic megafauna species known to have been mortalities, with common names and comments on extent of impact.

Species	Common name	Comments
Ceriantheopsis americanus	burrowing anemone	a few were observed by divers and collected by trawl surveys
Unidentified polychaetes	marine worms	100's were collected hanging from trawl net mesh
Axius serratus	mud shrimp	a few were collected in trawl collections
Squilla sp.	mantis shrimp	" "
Libinia sp.	spider crab	" "
Cancer irroratus	rock crab	100's were reported dead by divers and collected in surveys
Cancer borealis	Jonah crab	dozens were reported dead by divers and collected in surveys
Homarus americanus	American lobster	dozens were reported dead by divers and collected in surveys
Mytilis edulis	blue mussel	1000's were reported dead on wrecks by divers
Placopecten magellanicus	sea scallop	dozens dead and recent empty clappers were collected in surveys
Astarte sp.		a few were collected in surveys
Arctica islandica	ocean quahog	100's were collected dead or as recent empty clappers in surveys especially in the fall and offshore
Spisula solidissima	surf clam	1000's of dead clams, and clappers and bushels of unattached meats were collected during surveys
Ensis directus	razor clam	dozens of dead or recent clappers found in surveys
Lunatia heros	moon snail	several were collected dead in surveys
Asterias forbesi	starfish	hundreds were reported dead by divers and collected in surveys
Echinarachnius parma	sand dollar	100's were collected dead in surveys
Thyone sp.	sea cucumber	a few " " " " "
Sipunculoids		a few were collected in trawl surveys

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TABLE 3. A list of stations per cruise, indicating location, sample depth, bottom water temperature and dissolved oxygen (D.O.) and condition of invertebrate megafauna collected. (C = clappers, recently dead paired shells). S = weak organisms obviously stressed.)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	L I V E	Dead
CRUISE A							
	40.26.2	73 47.2	27	10.5	1.10	22 *C.irroratus*, 6 *C.borealis* 1 *Libinia* sp., 3 *Homarus*, 2 *Lunatia*, 2 *Pagurus* sp.	0
	40.19.8	73 46.8	31	9.5	6.40	4 *C.borealis*, 3 *Homarus*, 7 *Lunatia*, 3 *E.parma*, 2 *Aphrodite* sp.	2 *C.irroratus*, 2 *C.borealis* 3 *Asterias*
	40.10.2	73 54.2	18	20.4	N.A.*	10 *C.borealis*, 3 *Lunatia*, 5 *Pagurus* sp., 10 *E.parma*	0
CRUISE B							
	40 09.2	73 53.5	21	11.1	4.40	8 *C.irroratus*, 50 *Asterias*, 6 *Lunatia*, 30 *E.parma*	0
	40.11.0	73 48.5	30	9.0	2.80	1 *C.borealis*, 14 *C.irroratus*, 4 *Homarus*, 1 *Placopecten*, 50 *Asterias*, 6 *Lunatia*, 20 *E.parma*	1 C.irroratus, 20 Spisula (C)
CRUISE C							
	39 25.5	74 04.5	21	12.0	1.4	10 *C.irroratus*, 1 *Ovalipis ocellatus*, 25 *Asterias*, 5 *Lunatia*, 4 *Thyone* sp.	0
	39 38.0	73 56.5	24	10.8	0.00	3 *C.irroratus*, 100 *Asterias*, 15 *Lunatia*, 50 *Spisula* (S)	9 *C.irroratus*, 1 *Lunatia*

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE C (continued)							
	39 48.0	73 54.0	24	10.5	0.00	4 *C.irroratus*, 1 *Axius* (S), 11 *Lunatia*, 25 *Spisula*	2 *Spisula*, 1 *Lunatia*, 6 *C.irroratus*
	39 58.0	73 15.5	26	10.1	0.30	6 *C.irroratus*, 6 *Asteria*, 3 *Lunatia*, 50 *Spisula* (S)	10 *C.irroratus*
	39 51.5	73 45.0	30	10.5	0.05	3 *C.borealis*, 8 *C.irroratus*, 12 *Spisula*, many *Modiolus* sp. some *Axius*	6 *C.irroratus*, 1 *Homarus*, 1 *Placopecten*, 1 *Spisula*, some *Axius*
	39 55,5	73 30.5	39	8.5	1.55	2 *C.irroratus*, 30 *Placopecten*, many *Asterias*, 8 *Lunatia*, some *E.parma*, 2 *Aphrodite* sp., unidentified polychaetes (S)	1 *C.borealis*, 3 *C.irroratus*
	39 57.0	73 25.0	47	9.3	1.65	2 *C.irroratus*, 6 *Placopecten*, some *Asterias*, *Pagurus* sp. and unidentified polychaetes	0
CRUISE D							
	40 01	73 50.5	24	7.6	1.25	1 *C.irroratus*, 7 *Spisula*, some *Asterias* and *E.parma*	1 *C.irroratus*, 1 *Placopecten*, 26 *Spisula* (C), some *Asterias* and *E.parma*
	39 49	73 52.3	24	9.0	0.00	26 *Spisula*, 6 *Lunatia*, 1 *Ensis* sp.	52 *Spisula* (C), some *C. borealis*, *C.irroratus*, *Axium*, *Squilla* sp., unidentified polychaetes, 12 *Ensis* (C)
CRUISE E							
	39 52.5	74 01	16	14.5	3.86	2.5 bushels Spisula	1 *Spisula*, 12 *Spisula* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE E (continued)							
	39 50.5	74 01	16	21.0	N.A.*	5.0 bu. Spisula	13 Spisula
	39 48.5	74 00.6	20	17.5	1.85	4.5 bu. Spisula, 1 Limulus, 1 C.irroratus, 6-8 Sipunculid	1.3 bu. Spisula, 1.3 bu. Spisula (C)
	39 44	74 00.4	22	12.5	1.00	30 bu. Spisula	40 bu. Spisula
	39 48.5	74 04.5	11	20.5	N.A.*	4.25 bu. Spisula, 6 Limulus 5 O.ocellatus, 2 Libinia sp.	0
	39 51.4	74 02.7	9	20.5	N.A.*	60 bu. Spisula, 1 Lunatia, 1 O.ocellatus	0
CRUISE F							
			22	14.0	2.83	23 C.irroratus, 24 Asterias, 24 E. parma	0
			29	11.5	2.50	12 C.irroratus, 2 Placopecten, 4 Lunatia, 12 Asterias	2 Placopecten
			22	12.5	1.85	2 Spisula, 7 Lunatia, 1 E. parma, 3 unidentified polychaetes	22 Spisula, 2 C.irroratus 3 E.parma, many polychaetes. some Squilla sp. and Thyone sp.
			26	11.9	1.60	5 Spisula, 7 Thyone sp.	23 Spisula, 41 C.irroratus 12 Ensis sp. 1 Arctica, 2 unidentified pelecypods, 4 Squilla sp., 4 E.parma, 1 Thyone sp., 100's of polychaetes, some Ceriantheopsis.

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE G							
	39 28	74 15.5	13	15.6	1.69	365 *Spisula*, 1 *Limulus*	17 *Spisula* (C)
	39 28	74 00.5	24	12.9	0.00	30 *Spisula*, 1 *Libinia* sp.	0
	39 28	73 47.5	31	12.0	N.A.	12 *Spisula*, 3 *Arctica*, 1 *C. irroratus*	1 *Spisula*, 1 *C. irroratus*
	39 36	74 00.5	24	11.9	0.89	18 *Spisula*	6 *Spisula* (3-C)
	39 44.5	74 04	14	13.5	2.92	12 *Spisula*, 3 *Arctica*	3 *Spisula* (2-C)
	39 44.5	73 51.5	26	11.6	0.00	18 *Spisula*	4 *Spisula* (2-C)
	39 45	73 39	34	12.5	1.25	7 *Spisula*, 32 *Arctica*	1 *Spisula*
	39 56	73 44	32	8.8	2.10	2 *Arctica*	0
	39 56	73 57	21	11.5	2.89	64 *Spisula*	0
	40 05	74 01	16	12.6	2.43	14 *Spisula*	0
	40.04.5	73 47	29	9.9	1.91	44 *Spisula*, 5 *Arctica*	1 *Arctica* (C)
	40 05	73 40.5	37	9.4	2.63	5 *Spisula*, 54 *Arctica*, 1 *C. irroratus*, 1 *Asterias*	0
	40 05	73 21.5	40	7.7	3.40	128 *Arctica*, 1 *C. irroratus*	4 *Arctica* (C)
	39 57	73 31	37	8.4	2.61	234 *Arctica*	2 *Arctica* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	A l i v e	D e a d
CRUISE G (continued)							
	39 44.5	73 26	33	9,4	1,24	3 *Spisula*, 12 *Arctica*	1 *Spisula* (C)
	39 37.5	73 40	34	11.4	0.00	6 *Spisula*, 15 *Arctica*, 12 *Mytilus*	2 *Spisula* (1-C), 1 *Ensis* (C)
	39 28	73 35	34	11.0	0.00	45 *Arctica*	1 *C.borealis*, 1 *Placopecten* (C)
	39 22.5	73 43	34	12.3	1.10	36 *Spisula*, 212 *Arctica*, 1 *C.irroratus*, 1 *Lunatia*	2 *Spisula*
	39 13	73 44	41	11.6	2.73	73 *Arctica*	0
	39 13	73 59	26	13.6	1.90	3 *Spisula*, 5 *Arctica*, 1 *C. irroratus*, 1 *O.ocellatus*, 1 *Asterias*	0
	39 19.5	73 50.5	33	12.4	0.00	6 *Arctica*, 1 *Placopecten*	0
	39 20.5	74 05.5	24	14.0	0.00	44 *Spisula*, 14 *Arctica*	23 *Spisula*, 1 *Libinia* sp.
	39 13	74 09	23	15.2	2.61	51 *Spisula*, 4 *Arctica*	0
	39 14	74 21.5	18	16.0	2.36	38 *Spisula*, 1 *B.canaliculatum*	0
	39 22.5	74 18	16	15.2	2.11	17 *Spisula*, 1 *Placopecten*	4 *Spisula*

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE H	(Stations 9-25, Pre-hurricane Belle; 28 and after were post-hurricane)						
9	40 10.5	73 59	17	10.4	4.01	2 *O.ocellatus*	1 *C.irroratus*
10	40 10.5	73 53.5	21	10.3	4.80	3 *C. irroratus*	0
11	40 10	73 46.8	30	8.4	1.80	1 *Aphrodite*, 1 portunid crab	0
12	40 10	73 40.2	57	6.8	2.55	0	0
13	40 10	73 33.9	37	7.4	3.00	14 *C.irroratus*, 1 *Placopecten* - *Asterias*, *E.parma* 8 shrimp (?)	0
14	39 50	73 26	37	7.5	1.50	1 *C.irroratus*	1 *Placopecten* (meat only)
15	39 50	73 20	44	7.6	1.70	2 *C.irroratus*, 47 *Placopecten*	0
17	39 50	73 33.2	34	7.7	1.59	1 *Lunatia*	1 *C.irroratus*, 2 *Spisula* (meat only), 1 (shrimp?) 2 *Ensis*
18	39 50.1	73 38.5	33	8.3	1.46	1 *Spisula*	1 *Spisula* (meat only)
19	39 50	73 45.2	28	8.1	1.48	0	4 *Spisula* (3-C) meat only).
20	39 49.9	73 52.2	27	9.5	2.25	0	*C.irroratus*, 4 *Spisula*, *Axius*
21	39 50	73 58.3	23	10.4	2.66	5 *O.ocellatus*, *Asterias*, *polychaetes*	*Spisula* (meats only)
22	39 44.8	74 05.2	12	12.8	2.30	1 *O. ocellatus*, 1 *Limulus*	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE H (continued)							
23	39 39	74,08.5	17	11.1	0.00	1 *Spisula*, polychaetes	1 *C.irroratus*, 5 *Spisula* (3-C), polychaetes
24	39 30	74 02	28	10.8	0.00	1 *Spisula*	1 *C.irroratus*, 8 *Spisula* (7-C), polychaetes, 3 (shrimp?)
25	39 30	73 55.7	25	11.1	0.00	2 *Spisula*, polychaetes *Limulus*	6 *Spisula* (3-C), 2 *Axius* polychaetes.
28	39 30	74 14.8	14	18.3	4.91	0	3 *Spisula* (C), *Limulus*
29	39 30	74 08.5	18	17.4	4.80	Polychaetes (S)	*Spisula* (meats only)
30	39 30.1	74 01.7	23	15.0	4.16	1 *Lunatia*, 1 *Limulus*	0
31	39 30	73 55.7	26	13.0	2.90	0	0
32	39 31.2	73 48.3	34	11.8	0.37	11 *Spisula*	2 *Spisula* (C), 1 *Axius*, Polychaete
33	39 30	73 42.2	33	10.6	0.00	1 *Spisula*, 1 *Axius*, polychaete	0
34	39 29.9	73 36.6	34	10.3	0.00	3 *Spisula*, 1 *Lunatia*, polychaetes	1 *Spisula*
35	39 31	73 28.5	35	10.2	1.01	30 *Lunatia*	1 *C.borealis*, 1 *C.irroratus* 5 *Placopecten* (3-C) 1 *Spisula*. 1 *Squilla*.

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE H (continued)							
36	39 30	73 21,5	37	12.2	1.17	3 *C.irroratus*, 13 *Lunatia*	0
37	39 30	73 14	40	8.7	1.80	7 *C.irroratus*, 19 *Lunatia*, 2 *Aphrodite*, 3 *Ensis*	0
40	39 10.5	73 27	50	7.9	1.26	2 *C.borealis*, 15 *C.irroratus* *Asterias*, *Lunatia*, *E. parma* *Aphrodite* (Shrimp?) 1 *O. guadalpensis*	0
41	39 10	73 32	43	8.2	0.80	1 *C.borealis*, 322 *C.irroratus*, 1 *Homarus*, 6 *Lunatia*, 4 *Pagurus*	0
42	39 10	73 41	34	9.4	0.85	83 *C.irroratus*, 2 *Placopecten*, 2 *Lunatia*, 1 *Aphrodite*, 2 *O. guadalpensis*	0
43	39 10	73 47.5	36	11.8	1.90	51 *C.irroratus*, 1 *Homarus*, 2 *Placopecten*	0
44	39 10	73 53.8	43	11.0	1.40	218 *C.irroratus*, 5 *O.ocellatus*, 1 *Placopecten*, - *Aphrodite*	0
45	39 10.3	74 01	38	11.0	1.03	1 *C.borealis*, 10 *C.irroratus*, 9 *O.ocellatus*, 11 *Spisula*, 6 *Lunatia*, 1 *Squilla*	0
46	39 10.4	74 06.9	29	13.2	0.35	4 *C.irroratus*, 9 *O.ocellatus*, 3 *Spisula* - *Asterias*, *E.parma*	0
47	39 10.6	74 13	27	15.6	1.11	1 *C.borealis*, 1 *C.irroratus*, 10 *O.cellatus*, 11 *Spisula*, 10 *Asterias*, 3 *Aphrodite*, 1 *Limulus* 1 *O.guadalpensis*	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE H (continued)							
48	39 10	74 20	23	17.2	2.10	26 O.ocellatus, 1 Spisula, 2 Lunatia, 1 B. Canaliculatum	0
49	39 10	74 26.4	20	18.1	2.58	4 O.ocellatus	1 Spisula
50	39 10	74 32.9	17	18.4	4.22	1 C.borealis, 1 Spisula, 16 Limulus, 1 B.canaliculatum, many Thyone sp.	2 C.irroratus, 5 Spisula (3-C)
51	39 10	74 39.3	10	18.6	3.20	2 O.ocellatus, 487 Limulus, 1 Libinia	0
52	39 01	74 44.4	14	20.2	5.61	6 Libinia sp.	0
53	39 01.6	74 38.4	15	20.3	6.04	26 O.cellatus, 14 Limulus, 9 Libinia	0
54	39 00	74 32.5	16	18.5	6.34	7 O.ocellatus,- Lunatia, 2 Limulus	3 Spisula (2-C)
55	38 50	74 50.8	16	18.9	6.09	1 C.irroratus,- Asterias, 6 Limulus, 1 B.canaliculatum, 11 Libinia, 3 B.carica	0
56	38 51	74 37.9	16	17.6	6.51	2 Limulus, 10 O.guadalpensis, 1 Libinia	1 Spisula (C)
57	38 50.8	74 27.1	20	17.7	5.72	5 O.ocellatus, 30 Asterias, 1 Limulus	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE H (continued)							
58	38 51	74 12.5	34	10.7	4.72	21 C.irroratus, 2 Homarus - *Pagurus*, 2 *O. guadalpensis*,	0
61	38 50	74 00	44	9.9	4.65	77 *C.irroratus*, shrimp (?)	2 *Arctica* (C)
63	38 51	73 45	47	8.6	2.10	48 *C.irroratus*, 13 *Placopecten* - *Asterias* (shrimp?) 2 *Pagurus*	0
66	38 30	74 06.2	60	9.2	5.56	109 *C.irroratus*, 58 *Placopecten*, 1 portunid crab, 1 *Pagurus*	2 *Arctica*
67	38 20	74 12.5	55	8.8	3.80	67 *C.irroratus*, 12 shrimp? 3 *Strongylocentrotus*	*Arctica* (C)
68	38 21.5	74 04.5	57	9.1	N.A.*	43 *C.irroratus*, 53 *Placopecten*, 30 *Asterias*, 15 *E.parma*, 2 *Pagurus*, 21 *Strongylocentrotus* ?	2 *Spisula*
69	38 20.8	74 25	36	11.4	4.95	13 *C.irroratus*, 1 *Pagurus*	0
70	38 20	74 38	36	13.1	4.15	1 *C.borealis*, 31 *C.irroratus*, 1 *O.ocellatus*,- *Asterias*, *Pagurus*, *Strongylocentrotus* ?	0
71	38 20	74 44.4	26	15.8	4.43	6 *C.irroratus*, 5 *O.ocellatus*	0

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE H (continued)							
74	38 10	74 38.5	37	10.8	3.80	3 *C.irroratus*, 1 *Homarus*, 2 *O.ocellatus*, 13 *Asterias* - Shrimp ? 2 *O.guadalpensis*	0
75	38 10	74 11.5	66	9.4	5.8	3 *C.borealis*, 394 *C.irroratus*, 214 *Placopecten*, 1 *Arctica*	0
85	39 39.5	73 28.7	35	10.2	0.00	2 *Spisula*, 1 *Asterias*, 12 *Lunatia*	6 *C.irroratus*, 4 *Spisula* (3-C) 9 *Ensis*
86	39 40	73 42	32	9.2	0.50	2 *Lunatia*	1 *Spisula*
89	39 40	74 08	15	17.3	2.91	1 *Lunatia*, 1 *Libinia*	1 *Spisula* (C)
90	39 29	74 97.7	20	16.3	0.40	0	1 *Spisula*
91	39 30	74 01.4	25	13.4	0.01	0	10 *Spisula* (4-C) 1 *Lunatia*
92	39 29.3	73 54.7	26	11.6	0.87	2 *Spisula*,- *Lunatia*	5 *Spisula*
95	39 30	73 22.5	37	9.1	0.65	1 *C.irroratus*, 12 *Asterias* 12 *Lunatia*	2 *Ensis*
96	39 50	83 32.9	34	8.5	1.12	5 *C.irroratus*, 12 *Lunatia*,- *Ensis*	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
RUISE I							
1	39 30.7	74 13.5	9	17.0	1.15	39 *Spisula*, 45 *Libinia* sp. 1 *Lunatia*, 2 *Asterias*, 2 *Polinices*	10 Spisula (C)
2	39 29.2	73 59.9	24	14.9	0.10	1 *Astarte* sp.	49 *Spisula* (C)
3	39 29.4	73 46.5	29	12.6	0.00	0	51 *Spisula* (C)
4	39 30.2	73 34.6	33	11.4	1.45	22 *Arctica*	1 *Spisula* (C) 12 *Arctica* (9-C)
6	39 36.7	73 31.9	38	10.7	1.00	80 *Arctica*	10 *Spisula* (C), 54 *Arctica* (39 C)
7	39 44.9	73 27.2	39	10.4	0.90		2 *Spisula* (C)
8	39 44.4	73 40.4	26	18.0	1.50	5 *Spisula*, 8 *Arctica*	0
9	39 44.3	73 52.7	25	15.1	0.00	0	62 *Spisula* (C)
10	39 44,5	74 03.9	12	19.3	7.20	3700 *Spisula*, 5 *Libinia* sp. 1 *O.ocellatus*, 1 *Asterias*, 1 *Polinices*, 1 *Pagurus*	0
11	39 55.8	73 57.1	20	13.3	0.10	227 *Spisula*, 5 *Lunatia*	29 *Spisula* (16-C)
12	40 05.8	73 58.8	20	12.9	1.35	118 *Spisula*, 1 *Lunatia*	16 *Spisula* (1-C)
13	40 06.2	73 47.0	28	11.5	2.05	67 *Spisula*, 12 *Arctica*, 1 *Lunatia*	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE I (continued)							
14	40 03.7	73 35.6	37	9.9	1.75	48 *Arctica*	0
15	40 05.6	73 22.1	39	9.5	2.15	8 *Arctica*, 1 *C.borealis*	0
16	39 57.1	73 28.5	41	9.0	1.45	10 *Arctica*, 2 *C.irroratus*	0
17	39 55.1	73 42.8	32	11.9	1.95	26 *Spisula*, 2 *Lunatia*	41 *Spisula* (C) 2 *Arctica* (C)
18	39 39.2	73 58.0	24	15.0	0.00	25 *Mytilus*, *Sipunculid*	90 *Spisula* (C)
19	39 38.5	74 01.4	21	15.0	0.00	0	53 *Spisula* (C)
20	39 22.2	74 03.7	22	14.6	0.00	0	88 *Spisula* (C)
21	29 22,0	73 48,7	35	12.9	0.00	196 *Arctica*	7 *Spisula* (1-C) 12 *Arctica* (5C) 1 *C.irroratus*, 1 *Lunatia*
22	39 23,0	73 26,0	41	11.9	0.85	36 *Arctica*	20 *Arctica* (14-C)
24	39 13,3	73 44.8	42	11.1	0.00	147 *Arctica*	4 *Placopecten* (C)
26	38 57.4	73 53.6	40	14.2	1.55	444 *Arctica*, 2 *C.irroratus* 1 *Placopecten*, 2 *Ensis*, 1 *Lunatia*	0
27	37 57.7	74 06.4	37	13.1	2.05	5 *Spisula*, 54 *Arctica*, 4 *C.irroratus*	3 *Arctica* (2-C)
28	38 57.9	74 20.2	34	12.6	2.30	211 *Arctica*	3 *Arctica*

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE I (continued)							
29	38 57.5	74 33.2	17	16.5	3.05	40 *Spisula*, 2 *O.ocellatus*, 5 *Limulus*, 10 *Asterias*, sponge ?	0
30	38 56.9	74 43.2	12	18.6	6.05	1 *Libinia*, 2 *Limulus*, 1 *Asterias*	0
31	39 13.9	74 34.9	15	18.0	2.80	75 *Limulus*, 2 *Busycon*	0
32	39 13.2	74 22.8	18	16.6	3.75	4 *Spisula*, 7 *Busycon*, 1 *O.ocellatus*	23 *Spisula*
33	39 13.6	74 10.3	22	16.6	1.85	3 *Spisula*, 2 *C.irroratus*, 2 *O. ocellatus*	45 *Spisula* (C)
34	39 13.5	73 57.8	12	14.1	1.95	22 *Spisula*, 5 *Arctica*	19 *Spisula* (18-C)
1-S	39 59.8	74 02.4	5	19.6	8.70	2400 *Spisula*, 4 *Limulus*	0
2-S	39 41.2	73 49.6	23	17.6	3.50	40 *Spisula*	44 *Spisula* (43-C)
3-S	39 43.6	73 46.8	21	15.5	0.80	38 *Spisula*	68 *Spisula* (64-C)
4-S	39 48.7	74 00.0	18	14.2	0.00	51 *Spisula*	24 *Spisula* (16-C)
5-S	39 51.4	74 03.0	15	14.6	0.00	73 *Spisula*	62 *Spisula* (26-C)
6-S	39 31.0	73 41.1	32	12.3	0.53	0	12 *Spisula* (C)
7-S	39 29.7	73 51.6	32	13.6	0.00		71 *Spisula* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE I (continued)							
8-S	39 13.7	73 50.8	30	13.5	0.75	14 *Spisula*	7 *Spisula* (2-C), 1 *C. irroratus*, 1 *Lunatia*
9-S	39 13.3	74 29.2	N.A.*	17.1	3.30	11 *Spisula*, 2 *Busycon*	23 *Spisula* (13-C)
10-S	39 20.9	74 17.5	18	17.7	3.00	1 *Limulus*, 1 *Busycon*	16 *Spisula* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE J							
40	40 24.8	73 31.8	22	15.8	7.00	2 *C.irroratus*, 5 *O.ocellatus*,- *Asterias*,- *E.Parma*, 1 *Libinia* sp. 1 *Limulus*	0
41	40 28	73 36.7	20	15.2	3.41	6 *C.irroratus*, 1 *Homarus*	0
42	40 31,5	73 46	18	15.6	6.31	5 *C.irroratus*, 5 *Limulus*	0
43	40 28.2	73 47.3	26	13.1	6.69	5 *C.irroratus*	0
44	40 23.5	73 43.4	20	14.2	6.52	25 *C.irroratus*, 3 *Homarus*	0
45	40 18.2	73 48	39	11.7	1.64	4 *Homarus*	0
46	40 16	73 57.7	15	17.9	6.79	2 *C.irroratus*, 5 *Homarus*, 5 *O. ocellatus*	0
47	40 12.2	73 54.6	18	17.9	6.84	1 *C.borealis*, 4 *C.irroratus*	0
48	40 09	73 59.2	15	17.3	7.00	1 *C.borealis*, 1 *C.irroratus*, 1 *Callinectes*, 1 *Lunatia*, 1 *Limulus*	1 *C.irroratus*
49	40 06	73 59	20	17.6	6.75	1 *C.irroratus*	0
50	40 01.9	73 51	22	17.7	6.72	1 *C.irroratus*, Sponge (?)	0
51	39 57.3	73 52.5	22	17.0	6.19	0	*Axius*
52	40 01	73 39	35	12.0	1.54	1 *C.irroratus*	*Spisula* (loose meats only)

TABLE 3. (continued)

CRUISE J (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
53	40 10.8	73 13.5	40	11.4	1.67	32 *Placopecten* (S), Sponge	0
71	39 46.5	73 05	53	10.8	2.82	1 *Homarus*, 103 *Placopecten*	0
72	39 34	73 12	42	10.9	1.88	1 *C.irroratus*	0
73	30 39.5	73 22.5	33	11.0	2.36	1 *Homarus*	1 *E.parma*, 2 *Ensis* (C)
74	39 21.5	73 32.5	46	11.4	2.50	0	36 *Arctica* (35-C),- *E.parma* 1 *Ensis*,- polychaetes
75	39 38.5	73 41	27	17.5	6.43	1 *C.irroratus*, 1 *Homarus*	0
76	39 47.5	73 38.5	31	17.1	5.79	- *Arctica*,- *E.parma*	- *Arctica*
77	39 41.5	74 03	13	17.2	6.99	1 *Limulus*	0
78	39 26	74 01.5	22	17.7	6.96	0	0
79	39 33	74 12.5	9	16.6	6.86	1 *O.ocellatus*, 5 *Limulus*	0
80	39 16.7	74 07.5	26	18.0	6.81	1 *Callinectes*	0
81	39 16.3	74 25.5	13	16.6	6.90	1 *Callinectes*, 5 *Limulus*	0
82	39 13	74 24.5	15	17.3	6.60	1 *O.ocellatus*, 1 *Spisula*, 2 *Limulus*	0
83	39 03	74 11.5	29	17.0	7.02	- *E.parma*	0

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE J (continued)							
84	38 58.5	73 47.5	40	12.6	1.19	1 *O.ocellatus*, 2 *Placopecten*, 1 *Axius*	0
85	39 17.4	73 46	35	17.0	5.49	0	4 *Ensis* (C)
86	39 06.5	73 30	51	11.0	1.49	3 *C.irroratus*, 1 *Homarus*	3 *Ensis* (C)
95	38 46	74 05	46	11.3	1.50	- *E.parma*	0
96	38 44.5	74 28.5	27	18.8	6.89	1 *Libinia* sp., 6 *Limulus*	0
97	39 99	74 45	11	17.0	6.32	1 *O.ocellatus*, 5 *Limulus*	0
175	38 49.3	74 40.4	15	17.6	7.60	14 *Limulus*	0
176	38 54.7	74 49.9	13	17.6	7.56	4 *Limulus*	0
177	39 03.5	74 35.5	16	16.5	7.62	2 *C.irroratus*, - *Libinia* sp., 6 *Limulus*	0
178	39 05.8	74 40	15	16.1	7.91	1 *O.ocellatus*, 1 *Limulus*	0
179	39 16	73 45	40	13.2	1.77	- *Asterias*	*Spisula* (meats only), - *E.parma*, 5 *Ensis* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE K							
1	40 18	73 33	23		7.25	1 *Spisula*, 500 *E.parma*, 35 *Asterias*, 1 *Lunatia*, 66 *C.irroratus*	0
2	40 10	73 21	40		3.50	6 *Placopecten*, 1 *Arctica*, 86 *C. irroratus*, 11 *C.borealis*, 4 *Lunatia*, 4 *Modiolus*, 20 *Asterias*	13 *Arctica* (C)
3	39 58	73 07	45		3.82	36 *Asterias*, 4 *C.irroratus*, 2 *C. borealis*, 15 *Placopecten*, 4 *Arctica*	0
16	39 54	73 40	32		5.82	1 *Lunatia*, 1 *C.irroratus*	1 *Arctica* (C)
17	39 47	73 31	31		3.30	4 *C.irroratus*, 12 *Lunatia*, 118 *Arctica* (62-C)	255 *Arctica* (C) *Ensis* (C)
18	39 39	73 18	40		2.80	3 *Pagurus*, 11 *C.irroratus*, 28 *Arctica* (16-S)	67 *Arctica* (C), 11 *Placopecten* (C)
19	39 28	73 17	36		2.95	1 *Arctica*	5 *Spisula* (C), 3 *Arctica* (C)
20	39 23	73 29	41		3.00	9 *Lunatia*, 5 *Arctica* (1-S), 21 *C.irroratus*	1 *Spisula* (C), 81 *Arctica* (C) *Ensis* (C), 2 *Lunatia*, 100 *E.parma*
21	39 32	73 45	31		3.85	1 *C.irroratus*	4 *Arctica* (C), 1 *Spisula* (C) 1 *Lunatia*, 1 *Ensis* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE K (continued)							
22	39 36	73 52	27		7.35	0	4 Spisula (C)
23	39 20	74 15	22		7.20	1 Spisula	7 Spisula (C)
24	39 13	73 51	36		2.80	15 C.irroratus, 2 Lunatia 37 Arctica(25-S)	2 Spisula (C), 148 Arctica (C), 3 Placopecten (C), 2 Lunatia, sponge
25	39 07	73 39	45		1.75	16 C.irroratus, 1 C.borealis 8 Lunatia, 163 Arctica (41-S)	19 Placopecten, 81 Arctica
26	38 57	73 39	45		2.20	10 Arctica (1-S)	16 Arctica (C)
27	38 54	73 53	41		1.55	2 Lunatia, 2 Ensis, 3 C.irroratus, 1 C.borealis, 167 Arctica (55-S)	2 Placopecten (C), 33 Arctica (C)
28	39 05	74 20	27		3.35	0	10 Spisula (C)
29	39 00	74 07	36		2.25	1 Placopecten, 18 Arctica	32 Arctica (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE L							
	39 28	74 15.5	10	16.4	6.70	4 *Spisula*, 1 *Busycon*, 1 *Limulus*	152 *Spisula* (C)
	39 28	74 00.5	24	17.7	6.50	0	32 *Spisula* (C)
	39 28	73 47.5	29	18.1	6.25	0	9 *Spisula* (C), 2 *Arctica* (C)
	39 45	73 39	24	17.4	5.15	1 *Spisula*, 3 *Arctica*, 2 *Lunatia*	3 *Spisula* (C)
	3956	73 44	29	13.6	0.75	142 *Arctica*	17 *Arctica* (C)
	40 05	73 40.5	45	14.8	2.75	2 *Spisula*,38 *Arctica*,2 *Asterias*	0
	40 05	73 21.5	43	15.6	3.55	2 *Spisula*, 219 *Arctica*	1 *Spisula* (C),200 *Arctica* (C)
	39 57	73 31	39	18.0	6.65	10 *Spisula*, 1 *Arctica*	8 *Spisula*
	39 44.5	73 26	38	17.7	6.65	0	8 *Spisula*
	39 37,5	73 40	34	17.1	5.15	1 *Arctica*, 1 *Lunatia*	2 *Arctica* (C)
	39 28	73 35	32	16.4	4.15	0	9 *Spisula* (C)

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE M							
1	40 19.2	73 32.8	32	N.A.*	7.05	1000 *E.parma*, 100 *Asterias* 1 *C.irroratus*	0
2	38 00.4	74 06.1	103	N.A.*	4.20	100 *Asterias*, 6 *Henricia*	0
3	38 02.8	74 14.5	72	N.A.*	5.75	3 *Placopecten*, 6 *Astropecten*	2 *Arctica* (C)
4	38 05.7	74 24.0	42	N.A.*	5.85	10 *E.parma*, 6 *Asterias*, 3 *Placopecten*	1 *Spisula* (C), 3 *Placopecten* (C)
5	38 09.3	74 33.9	37	N.A.*	7.20	10 *E.parma*,1 *Pagurus*,1 dorid *nudibranch*, 2 *O. guadalpensis* 1 *C.irroratus*,3 *Placopecten*	½ Bushel *Spisula* (C)
6	38 15.2	74 40.0	37	N.A.*	N.A.*	3 *Limulus*,30 *Asterias*,15 *E.parma* 2 *C.irroratus*,1 *Lunatia*, 3 *Pagurus*	1 *Spisula* (C)
7	38 54.1	74 34.2	20	N.A.*	8.50	1 *Limulus*,8 *O.ocellatus*,6 *C.irroratus*,3 *Libinia* sp.	0
8	39 06.3	74 18.9	27	N.A.*	8.15	6 *Asterias*,1 *O.ocellatus*,6 *E.parma*,2 *Limulus*,1 *Pagurus*	2 *Spisula* (C)
9	38 59.0	74 04.9	36	N.A.*	N.A.*	4 *C.irroratus*, 6 *Asterias*	6 *Arctica* (C), 6 *Ensis* (C)
10	38 52.4	73 53.5	39	N.A.*	7.50	6 *C.irroratus*	12 *Ensis* (C), 177 *Arctica* (C), 6 *Placopecten*
11	38 46.6	73 43.5		N.A.*	4.90	16 *Asterias*, 2 *Placopecten* (1-S)	25 *E.parma*, 15 *Placopecten* (5-C) 10 *Arctica* (C)

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE M (continued)							
12	38 38.8	73 29.5	77	N.A.*	4.90	1 Placopecten	0
13	38 19.6	73 33.2	125	N.A.*	4.70	0	0
14	38 46.6	73 08.0	92	N.A.*	4.50	100 Astropecten, 6 Henricia	0
15	38 52.6	83 18.8	78	N.A.*	5.70	5 Placopecten	1 Placopecten (C), 2 Arctica (C)
16	39 00.0	73 30.5	57	N.A.*	4.40	1 Astropecten, 1 Asterias, 1 Astarte, 1 Arctica	3 E.parma, 10 Placopecten (C), 9 Arctica (C)
17	39 06.5	73 39.7	66	N.A.*	7.30	50 Asterias, 50 C.irroratus 2 Arctica (1-S)	25 E.parma, 200 Ensis (C), 68 Arctica (C)
18	39 12.7	73 51.1	37	N.A.*	8.25	0	1 Ensis (C), 11 Arctica (C)
19	39 19.8	74 04.0	24	N.A.*	8.15	2 Limulus	6 Spisula (C)
20	39 38.0	73 55.0	30	N.A.*	8.55	0	4 Spisula (C)
21	39 30.0	73 42.5	37	N.A.*	8.20	0	3 Spisula (C), 1 Lunatia
22	39 21.1	73 29.0	50	N.A.*	5.12	20 E.parma, 1 Asterias, A.vulgaris, 12 Arctica (9-S)	20 E.parma,approx.350 Arctica (C)
23	39 38.7	73 18.3	38	N.A.*	7.90	1 Arctica	78 Arctica (C)
24	39 47.4	73 30	35	B,A,*	8.15	0	1 Spisula (C), 6 Arctica (5-C)

* Not available

TABLE 3. (continued)

				Bottom			
Sta. No.	Lat.	Long.	Depth (m)	Temp. °C	D.O. mg/l	Alive	Dead
CRUISE M (continued)							
25	39 56.1	73 42.4	35	N.A.*	7.95	0	5 *Spisula* (C), 1 *Arctica* (C)
26	40 08.5	73 20.9	44	N.A.*	4.85	6 *Modiolus*, abt.1000 *E.parma* 10 *Asterias*, 1 *Henricia*	9 *Astarte* (C)
27	39 59	73 09	73	N.A.*	5.15	3 *Lunatia*, 50 *E.parma*, 10 *Asterias*	3 *Arctica* (C), 1 *Ensis* (C)
28	39 50	72 57.7	74	N.A.*	4.20	40 *Astropecten*	0
29	39 39.3	72 45.7	74	N.A.*	4.85	50 *Astropecten*,3 *Asterias*, 8 *Placopecten*	3 *Placopecten* (C)
30	39 28	72 33.0	74	N.A.*	4.20	10 *Asterias*	0
31	39 30	73 06.1	64	N.A.*	4.50	Abt.500 *E.parma*,2 *C.borealis*, 10 *A.vulgaris*,2 *Asterias*,1 *Pagurus*, 8 *Strongylocentrotus*, 1 *C.irroratus* sp., 14 *Placopecten*	4 *Placopecten* (C), 3 *Arctica* (C)
32	39 22.7	72 55.7	78	N.A.*	4.95	25 *Astropecten*,15 *Asterias*, 1 *Modiolus*, 2 *C.borealis*,31 *Placopecten*	3 *Placopecten* (C), 1 *Arctica* (C)
33	39 13.6	72 43.3	127	N.A.*	4.95	9 *Asterias* (?)	0
34	38 58.8	72 52.0	125	N.A.*	4.55	8 *Benthopecten armatus*, 1 *Heterocrypta granulata*	0

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	D.O. mg/l	Alive	Dead
CRUISE M (continued)							
35	39 07.0	73 04.7	80	N.A.*	4.60	2 C.borealis, 1 B.armatus, 6 Astropecten, 3 Asterias, 1 Astarte, 3 Placopecten	3 Placopecten (C)
36	39 15	73 18	61	N.A.*	4.65	100 E.parma, 20 Asterias, 1 Modiolus, 5 Strongylocentrotus, 1 Cancer sp., 22 Placopecten	1 Placopecten (C), 14 Arctica
37	38 25	73 36,6	121	N.A.*	4.45	Abt. 200 Astropecten	0
38	38 31	73 48	66	N.A.*	4.90	2 A.vulgaris, 10 Placopecten	2 Placopecten (C) 1 Artica (C)
39	38 35	73 58.6	53	N.A.*	4.75	Abt.2000 E.parma, 25 Asterias, 1 Modiolus, 23 Placopecten, 16 C.irroratus	2 Placopecten (C), 1 Arctica (C)
40	38 13.7	73 54.9	80	N.A.*	N.A.*	15 Astropecten, 1 Cancer sp.	0
41	38 20	74 22	58	N.A.*	4.95	20 Asterias, 35 E.parma, 3 Arctica, 7 Placopecten	3 Arctica (C) 2 Placopecten (C).
42	38 26.3	74 20.6	45	N.A.*	5.35	15 C.borealis, 10 E.parma, 9 Placopecten, 3 Pagurus	3 Ensis (C), 9 Arctica (C) 15 E.parma
43	38 32	74 31.6	38	N.A.*	7.85	1 Henricia, 1 Buccinum, 25 E.parma, 2 Asterias, 3 Limulus, 6 C.irroratus	0

* Not available

TABLE 3. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom D.O. mg/l	Alive	Dead
CRUISE M (continued)							
44	38 42.3	74 10.7	70	N.A.*	6.00	1 *C.irroratus*, 2 *Asterias*, 2 *Strongylocentrotus*, 5 *E.parma*	0
45	39 47.8	74 22.4	36	N.A.*	8.25	1 *C.irroratus*, 200 *Asterias*, abt.500 *E.parma*, 1 *Libinia* sp.	2 *Spisula* (C)
46	38 51.4	74 39.3	15	N.A.*	N.A.*	1 *C.irroratus*, 5 *Libinia*, 3 *O. ocellatus*	0
47	38 43.9	74 53.8	25	N.A.*	N.A.*	1 *Limulus*, 3 *Libinia*, 4 *C.irroratus*, 3 *O.ocellatus*, 1 *Asterias*, 1 *Pagurus*	1 *Spisula* (C)
48	38 37.8	74 43.4	N.A.*	N.A.*	N.A.*	1 *Callinectes*, 1 *Libinia*, 2 *O. ocellatus*, 8 *C.irroratus*	3 *Spisula* (C)

* Not available

PLANKTON WORKSHOP

SUMMARY REPORT

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1.0 Introduction

An extensive bloom of the dinoflagellate Ceratium tripos (O.F. Muller) Nitzsch developed throughout the Middle Atlantic Bight (between 36°N, 41°N and the continental shelf break) from January through July, 1976. By late June - early July an oxygen minimum layer ($<$2.0 ppm) had developed below the thermocline between the 20 and 40 m isobaths off the New Jersey coast from Atlantic City to Sandy Hook.[1] Local anoxic conditions were most widespread off of Barnegat Inlet (39°45' N) in early July and off of Great Bay (39°30' N) by late July. The presence of this sub-thermocline oxygen minimum layer and associated sulfide production apparently resulted in mass mortalities of demersal fishes and benthic invertebrates.[2]

The occurrence of the C. tripos bloom and the subsequent development of the oxygen minimum layer has led to the hypothesis that C. tripos was involved in generating the BOD required to produce the oxygen minimum. In an effort to clarify the role of C. tripos, this workshop addressed the following questions:

(1) What was the areal extent of the bloom and the time-course of its development?

(2) What are the most likely causes of the bloom and its demise?

(3) What were the effects of the bloom on the distributions of organic matter and dissolved oxygen?

The session was concluded with recommendations for future monitoring and research strategies.

For purposes of this discussion, the New York Bight (Fig. 1) will be divided into 5 regions: (1) Long Island and (2) New Jersey coastal areas ($<$20 m deep within 5 km of the coastline), (3) lower Hudson Estuary (including the Upper and Lower Bays of New York Harbor), (4) the apex (bounded by $40^{\circ}10'$ N and $73^{\circ}30'$W) and (5) the outer New York Bight (south and east of the apex to the shelf break between Cape May and Montauk Point).

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[1] National Marine Fisheries Service, 1976. Red Flag Report: Mortalities of fish and shellfish associated with anoxic bottom water in the Middle Atlantic Bight. Middle Atlantic Coastal Fisheries Center, Sandy Hook, New Jersey.

[2] Interagency Committee Investigating the 1976 New York Bight Oxygen Depletion Phenomenon, 1976. Results of the Benthic Workshop, National Marine Fisheries Service, Middle Atlantic Coastal Fisheries Center, Sandy Hook, New Jersey.

2.0 Background: Phytoplankton Ecology in the New York Bight

2.1 Water Column Stratification and Dissolved Oxygen

Seasonal variations in water column stratification and dissolved oxygen in bottom water parallel each other off the New Jersey coast. During winter months, the water column is well mixed and dissolved oxygen concentrations are near saturation (6-8 ml liter^{-1}). As the water column begins to stratify in April, dissolved oxygen concentration in the subpycnocline layer begins to decline so that by July-August concentrations are usually 10-40% of saturation (2-4 ml liter^{-1}). Local anoxic conditions occasionally develop during the summer below the thermocline near the sludge dump site in the apex (Fig. 1).[3] During the summer of 1976, the oxygen minimum layer was more widespread, existed over a longer period of time, and was characterized by lower oxygen concentrations.

[3] National Marine Fisheries Service, 1972. The effects of waste disposal in the New York Bight. NTIS acquisition AD739531-39, AD743936.

2.2 Phytoplankton Productivity

Major studies of phytoplankton productivity include those of Ryther and Yentsch (1958) in the outer Bight, Mandelli *et al.* (1970) along the Long Island coast and Malone (1976 a, b, c, d) in the lower Hudson Estuary and apex of the New York Bight. The following synthesis is based on these studies.

Annual phytoplankton productivity decreases with increasing depth and distance from the mouth of the Hudson-Raritan estuarine complex (Fig. 1). Phytoplankton productivity in the apex is about 430 g C m^{-2} yr^{-1}, or 70 - 80% of the annual input of particulate organic carbon (POC) to the apex. The remainder is related to sewage wastes generated in the New York - New Jersey metropolitan region transported into the apex by estuarine runoff and ocean dumping (Garside and Malone, 1976; in press). Phytoplankton productivity in the outer Bight decreases from 160 to 100 g C m^{-2} yr^{-1} as water column depth increases from less than 50 m near the Long Island and New Jersey coasts to 1000 m over the continental slope.

Ryther and Dunstan (1971) present evidence that organically rich water from the apex extends eastward for less than 80 km and south along the New Jersey coast for at least 240 km. Based on the distribution of dissolved inorganic nitrogen and phosphorus during September, 1969 and on bioassay experiments with *Skeletonema costatum*, they concluded that phytoplankton growth in the Bight is nitrogen limited.

Phytoplankton productivity in the apex fluctuates between 0.1 and 6.6 g C m^{-2} d^{-1} (mean = 1.17) compared to 0.1 to 1.1 (mean 0.35) in the outer Bight. Seasonal variations in the outer Bight are characterized by a single bloom period which appears to decrease in length and increase in amplitude as depth increases. Inshore ($<$ 50 m in the outer Bight), productivity ranges between 0.5 and 1.0 g C m^{-2} d^{-1} from December through April and is less than o.5 for the remainder of the year. Offshore ($>$ 100m), productivity exceeds 0.5 only during March and April. In contrast, seasonal variations in the apex a characterized by two bloom periods which coincide with periods of minimum surface temperature change in February-March (2 - 8° C) and June-July (19 - 23°C). Chain forming diatoms (netplankton retained on a 20 µm mesh screen) with mean euphotic zone generation times of 1 - 3 days dominate phytoplankton blooms in February-March. During these months the water column (20 - 30 m deep) is well mixed, the euphotic zone extends to the bottom, and phytoplankton populations are nearly uniformly distributed in the water column. Phytoplankton productivity is generally higher during the June - July bloom period when small (nanoplankton with mean spherical diameters less than 10 µm) green algae growing at mean euphotic zone generation times of 0.5 to 1.5 days dominate phytoplankton blooms. During this period, the water column is well stratified with the thermocline located between 5 and 15 m (5 - 20 m off the bottom); the euphotic zone is 5 to 15 m deep; and phytoplankton populations are concentrated near the surface with maximum densities along the New Jersey coast within 20 km of the mouth of the estuary.

These variations in phytoplankton productivity reflect the seasonal cycle of incident radiation and temperature, limits imposed by water column depth on vertical mixing and rates of nutrient recycling, fluxes of "new" nutrients into the euphotic zone from subpycnocline layers and sources outside of the Bight, and grazing. High productivity and the occurrence of two major bloom periods in the apex reflect (1) the continuous input of nutrient rich estuarine water (Hudson River), (2) the effects of thermal stratification on the distribution of estuarine water, and (3) seasonal variations in grazing pressure. Winter diatom blooms develop because grazing pressure is low. It appears that very little of the diatom crops produced is grazed and that most of this biomass sinks to the bottom where it may serve as organic substrates for seabed oxygen consumption during the spring and summer. Thus, winter diatom blooms in the apex may be a factor in the development of oxygen minimum layers during the summer.

Phytoplankton blooms during the spring and summer do not appear to have a similar fate. These blooms are concentrated in the surface layer (upper 10 m) where they are rapidly grazed and dispersed throughout the Bight because of the low sinking rates characteristic of the bloom species as well as high grazing rates.

In the outer Bight, vertical mixing, upwelling and the breaking of internal waves are the most important processes involved in euphotic zone nutrient enrichment. Nutrient supplies are not continuous and thermal stratification limits rather than enhances the flux of nutrients into the euphotic zone. Consequently, phytoplankton productivity is low throughout the summer and phytoplankton blooms are most frequent during March, April and May.

Based on nutrient distributions and experimental observations, dissolved inorganic nitrogen (DIN) supply and phytoplankton uptake are closely coupled during late spring and summer in both the outer Bight and the apex. Euphotic zone DIN concentrations are typically less than 1.0 μM from May through August. In the apex, high nanoplankton productivity and low DIN concentrations are reflected in DIN turnover times of 0.5 to 2.0 days in the surface mixed layer.

2.3 Distribution of Phytoplankton Species

A review of species abundance and distribution is presented by Malone (1976d). Phytoplankton cell densities are usuall in the range of 10^6 - 10^9 cells liter^{-1} in estuarine and coastal waters compared to 10^4 - 10^7 liter^{-1} in the apex and 10^3 - 10^5 liter^{-1} in the outer Bight. Phytoplankton populations are typically dominated by diatoms (cold months) and chlorophytes (warm months) in estuarine and apex water and by diatoms in the outer Bight.

The diatoms *Skeletonema costatum*, *Asterionella japonica*, *Leptocylindrus danicus*, *Thalassionema nitzschioides* and *Chaetoceros debilis* are abundant in both estuarine and Bight waters. *Rhizosolenia alata*, *R. faeroense*, *Chaetoceros socialis* and *Nitzschia closterium* usually make up a larger proportion of the diatoms present in the outer Bight than in the apex. The chlorophyte, *Nannochloris atomus*, frequently dominates estuarine and apex phytoplankton during the summer. The dinoflagellates *Prorocentrum micans*, *Peridinium* spp. and *Ceratium* spp. are often abundant during the spring, summer and fall.

More specifically, Mandelli *et al*. (1970) described the species composition of the netplankton along the southern coast of Long Island. Phytoplankton biomass peaked during fall and late winter. Both of these peaks were produced by blooms of *S. costatum*. Diatoms dominated the September - March, 1966 period while dinoflagellates were most abundant during the April - August 1966 period. Among the diatoms, *S. costatum*, *Thalassiosira* sp., *Chaetoceros* sp. and *R. alata* were successively abundant from

September through December. This succession appeared to be repeated during February and March. *Peridinium depressum* and *Ceratium massilence* bloomed in April and May, respectively. *Ceratium tripos* was the dominant netplankton from June to August. During March, 1967 a succession of species was observed in which *S. costatum* dominated during the first week, *Thalassionema nitzschioides*, *Rhizosolenia* sp., *A. japonica* and *Nitzschia seriata* the second week and *Ceratium tripos*, *C. macroceros*, *C. furca* and *Peridinium depressum* the last two weeks. This alternating pattern of diatom and dinoflagellate abundance appears characteristic of shallow coastal waters off western Long Island.

More recently, observations along the New Jersey coast (Myra Cohn, personal communication) indicate that *C. tripos* was abundant during the summers of 1974 and 1975. Cell densities ranged from 40 ml^{-1} to 740 ml^{-1} (geometric mean = 133 ml^{-1} in June, 1975 and 222 ml^{-1} in July, 1975). Increases in *C. tripos* cell densities are also typical of Fire Island Inlet on the Long Island coast (Sylvia Weaver, personal communication). From 1973 to 1975 peaks in cell density (as high as 5 ml^{-1} occurred in May and June following slow increases beginning as early as January (1974).

2.4 Biology of Ceratium tripos

The following summary is based largely on an overview prepared by Dr. Theodore J. Smayda (University of Rhode Island) for the IDOE/NSF sponsored workshop held in Washington, D.C. on 15 and 16 October, 1976.

C. tripos is an armored (cell wall comprised of cellulose plates) dinoflagellate. It is a holoplanktonic species commonly found along the east coast of the U.S. north of Cape Hatteras to the Gulf of Maine. It is motile, capable of swimming at speeds of 40 - 100 cm hr^{-1}. Because of its large size (1 - 10 x 10^5 um^3), this swimming behavior is required for C. tripos to remain in suspension for extended periods in stratified waters, i.e. cells which have lost their motility will sink at about 8 m d^{-1} (Laws, 1975).

The organism is eurythermal and euryhaline on the basis of both distribution and experimental growth studies. C. tripos is photosynthetic with light-dependent growth rates of 0.3 - 0.4 divisions d^{-1} (Nordli, 1958). Like most other species of Ceratium, cell division usually occurs between midnight and sunrise.

Large aphotic zone populations of C. tripos have been observed, but the extent to which this is a consequence of photosynthetic growth at sub-euphotic zone light intensities, long dark survival times, or heterotrophic growth is unknown. Circumstantial evidence suggests that C. tripos may have the potential for heterotrophic growth on particulate organic matter (POM). Observations of particle ingestion by Ceratium sp. have been reported, and morphologically, C. tripos appears to be capable of phagotrophy.

3.0 Distribution of *Ceratium tripos*: January - September 1976

3.1 Time-Course of the Bloom

C. tripos was abundant in the apex at least as early as 7 February 1976, but showed little increase in population size during February (Fig. 2). Cell densities increased steadily from a geometric mean of 5.8 cells ml^{-1} by the end of March. The growth rate of 0.06 doublings d^{-1} calculated from these changes yields a mean water column cell density of 240 ml^{-1} by late May which is within the range of densities reported from the layer of maximum cell density in the apex at this time (Fig. 2).

A similar pattern was observed at Fire Island Inlet (Fig. 2) where cell density increased from less than 0.1 ml^{-1} in January to 22 ml^{-1} by the end of March, a rate of 0.05 d^{-1}. The population remained relatively stable through April and May and declined from a maximum of 50 ml^{-1} in May to less than 0.1 ml^{-1} by the end of July. This pattern roughly paralleled variations at a station 8 km south of Fire Island Inlet where cell density peaked in May and June and declined rapidly thereafter to near zero in August (Fig. 3).

Mean cell densities along the New Jersey shore peaked near mid-June (Fig. 2). In the New York Harbor region, cell densities were highest in March (29-75 ml^{-1}), declined to 10 ml^{-1} by the end of May, and remained constant at 10 ml^{-1} through mid-July.

Cell densities in the outer Bight increased from 1-60 ml^{-1} (mean = 10 ml^{-1}) near the end of March to 10-400 ml^{-1}

by mid-June (mean 240 ml^{-1}). Based on qualitative net phytoplankton samples collected from 10 m with a Hardy Continuous Plankton Recorder (225 x 234 um mesh), C. tripos was present throughout the Bight in January and increased to a maximum in May (Fig. 4). The decrease from May to June was probably a consequence of an aggregation of cells below the thermocline as discussed in the next section.

3.2 Vertical Distribution

Vertical profiles of temperature, chlorophyll a and *C. tripos* cell density showed little stratification from January through March when netplankton (phytoplankton retained on a 20 um mesh screen) accounted for more than 80% of chlorophyll a in the water column. As the water column began to stratify in April, the vertical distributions of chlorophyll and *C. tripos* began to exhibit patterns of stratification which varied systematically across the shelf (Fig. 5). Based on continuous vertical profiles between 30 April and 5 May, seaward of the shelf break (stations 93 and 94) maximum chlorophyll a concentrations occurred in the upper 25 m and diatoms dominated the phytoplankton. Across the shelf break (stations 95 - 97) a broad maximum between 10 and 35 m was observed which was dominated by diatoms near the surface and by *C. tripos* at depth. Further inshore (stations 98 - 101, 66, 72) a strong narrow band maximum developed as the diatom population dropped out. The layer consisted almost entirely of *C. tripos* (> 90% of total cells) and was located between 0.3 and 3% light depths in association with the 10° to 13°C isotherms. The depth of the layer, which varied in thickness from 1 - 3 m, decreased gradually from 35 m at station 98 (75 km offshore) to 20 m at station 72 (10 km offshore). This trend apparently persisted as thermal stratification continued to develop so that by May and June (Fig. 6) most of the *C. tripos* population was concentrated in a thin layer immediately below the thermocline, in association with the 10°C isotherm and between the 0.1 and 10% light depths. Because of nanoplankton blooms in the upper 10 m and high concentrations of detritus, the C. tripos maximum was below the 1% light depth in the apex and south along the New Jersey coast within 20 km of the shoreline to about Barnegat Inlet ($39^{\circ}45'$ N).

3.3 Horizontal Distribution in the Layer of Maximum Chlorophyll

Interpretation of areal distributions of C. tripos cell density in terms of population size must be made in the context of temporal variations in the vertical distribution of cells. The population was nearly uniformly distributed with depth in the upper 30 - 40 m during January-March when the water column was well mixed and was aggregated near the base of the thermocline during April-June when the water column was thermally stratified.

Within the apex in February and March, population size increased with distance from the mouth of the estuary, especially along the New Jersey coast (Fig. 7). This pattern was closely related to the flow of estuarine water (Fig. 8) so that cell densities were lowest when the proportion of estuarine water was greatest. Conversely, maximum chlorophyll a concentrations (Fig. 9) paralleled the distribution of low salinity estuarine water reflecting the rapid response of diatom populations (dominated by Nitzschia seriata with S. costatum and Rhizosolenia sp. abundant) to nutrient enrichment.

This pattern continued across the shelf along a southeast transect originating in the apex and extending to the shelf break in late March (Fig. 10). C. tripos reached maximum cell density (60 ml^{-1}) near the shelf break while Nitzschia seriata was most abundant in the apex. Based on these observations and the degree to which C. tripos clogged zooplankton nets during March (Fig. 11), high densities of C. tripos had developed throughout the New York Bight by the end of March with maximum densities occurring in the offshore reaches of the outer Bight (mid-shelf to the shelf break). This inshore-offshore increase in cell density apparently persisted into April (Fig. 4).

As the water column stratified, the distribution shifted so that by mid-May an inshore-offshore decrease in abundance was observed with maximum cell densities located in the apex (Fig. 12). Nanoplankton accounted for most of the chlorophyll _a_ in the surface layer throughout the Bight except for the center of high chlorophyll _a_ (6 µg liter^{-1}) off Long Island and a very patchy region off New Jersey where a maximum of 10 µg liter^{-1} was reported. _C. tripos_ accounted for more than 85% of the chlorophyll _a_ at all depths at these two locations. As thermal stratification continued to develop, the distribution of _C. tripos_ shifted to the southeast (Fig. 13) so that by mid-June the center of maximum abundance was located in about 60 m of water 80 km east of Seaside Park on the New Jersey coast (39°55' N, 73°15' W). Surface chlorophyll _a_ concentrations were low throughout the outer Bight but remained high within the apex due to the growth of nanoplankton populations (Fig. 13). During May the isopleths of cell density roughly paralleled isobaths off both the Long Island and New Jersey coasts. In June this pattern persisted only off the Long Island coast. Off New Jersey, isopleths of cell density were roughly normal to the coastline, and high cell densities intruded closer to the coastline. As a consequence, high cell densities were distributed over a larger area of the New Jersey shelf in relatively shallow water (20 - 40 m). Comparable cell densities over the Long Island shelf were in waters 40 - 60 m deep.

3.4 Conclusions

While the data were not collected synoptically in time or space, coastal observations correlated well with those in the apex and outer Bight (Figs. 2, 4, 12, 13). Temporal variations in *C. tripos* cell density at Fire Island Inlet reflected the early stages of the bloom prior to stratification, and mean cell densities along the New Jersey shore appeared to reflect at least the latter stages of the bloom during the period of thermal stratification.

The *C. tripos* bloom apparently began throughout the New York Bight in January with maximum cell densities developing in the mid-shelf to shelf break region in late March prior to the onset of thermal stratification. During this period (January - March) vertical distributions of cells were relatively uniform, the bulk of the population was in the euphotic zone, and population size was increasing at a relatively constant rate of 0.05 - 0.06 doublings day^{-1}. The temporal and spatial distributions of cells indicate that the population was increasing most rapidly in the outer Bight during March or that the outer Bight received a larger initial inoculum of cells than the inner Bight. The large area over which the bloom occurred indicates that it did not develop in response to local nutrient enrichment of the coastal zone during the actual period of the bloom. This is supported by the observation that *C. tripos* cell densities were lowest in the apex where local nutrient enrichment is greatest. *The causes of the bloom, whether they were related to increased growth or decreased mortality rates, must have involved processes operative on spatial scales on the order of the* *continental shelf and time scales on the order of months to years*.

As the water column began to stratify, the *C. tripos* popupation aggregated in a narrow band at the base of the thermocline, and by mid-June the center of maximum abundance had moved from offshore near the shelf break to within 100 km of the New Jersey coast east of Seaside Park. The temporal and spatial development of the bloom suggest an onshore transport of cells once the population began to aggregate below the thermocline. By mid-June a large population of cells was situated below the thermocline in a relatively flat region of the New Jersey shelf between the 20 and 40 m isobaths. Much of this population was below the euphotic zone in a subthermocline layer about 15 m thick.[4] This is in marked contrast to the population off the Long Island coast where the slope of the shelf is initially greater and the maximum layer was well off the bottom in a subthermocline layer about 30 m thick[4] over most of its extent, i.e. the layer of maximum cell density tended to intersect the shelf along an isobath rather than to distribute over a surface. Maximum population size was probably achieved after March and before July, and population size declined rapidly during July.

There is no evidence that the C. tripos bloom influenced the growth of netplankton diatoms or nanoplankton populations. The distribution and abundance of these groups were similar to previous years' observations.

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[4] Armstrong, R.S., 1976. Climate conditions related to the occurrence of anoxia in waters off New Jersey during summer, 1976. National Marine Fisheries Service, Atlantic Environmental Group, Narragansett, Rhode Island. This report, p. 17-31.

4.0 Growth and Respiration of Ceratium tripos

Measurements of photosynthesis in the apex during February and March and off Long Island in late April - early May indicate that C. tripos was growing at a mean euphotic zone growth rate of 0.04 doublings day^{-1} (carbon specific growth; C:Chl = 275). Light saturated rates were 0.3 - 0.4 d^{-1} in agreement with the rates of cell division reported by Nordli (1958). Photosynthetic growth could account for the increase in population size observed prior to thermal stratification (January - March).

Once the water column stratified, the problem becomes more complex as euphotic zone nutrients were depleted and the C. tripos population aggregated near the base of the thermocline. While maximum cell densities were observed in June, it is possible that population size did not increase. Mathematically, the population was large enough by the end of March to account for observed cell densities in the maximum layer during June. Changes in cell density reflected changes in the distribution of cells as well as the balance between growth and mortality.

C. tripos photosynthesizes in the presence of sufficient light. In late April, C. tripos growth rates were 0.06 d^{-1} averaged over the euphotic zone and 0.02 d^{-1} at the 1% light depth. Local turbulence disrupted the C. tripos layer off Long Island in May (Fig. 12) resulting in a uniform distribution of cells across the euphotic zone. Productivity at this station was 3.5 g C m^{-2} d^{-1} giving a mean euphotic zone growth rate of 0.2 d^{-1}. A sample from 30 m (1% light depth) in the maximum layer in May had a productivity of 8 mg C m^{-3} d^{-1} and a growth rate of 0.02 d^{-1}. Thus, cells in the maximum layer in the lower reaches of the euphotic zone were probably growing at very slow rates photosynthetically (45 - 60 day generation times).

Within about 20 km of the New Jersey coast and 80 km of Sandy Hook, the bulk of the *C. tripos* population was located below the compensation light depth (compensation intensity = 100 - 150 uE m^{-2} d^{-1}) between the thermocline and the bottom. Two independent estimates of respiration rates (from measured photosynthesis-light curves and the carbon content of the cells) indicate that *C. tripos* respires about 3% of its cell carbon d^{-1} at 10°C. Consequently, some form of heterotrophic metabolism or continuous recruitment from offshore photosynthetic populations must have occurred to account for the observed increase in population density after the water column stratified.

5.0 Suspended Particulate Organic Matter and Phytoplankton Biomass in the Apex

Water column POC levels from September, 1973 through November, 1975 fluctuated about a mean of 9.8 g C m^{-2} (1 s.d. = 2.9). The maximum turnover time of this organic matter is 2 - 15 days (annual mean = 8 days) and reflects the fact that particulate organic matter (POM) does not tend to accumulate in the water column under most circumstances.

This rapid turnover of POM was not observed in February and March, 1976 (Fig. 14). During this period, POC accumulated in the water column to levels which were 2 - 3 times higher than previously observed. This increase coincided with the initial phases of the *C. tripos* bloom (Fig. 2). *C. tripos* accounted for 25 - 45% of suspended POC until the end of March when it accounted for 64%. Elimination of *C. tripos*-C from the suspended POC pool gives water column POC concentrations which reflect the diatom bloom in early March and are in the range of values previously reported (Fig. 14).

The influence of *C. tripos* on the pool of phytoplankton-C was enormous (Fig. 15). Prior to 1976, phytoplankton-C accounted for 15-45% of suspended POC with proportions of 35 - 45% typical of phytoplankton blooms regardless of time of year and dominant species. However, during February and March, 1976 phytoplankton-C increased from 56 - 84% of the suspended POC pool. Removal of *C. tripos* brings the proportion of phytoplankton-C back into the range usually observed in the apex and shows the diatom bloom peaking in early March (Fig. 15).

The gradual increase in the biomass of C. tripos and the accumulation of POC in the water column which occurred as a consequence did not appear to influence the typical development of the winter-spring diatom bloom.

Temporal variations in copepod abundance and grazing rates indicate that very little of the diatom bloom is grazed at temperatures below 10°C (Chervin, personal communication). Above 10°C selective grazing could become important since estuarine copepods (the major particle grazers in the apex) do not eat C. tripos, and increased copepod grazing pressure during the spring is probably a factor in the transition from netplankton to nanoplankton dominated phytoplankton blooms. C. tripos appears to be a slow growing species which is subject to low predation pressure.

6.0 Conclusions

6.1 Accumulation of Ceratium tripos off the New Jersey Coast

The temporal and spatial distributions of C. tripos in the New York Bight show an increase and a shift in maximum abundance from offshore prior to stratification to inshore as the water column stratified. The increase in cell density was most pronounced off the New Jersey coast. Two hypotheses have been suggested to account for these distributions, neither of which is mutually exclusive.

The first is similar to the accumulation mechanism demonstrated for Prorocentrum micans and other dinoflagellates in Chesapeake Bay.[5] It requires a two-layered circulation pattern with an onshore flow of bottom water and an offshore flow of surface water, organisms which aggregate in the bottom layer, and often an ability to survive extended periods of darkness. A two-layered, thermohaline circulation has been described for the New York Bight (Ketchum and Keen, 1955; Bumpus, 1965), and it has been well documented in this report that the C. tripos population aggregated near the upper boundary of the bottom layer. It is possible that most of the increase in population size occurred prior to stratification when the population was distributed throughout the euphotic zone and nutrients were plentiful. Once the water column stratified, *C. tripos* aggregated near the base of the thermocline throughout the Bight and the onshore movement of bottom water resulted in a shift in the location of maximum abundance from offshore to inshore. This process took place over a three month period (April - June), and, while we cannot determine whether the observed increase in cell density was a consequence of growth or an aggregation of cells, it is obvious that some form of anabolic metabolism was required to satisfy cellular respiratory demands during this period. Since the *C. tripos* layer was located between the 1% and 3% light depths over most of the outer Bight more than 20 km from the New Jersey coast, it is likely that the population in this region was synthesizing organic matter by photosynthesis.

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While some form of shoreward entrainment must have taken place, several objections exist which question the importance of this mechanism. (1) A shoreward flow of bottom water would not only transport C. tripos into the region where the oxygen minimum layer was most pronounced, but also oxygenated water. (2) Estimates of photosynthetic growth rates at the 1% light depth were 0.02 d^{-1} in both late April and in May. However, the rate of increase of population density from May to June off the New Jersey coast and along the New Jersey coast was 0.04 d^{-1}. If the coastal population was being maintained by recruitment from offshore populations, the increase in cell density must have reflected an increase in concentration rather than an increase in population size. (3) Nitrate + nitrite concentrations were low throughout the water column across the shelf except in the apex (Fig. 16). The nitrogen budget for the apex during May - July, 1975 (Table 1) indicates that the nitrogen supply to the euphotic zone and phytoplankton uptake rates are high and closely coupled and that regenerated ammonia is the main source of nitrogen. Phytoplankton blooms during May and June are usually dominated by small-celled phytoplankters growing at mean euphotic zone rates of 0.5 - 2.0 d^{-1}. These blooms are localized in the surface mixed layer (upper 10 m of the water column) and are most pronounced off the New Jersey coast. There is no evidence that *C. tripos* influenced the development of these blooms during June, 1976, and nanoplankton chlorophyll concentrations in the surface layer were similar to previous years. The nutrients required for nanoplankton growth are derived from estuarine runoff and regeneration above the thermocline (Malone, 1976 c). Considering the distribution of *C. tripos* and its photosynthetic growth rate, it is unlikely that it was competing (or could compete) with nanoplankton populations for these nutrients. If photoautotrophy was involved in the maintenance or growth of the sub-thermocline population, nutrient inputs must have been greater than in previous years and must have involved onshore transport of bottom water across the shelf. However, if *C. tripos* is capable of "luxury" nutrient uptake and can store nutrients for periods of weeks to months, the nutrient distributions of May and June might not be a factor. (Although luxury consumption of this magnitude has never been reported.)

Presumably, the collapse of the bloom in June and July was a consequence of the exhaustion of nutrient supplies (internal or external). Grazing is unlikely since copepods have been shown not to eat *C. tripos*.

The second hypothesis involves heterotrophic growth (or maintenance) by the *C. tripos* population situated below the Hudson River plume off the New Jersey coast. This hypothesis is also based on circumstantial evidence. (1) The growth of *C. tripos* had no obvious effect on the growth of diatom populations during May and June in the apex. Yet, the growth of *C. tripos* during February and March increased the POC content of the water column by a factor of 2 or 3 over previous years. (2) *C. tripos* did not respond (as reflected in distribution of biomass) to estuarine runoff as other photoautotrophic populations did. The observed downstream increase in biomass (in contrast with the distribution of diatoms in February and March and nanoplankton in May and June) would develop if *C. tripos* was feeding phagotrophically on POM of estuarine origin or phytodetritus. Since *C. tripos* may have the ability to ingest POM, it is possible that the observed accumulation of *C. tripos* in the water column was a consequence of phagotrophic uptake of POM which settled to the bottom or washed out of the system in previous years. Aggregation near the bottom of the thermocline would be advantageous in that the population is in a region where POM tends to accumulate as it settles through the water column. By metabolizing POM in the water column which was previously lost from the system, a substantial increase in water column BOD would be generated without necessarily increasing the input of nutrients or POM. Based on the proportion of C.tripos-C in the POC pool of the water column at the end of March (64%), it is possible that as the discharge of the Hudson River began to decline in May and June (Fig. 17), the population off the New Jersey coast suffered mass mortalities due to limited food supplies.

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[5] Tyler, M.A. and H. H. Seliger, 1976. Long-range, subsurface transport of the mahogany tide-forming dinoflagellate in the Chesapeake Bay. Abstract, 39th Annual Meeting, ASLO.

6.2 Ceratium tripos and the Oxygen Minimum Layer

The role of C. tripos in the development of the oxygen minimum layer off New Jersey is difficult to evaluate in the absence of data on the time and space distribution of dissolved oxygen in the bottom layer and more complete information of the time and space distributions of POC, chlorophyll a and C. tripos. The apex of the New York Bight has been subject to considerable organic loading over the past two decades, and the development of oxygen minimum layers and local anoxia are not unusual during the summer in the apex.

However, based on the effect of C. tripos on the content of POC in the water column and on the development of large, sub-thermocline populations, it is likely that C. tripos was involved in producing the oxygen demand required to account for the oxygen minimum layer. In the latter context, a flocculent suspension of organic matter at least 1 cm thick coated the bottom during July between Sandy Hook and Atlantic City from 5 to 50 km offshore (Frank Steimle, personal communication). The floc consisted primarily of phytoplankton cells dominated by C. tripos. Microscopic examination indicated a steady increase in the decomposition of C. tripos cells during July. The few diatoms present appeared to decay more slowly, and decomposition was more complete off northern than southern New Jersey by the end of July.

A computer simulation model was built at Brookhaven National Laboratory to explore the combined effects of benthic respiration and C. tripos respiration on the rate of oxygen depletion below the thermocline. C. tripos respiration rates were calculated from the expression $R = aW^b$ (Banse, 1976) where a and b are temperature-dependent constants and W and R are the weight of the cell in picograms of carbon and the respiration rate in picograms of carbon/cell/hr, respectively. The carbon content of C. tripos was calculated from both CHN analysis and regression of netplankton chlorophyll a on netplankton carbon. The values range from 20,000 to 30,000 pg/cell^{-1}, and a mean value of 25,000 was chosen for calculation of respiration rates. Using a $Q_{10} = 2.3$ the specific respiration rate of a single cell was calculated as 0.003 hr^{-1} at 10 C.

The following additional information was input.

(1) A mean benthic respiration rate of 11 ml O_2/m^2 hr^{-1} (1.0 mg at O_2/m^2 hr^{-1}) was calculated from Thomas, et al., (1975) for an "average" community in the New York Bight.

(2) Eddy diffusion coefficients of 1.0 cm^2 sec^{-1} across the thermocline and 10 cm^2 sec^{-1} below the thermocline were used.

(3) The thermocline was placed 25 m above the bottom.

(4) The overlying water was nearly saturated with oxygen, starting with 0.6 mg-at O_2 l^{-1} (= 6.72 ml·l^{-1}).

(5) Using data collected on six cruises, the following numbers of cells were placed in the bottom 20 m: (a) 0-5m (above the bottom) 2 x 10^7 cells/m^3; (b) 5-10m, 4 x 10^7 cells/m^3;

(c) 10-15m, 6 x 10^7 cells/m^3; (d) 15-20m, 2 x 10^8 cells/m^3; (e) 20-25m, 0cells/m^3. (The exclusion of cells from the upper 5 m is due to the consideration that these cells may be at or above the compensation depth and do not contribute substantially to oxygen depletion.)

The model output indicates that within two months the oxygen concentration in the bottom 5 m layer reaches a steady state concentration which is 45% of the initial oxygen concentration. The simulated rate of oxygen depletion below the thermocline is extremely sensitive to changes in eddy diffisivity, and small decreases in diffusivity are sufficient to cause simulated anoxia.

These calculations show the potential metabolic influence of C. tripos. The water column integrated C. tripos respiration rate exceeds the benthic oxygen consumption rate by a factor of 19.5. C. tripos biomass is also a large potential source of BOD. Oxidation of the C. tripos biomass (3255 mg-at C m^{-2}) within 20 m of the bottom would require 8463 mg-at O_2 m^{-2} or 71% of the initial oxygen content. Thus, the combined effects of respiration and subsequent death and decay of the biomass are more than sufficient to produce anoxia under the conservative conditions of the model.

The occurrence of an oxygen minimum layer and local anoxic waters off the New Jersey coast in contrast to the Long Island coast may reflect differences in bottom topography, residence time of water in the bottom layer and turbulent mixing. The shelf within 50 km of the coast is much flatter and shallower off New Jersey than off Long Island. As a consequence, the C. tripos layer between the 20 and 40 m isobaths off New Jersey was distributed over the bottom surface in a sub-thermocline water column 5 - 15 m thick while the C. tripos maximum off Long Island intersected the bottom along an isobath and was well off the bottom (> 30 m) over most of its extent. In addition, high cell densities occurred over larger areas off New Jersey. These observations and the possibility that the residence time of bottom water is longer off New Jersey than off Long Island could explain the development of a more intense and widespread oxygen minimum layer off New Jersey.

Phytoplankton productivity per se was probably not a major factor even though it quantitatively accounts for most of the input of particulate organic matter to the region. With the exception of winter diatom blooms which apparently go ungrazed, there is no evidence that a significant portion of phytoplankton production accumulates below the thermocline during the summer. The dominance of small celled phytoplankton (usually less than 10 um in diameter), vertical chlorophyll a distributions, the importance of ammonia as a nitrogen source for phytoplankton, and the rapid increase in zooplankton grazing pressure during May and June are consistent with the rapid turnover of POC calculated for the apex in the absence of C. tripos. In effect, the C. tripos bloom provides a mechanism by which large quantities of POC can be accumulated over an extended period (several months). Respiratory oxygen consumption by a sub-thermocline population below the euphotic zone and the rapid (weeks to months) decomposition of the accumulated biomass were the most probable factors contributing to the development of the extensive oxygen minimum layer off the New Jersey coast. It was the change in the relative abundance of phytoplankton species and the effects of this change on the distribution and quantity of POC in the sub-thermocline water column which was most important in terms of the role of phytoplankton. Unfortunately, it is this type of species succession problem which we understand least. The basic question of why the *C. tripos* bloom occurred in the first place remains unanswered.

7.0 Future Research and Monitoring

Our inability to deal with the question of why C. tripos became so abundant over such a large area is indicative of two major problems, one related to basic research and the other to communications between the various government agencies and private research groups working in the New York Bight and adjacent waters. Scientifically, we do not know enough about the processes which influence the succession of species in planktonic communities. Of prime importance is increased funding for field and laboratory research designed to study the biology of planktonic species and the environmental regulation of their growth and distribution in the field.

In terms of the organization of field and laboratory studies and monitoring programs, emphasis should be placed on (1) coordinated sampling programs which involve the measurement of a minimum number of easily determined variables and (2) rapid collation and dissemination of data between agencies and research groups. The "minimum number of easily determined variables" includes the concentrations of particulate organic carbon, particulate nitrogen and chlorophyll a, phytoplankton and zooplankton species abundance, and zooplankton dry weight. Other variables which should be measured in conjunction with these include dissolved oxygen, ammonia, nitrite, nitrate, phosphate and silicate concentrations, incident solar radiation and the rate of attenuation of downwelling radiation in the water column. Samples should be collected weekly at select stations along the coast (e.g. Barnegat Inlet, Ambrose

Light Tower, Fire Island Inlet) from at least surface and near-bottom depths. Each month, three transects should be run across the continental shelf to 1000 m, one originating from and normal to the Long Island coast, a second originating from and normal to the New Jersey coast, and a third originating from the Ambrose Light Tower and bisecting the Bight. Stations should be located at 5 - 20 km intervals and samples collected from standard depths. Wherever and whenever possible, continuous vertical and horizontal profiles of temperature, salinity, dissolved oxygen and chlorophyll a should be obtained.

Such a monitoring program should be designed with three major goals in mind: (1) to provide information which can be used to evaluate the causes of anomolous phenomena after the fact, (2) to provide information which can be used to make management decisions, and (3) to provide information which can be used to develop research programs in advance of anticipated events. The success of this program will be determined by the quality of the information produced and by how rapidly it can be made available to the groups involved. The speed with which information is disseminated is critical. All samples must be processed within one week of collection. Unusual observations, events or trends should be communicated and discussed verbally, and hard copy data reports (with comments on anomolies) should be made available to all involved parties each month within one month of sample collection.

8.0 Acknowledgments

The data presented herein was collected as part of research projects and monitoring programs conducted by NOAA (Marine Ecosystems Analysis Project and National Marine Fisheries Services), ERDA (Brookhaven National Laboratory) U.S. E.P.A. and the New Jersey Department of Environmental Protection. This report was made possible by the complete cooperation of the workshop participants and the institutions and agencies which they represent. It is hoped that this will mark the beginning of a trend of increased dialogue and cooperation as monitoring and research programs develop in our heavily utilized coastal and estuarine environments.

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Table 1. Time and space averaged nitrogen budgets for the apex of the New York Bight (1974, 1975) calculated from estuarine discharge and respiration estimates of Garside and Malone (in press) and primarily productivity (based on an area of 1250 km^2 and assuming a C:N ratio = 6 by weight).

		10^5 kg N day^{-1}
February-March		
Inputs:	Estuarine runoff	1.6
	Regeneration[1]	2.2
Phytoplankton Uptake		2.7
Input - Uptake		2.3
May-July		
Inputs:	Estuarine runoff	1.4
	Regeneration[2]	3.2
Phytoplankton Uptake		3.8
Input - Uptake		0.8

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[1] Water column + benthic regeneration

[2] Water column regeneration only

Figure 1. The New York Bight: (A) - lower Hudson and Raritan River Estuaries, (B) - apex of the New York Bight, (C) - outer New York Bight.

Figure 2. Temporal variations in Ceratium tripos cell density in the New York Bight from January to August, 1976; ▲ - Fire Island Inlet, data provided by Sylvia Weaver; ● - apex of the New York Bight, data provided by Tom Malone; ○ - Long Island shelf inshore of the 75 m isobath, data provided by Paul Falkowski and Wayne Esaias; ■ - New Jersey coastal waters, data provided by Myra Cohn, Paul Hamer, Paul Olsen and Frank Takacs.

Figure 3. Particle size frequency distributions (peak due to Ceratium tripos) from 8 km offshore of Fire Island (Long Island), data provided by Mike Dagg.

Figure 4. Relative abundance of Ceratium tripos along a transect which bisects the Bight from the apex to the continental slope; samples were collected with a Hardy Continuous Plankton Recorder towed at 10 m; data provided by Dan Smith and Bob Marrero.

Figure 5. Vertical profiles of chlorophyll concentration along a transect normal to the Long Island coast to the continental slope (stations 93 and 94 - continental slope; stations 95 to 97 - offshore of the 75 m isobath; stations 98 to 101, 66 and 72 - inshore of the 50 m isobath), data provided by Wayne Esaias.

Figure 6. Distribution of chlorophyll a (μg liter^{-1}) across

the shelf along transects originating in the apex and off the New Jersey coast (Seaside Park) and extending southeast; data provided by Wayne Esaias.

Figure 7. Distribution of maximum *Ceratium tripos* cell density (cells ml^{-1}) in the apex of the New York Bight; data provided by Tom Malone.

Figure 8. Distribution of surface salinity (ppt) in the apex of the New York Bight, data provided by Tom Malone.

Figure 9. Distribution of maximum chlorophyll *a* concentration (μg $liter^{-1}$) in the apex of the New York Bight, data provided by Tom Malone.

Figure 10. Histogram of cell density across the shelf originating off Long Island (station 3) and extending south to the shelf break (station 1); stations 1, 2, and 3 were located in water 100, 50, and 30 m deep, respectively; data provided by Wayne Esaias.

Figure 11. Distribution of *Ceratium tripos* as indicated by the degree to which 0.333 um mesh nets were clogged by *Ceratium tripos* during March, 1976; data provided by NMFS, Sandy Hook Laboratory.

Figure 12, Distribution of surface chlorophyll *a* (μg $liter^{-1}$) from underway fluorescence (a) and *Ceratium tripos* cell density (cells ml^{-1}) in the chlorophyll *a* maximum layer (b) during 17-24 May, 1976; data provided by Wayne Esaias.

Figure 13. Distribution of surface chlorophyll *a* (ug $liter^{-1}$) from under fluorescence (a) and *Ceratium tripos* cell density (cells ml^{-1}) in the chlorophyll *a* maximum layer (b) during 9-13 June, 1976; data provided by Wayne Esaias.

Figure 14. Temporal variations in mean water column particulate organic carbon content of the apex from September, 1973 to April, 1976; vertical bars = 1 s.d.; data provided by Tom Malone.

Figure 15. Temporal variations in the proportion of water column particulate organic carbon accounted for by phytoplankton in the apex from September, 1973 to April, 1976; data provided by Tom Malone.

Figure 16. Distribution of dissolved nitrate + nitrite (ug-at N $liter^{-1}$) across the shelf along a transect originating in the apex and extending southeast; data provided by Wayne Esaias.

Figure 17. Fresh water flow (10^3 cfs = 28 m^3 sec^{-1}) of the Hudson River at Green Island during May and June, 1976; data provided by the New York Department of Water Resources.

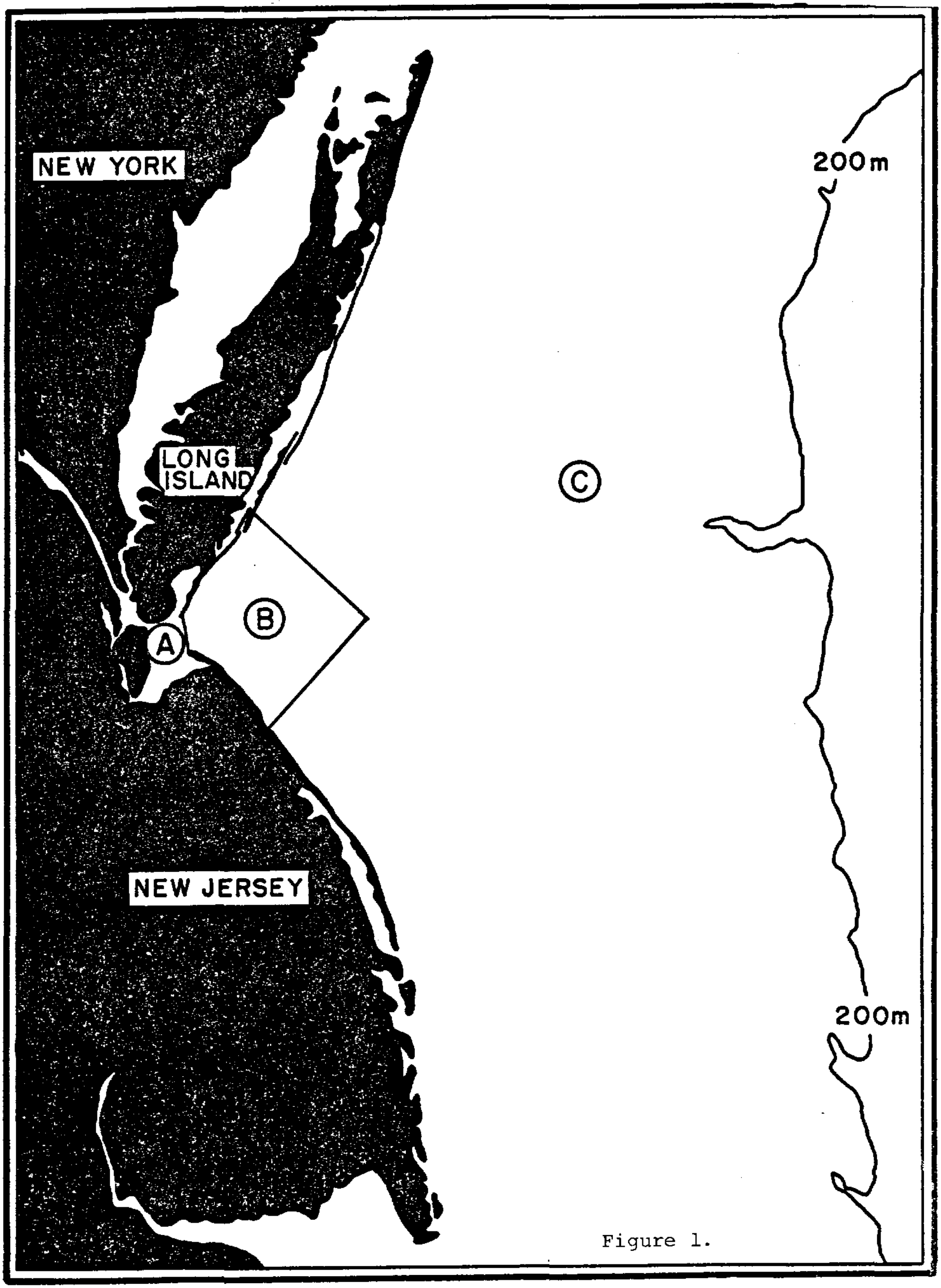
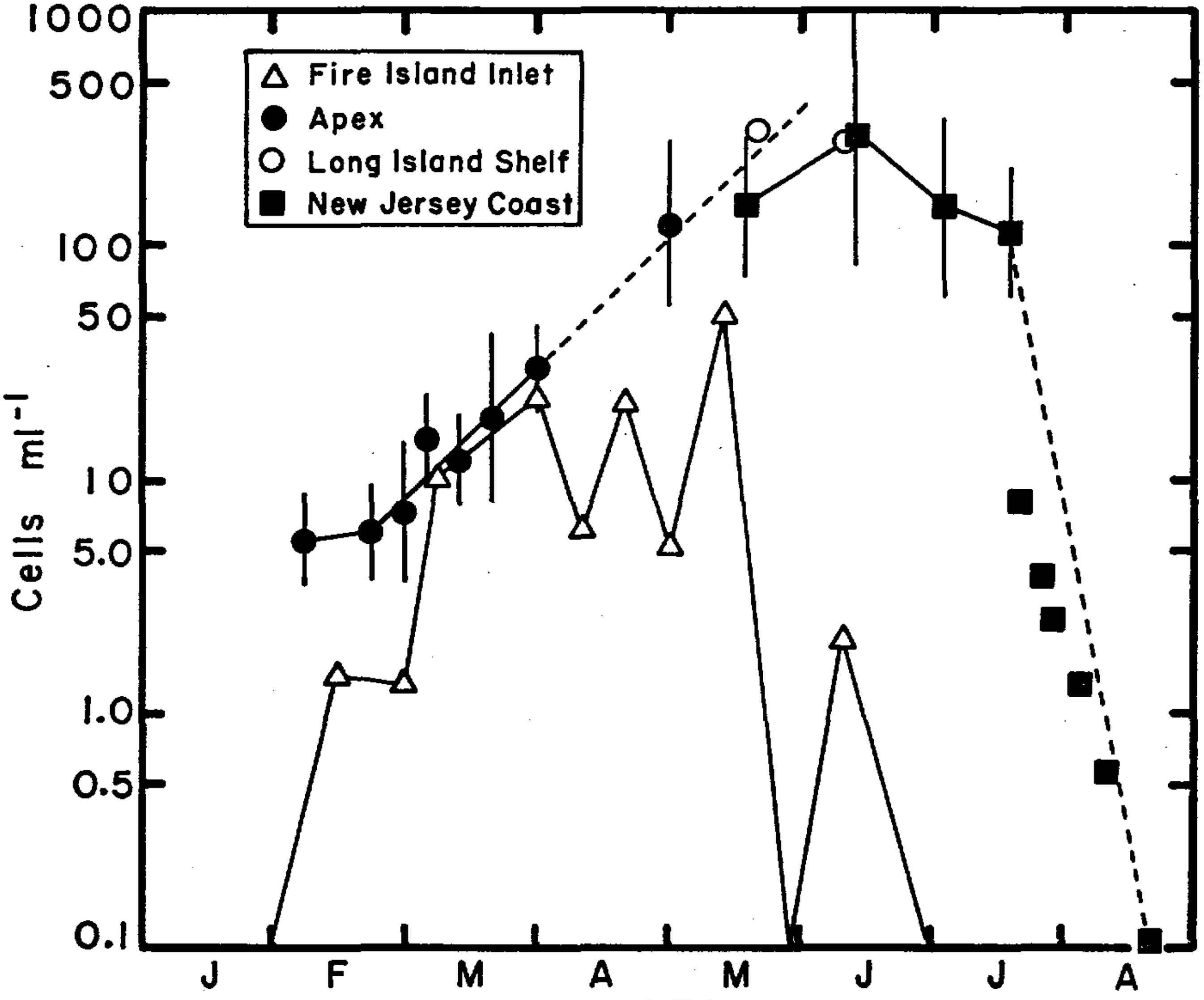


Figure 1.



△ Fire Island Inlet
● Apex
○ Long Island Shelf
■ New Jersey Coast
Cells ml⁻¹
1000
500
100
50
10
5.0
1.0
0.5
0.1
J
F
M
A
M
J
J
A
1976

Figure 2.

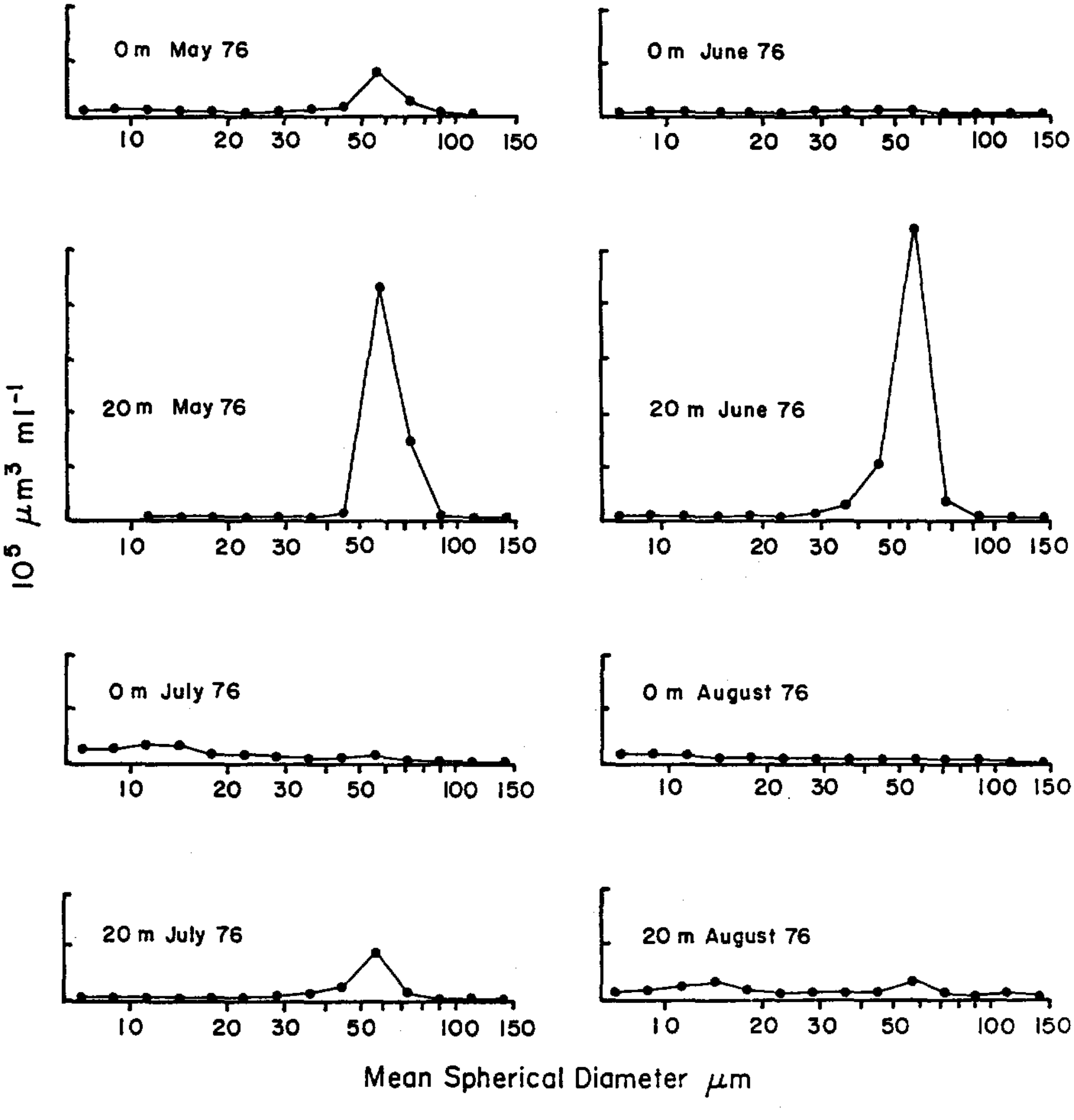

0 m May 76
0 m June 76
20 m May 76
20 m June 76
0 m July 76
0 m August 76
20 m July 76
20 m August 76
10
20
30
50
100
150
10^5 µm³ ml⁻¹
Mean Spherical Diameter µm

Figure 3.

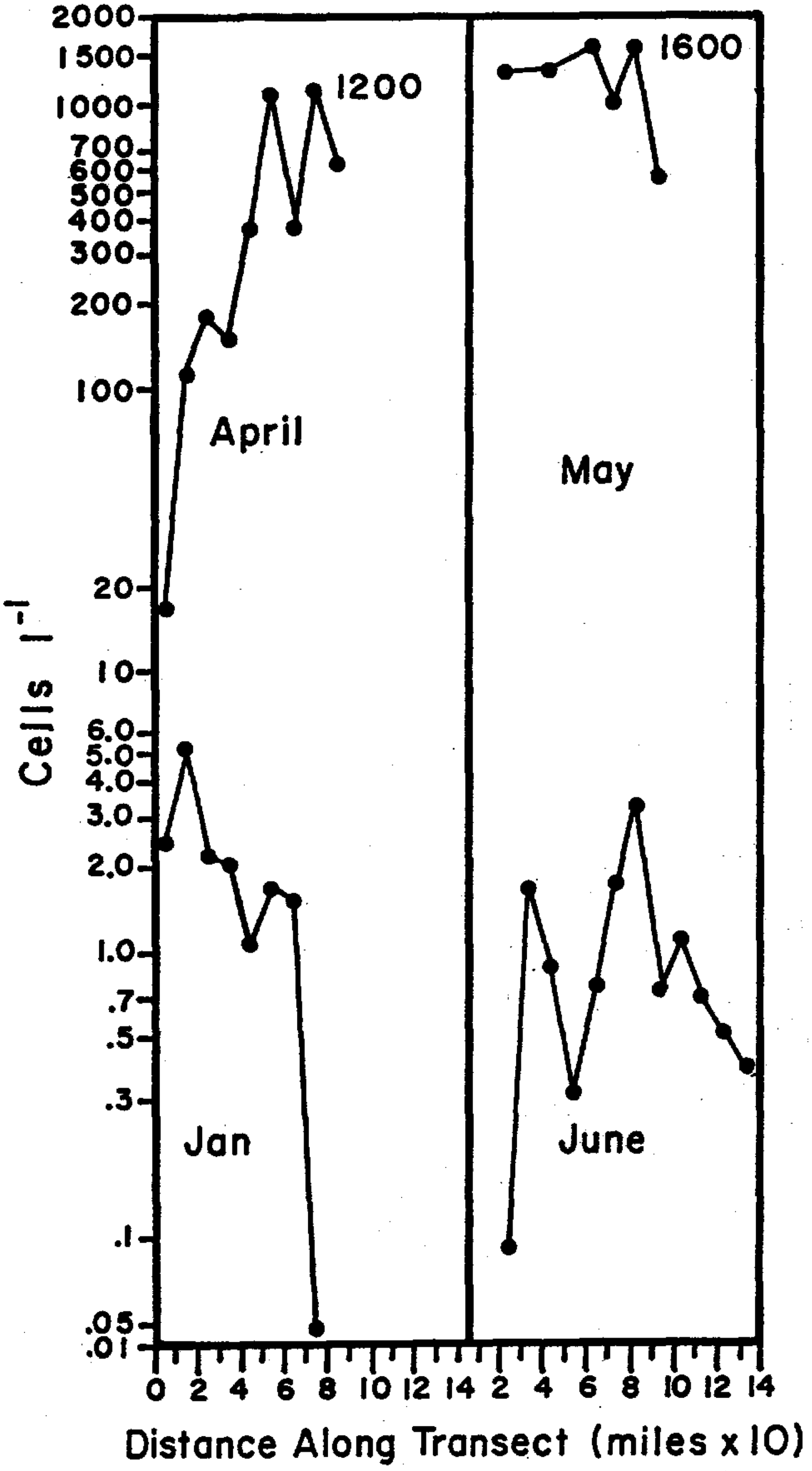

2000
1500
1000
700
600
500
400
300
200
100
20
10
6.0
5.0
4.0
3.0
2.0
1.0
.7
.5
.3
.1
.05
.01
Cells l^{-1}
April
1200
May
1600
Jan
June
0 2 4 6 8 10 12 14 2 4 6 8 10 12 14
Distance Along Transect (miles x 10)

Figure 4.

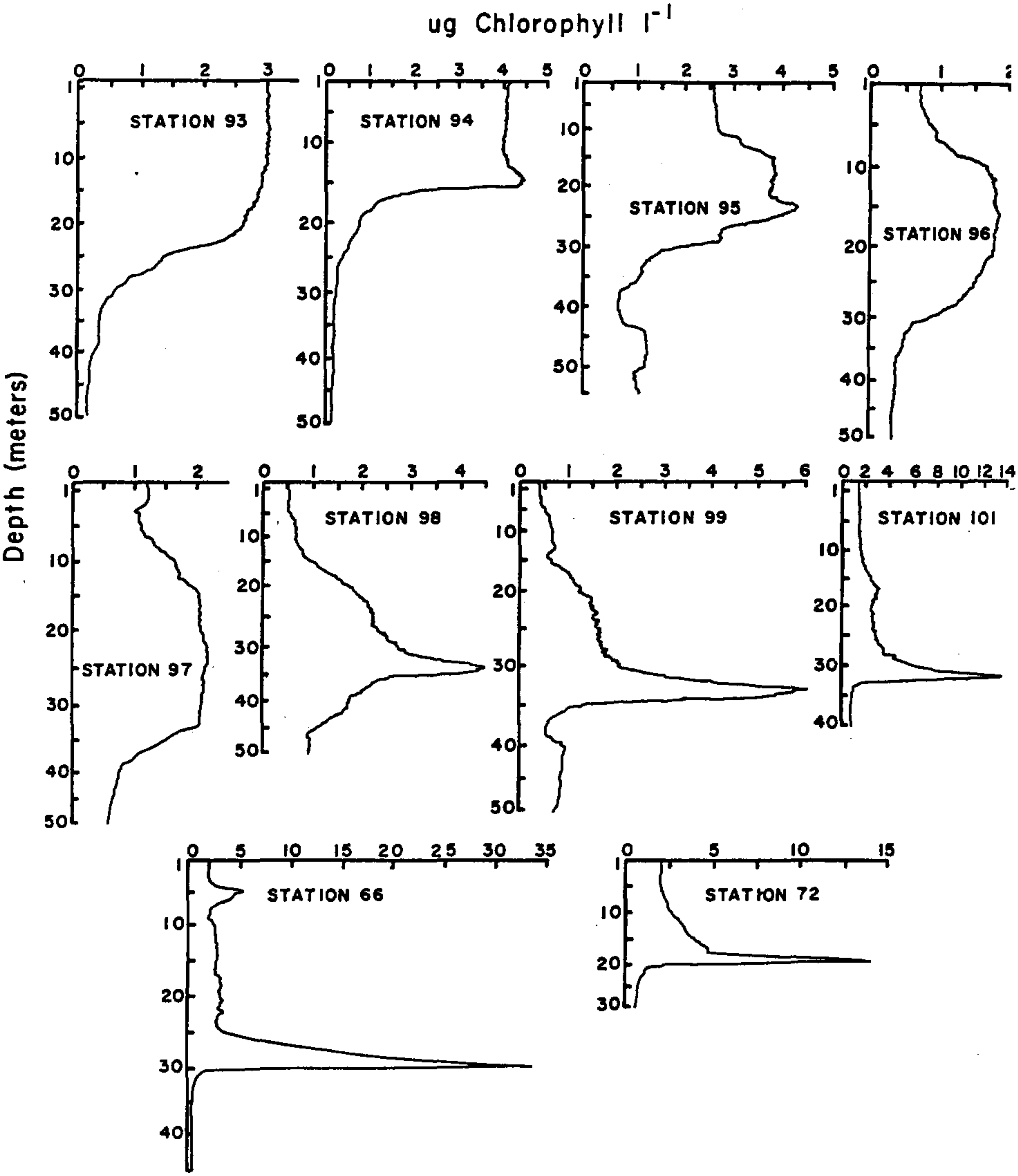

ug Chlorophyll l⁻¹
Depth (meters)
STATION 93
STATION 94
STATION 95
STATION 96
STATION 97
STATION 98
STATION 99
STATION 101
STATION 66
STATION 72
0
1
2
3
4
5
6
8
10
12
14
15
20
25
30
35
40
50

Figure 5.

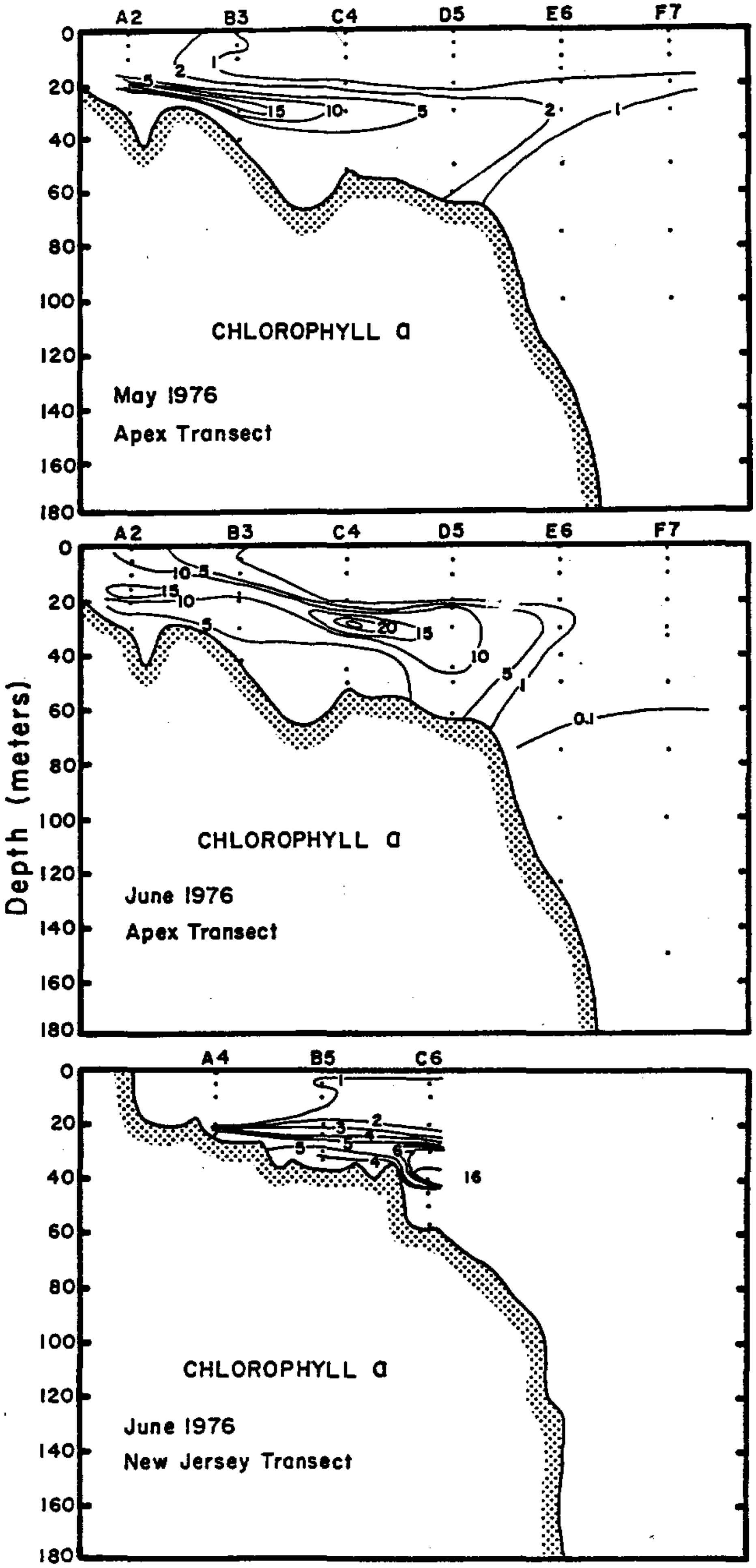
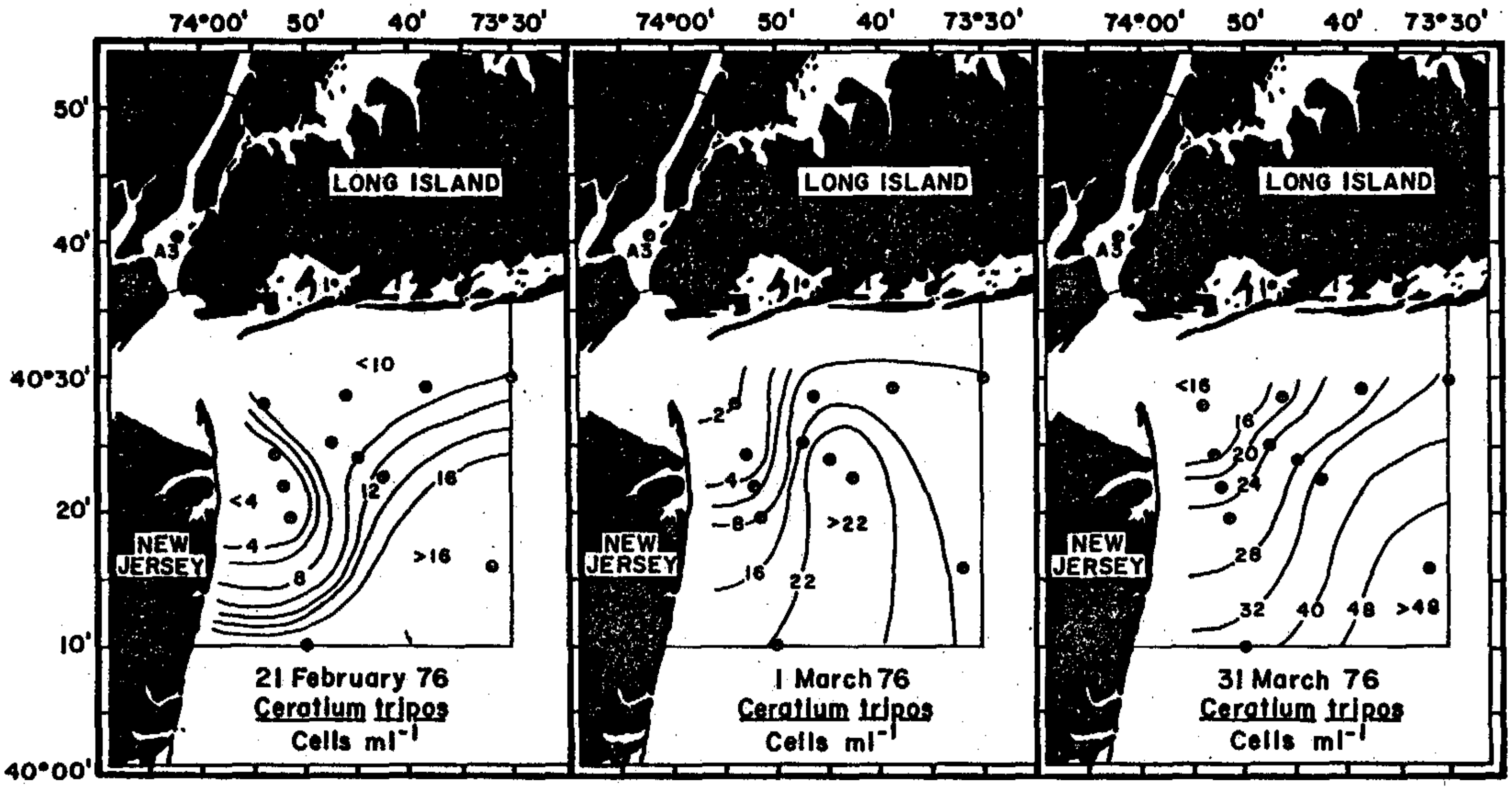

A2
B3
C4
D5
E6
F7
0
20
40
60
80
100
120
140
160
180
1
2
5
15
10
5
2
1
CHLOROPHYLL a
May 1976
Apex Transect
A2
B3
C4
D5
E6
F7
10
5
15
10
1
5
20
15
10
5
1
0.1
CHLOROPHYLL a
June 1976
Apex Transect
Depth (meters)
A4
B5
C6
1
2
3
4
5
5
6
4
16
CHLOROPHYLL a
June 1976
New Jersey Transect

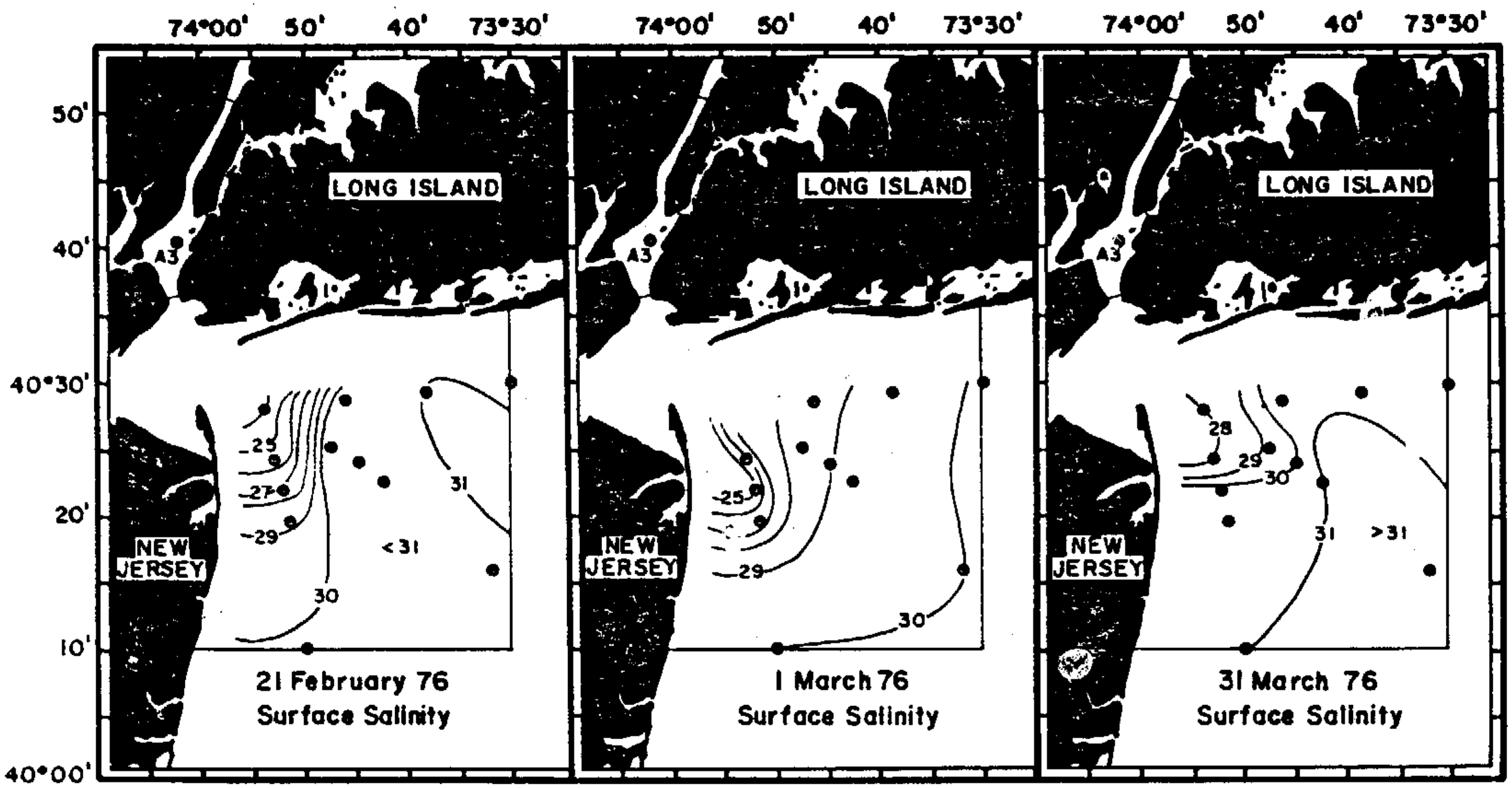
Figure 6.



21 February 76 *Ceratium tripos* Cells ml^{-1}

1 March 76 *Ceratium tripos* Cells ml^{-1}

31 March 76 *Ceratium tripos* Cells ml^{-1}

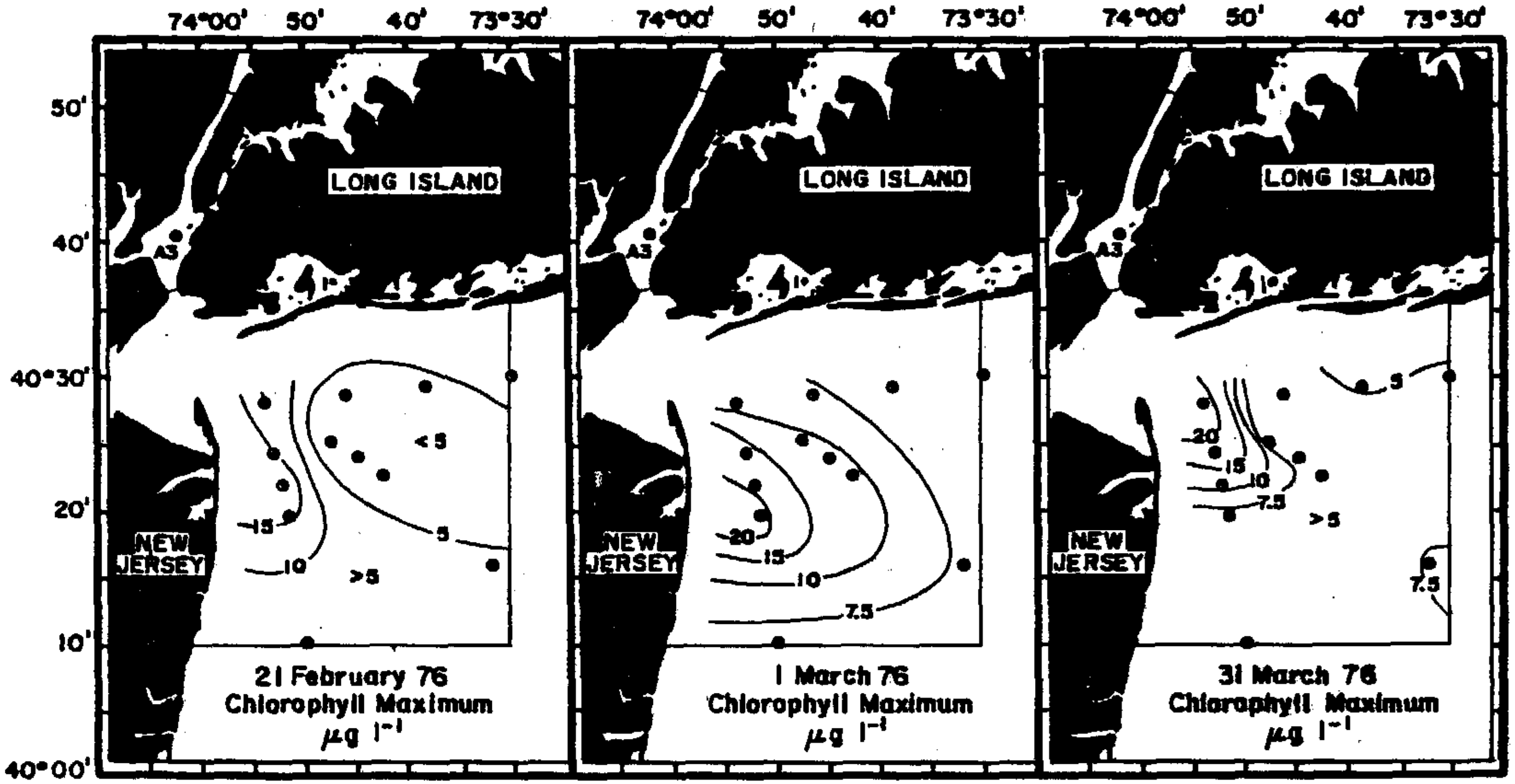


21 February 76
Surface Salinity

1 March 76
Surface Salinity

31 March 76
Surface Salinity

Figure 8.



21 February 76
Chlorophyll Maximum
$\mu g\ l^{-1}$

1 March 76
Chlorophyll Maximum
$\mu g\ l^{-1}$

31 March 76
Chlorophyll Maximum
$\mu g\ l^{-1}$

Figure 9

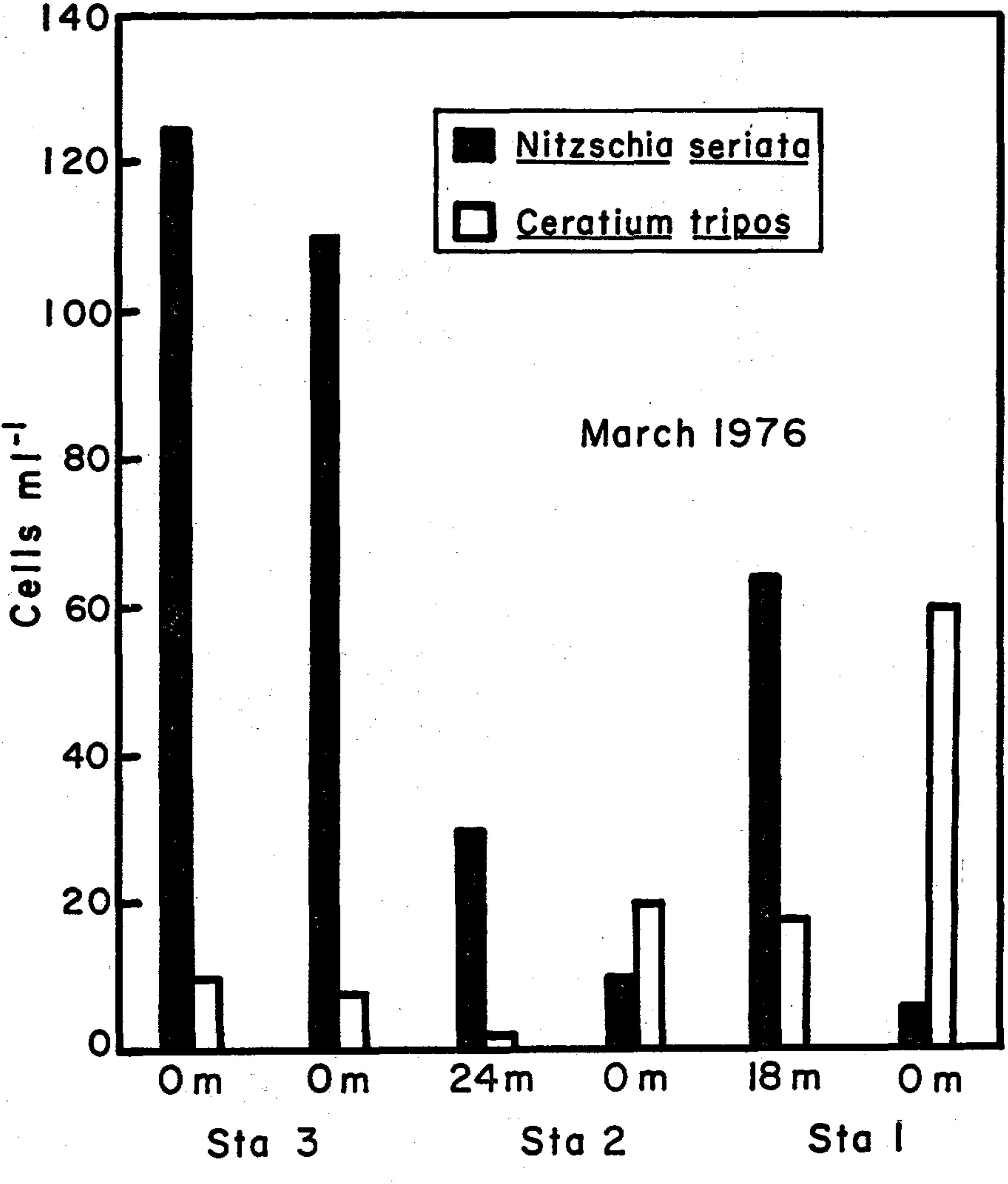

140
120
100
80
60
40
20
0
Cells ml^{-1}
Nitzschia seriata
Ceratium tripos
March 1976
0 m
0 m
24 m
0 m
18 m
0 m
Sta 3
Sta 2
Sta 1

Figure 10.

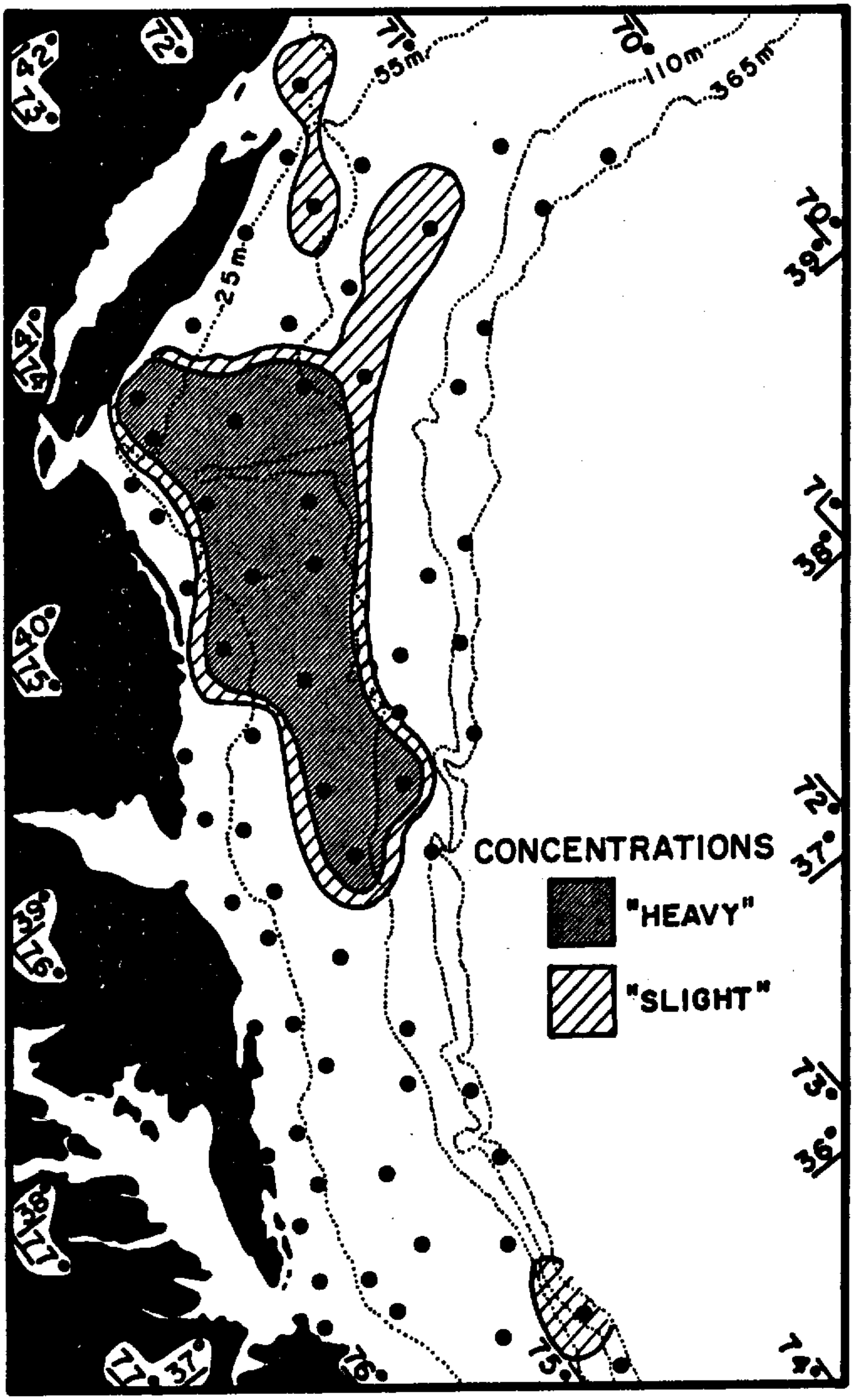

42°
73°
72°
71°
55m
70°
110m
365m
70°
39°
25m
41°
74°
71°
38°
40°
75°
72°
37°
CONCENTRATIONS
"HEAVY"
"SLIGHT"
39°
76°
73°
36°
38°
77°
77°
37°
76°
75°
74°

Figure 11,

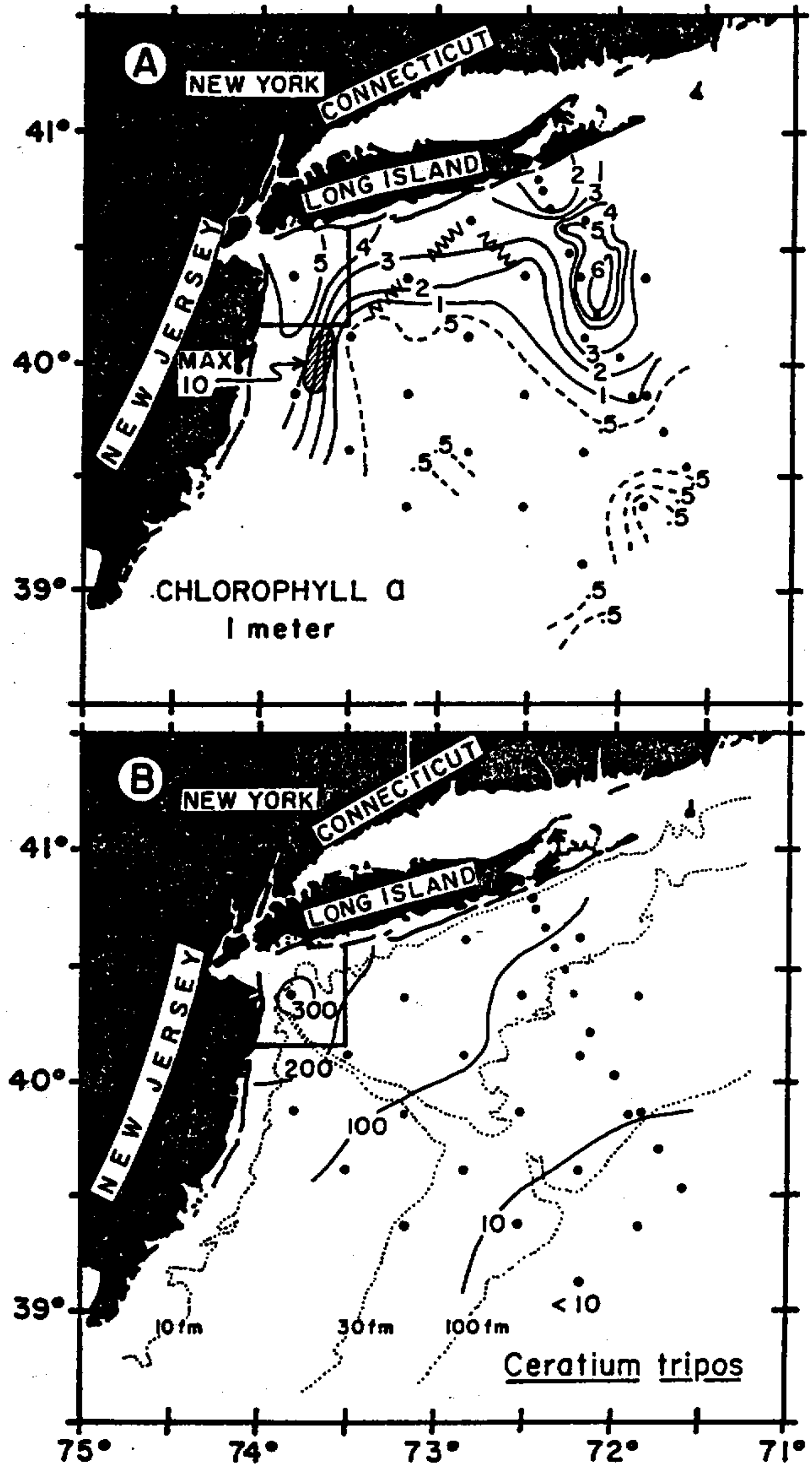

A
NEW YORK
CONNECTICUT
LONG ISLAND
NEW JERSEY
41°
40°
39°
MAX
10
1
2
3
4
5
6
.5
CHLOROPHYLL a
1 meter
B
NEW YORK
CONNECTICUT
LONG ISLAND
NEW JERSEY
300
200
100
10
< 10
10 fm
30 fm
100 fm
Ceratium tripos
75°
74°
73°
72°
71°

Figure 12.

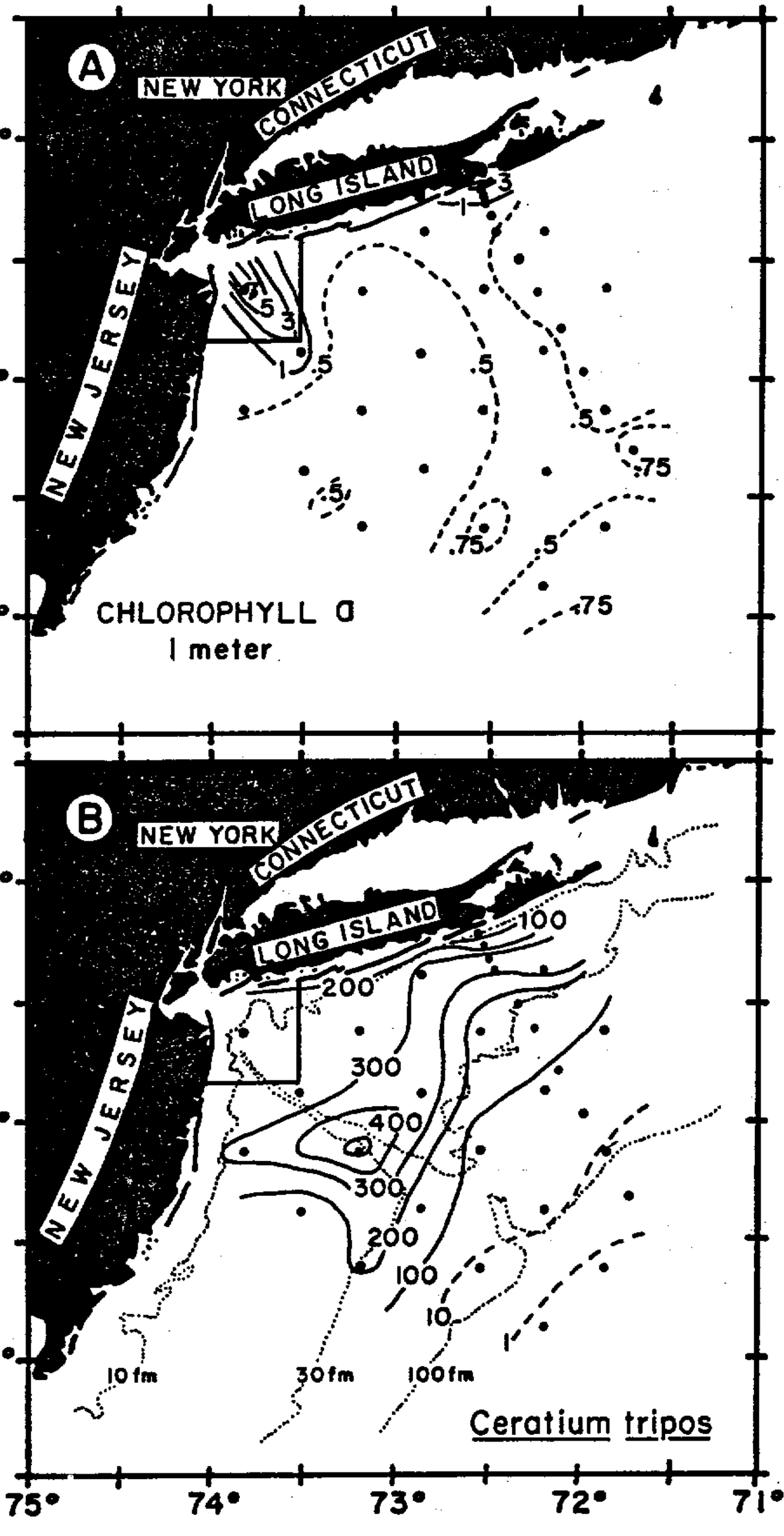

A
NEW YORK
CONNECTICUT
LONG ISLAND
NEW JERSEY
CHLOROPHYLL a
1 meter
.5
.75
1
3
5
41°
40°
39°
B
100
200
300
400
10
1
10 fm
30 fm
100 fm
Ceratium tripos
75°
74°
73°
72°
71°

Figure 13.

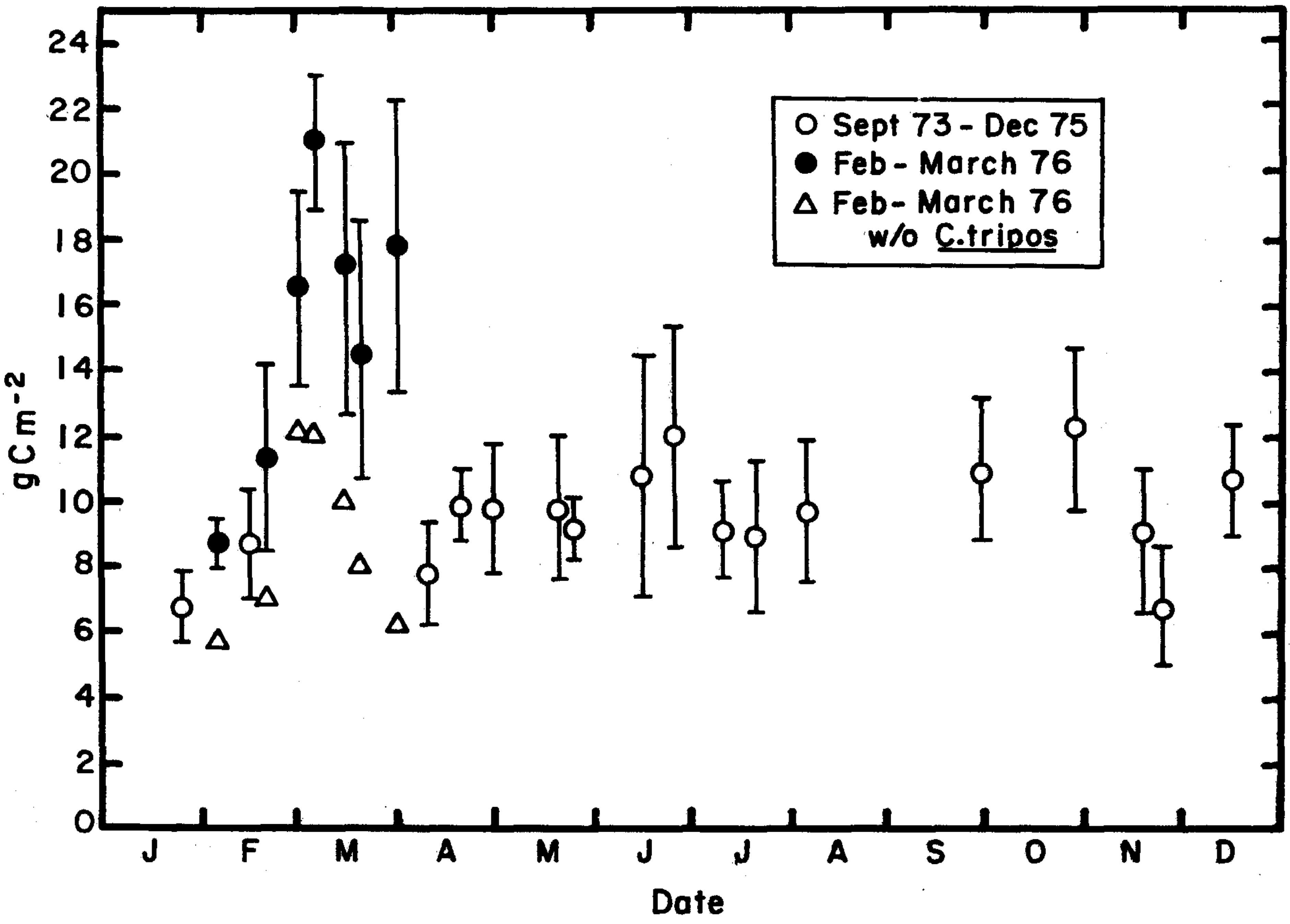
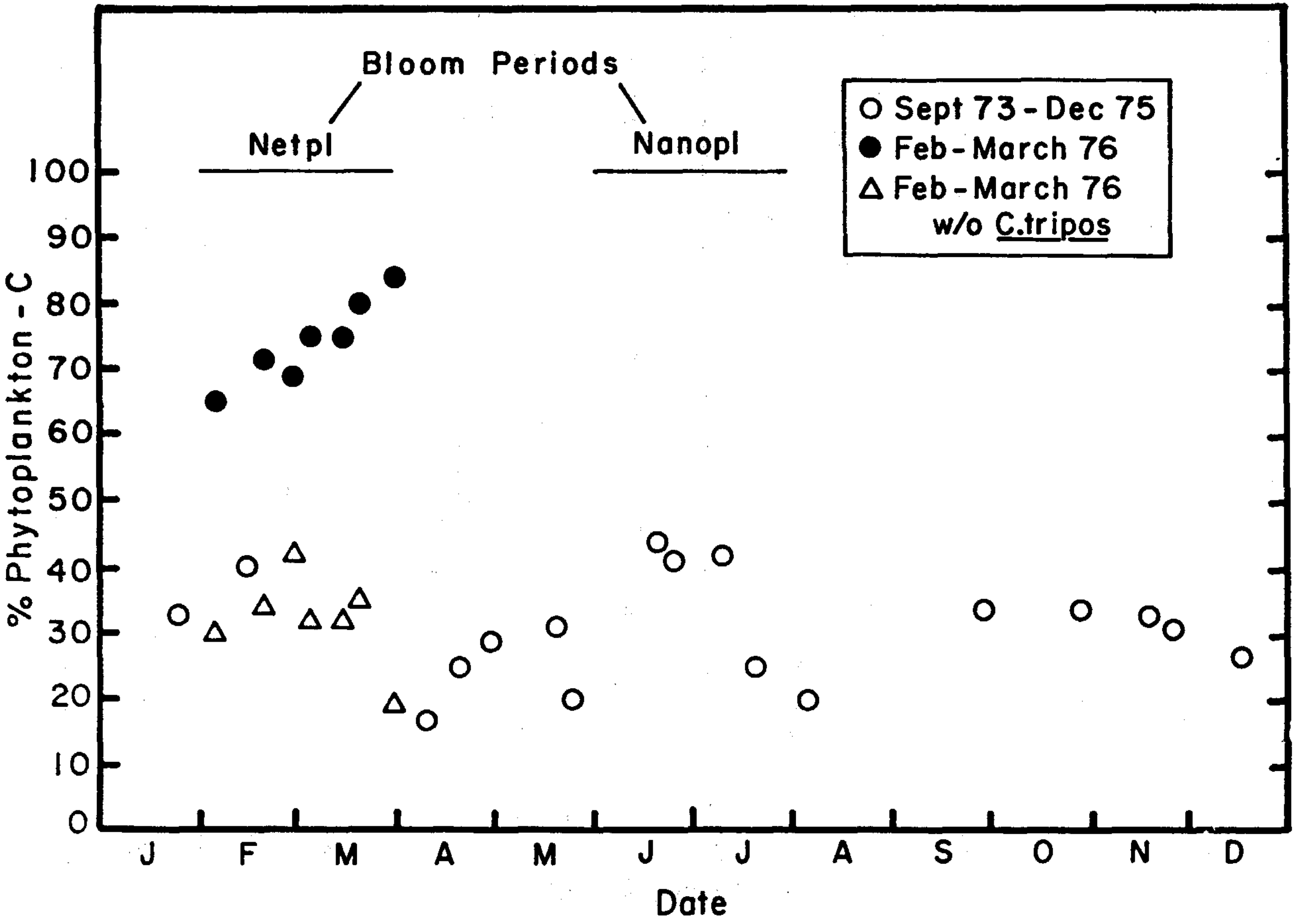

Sept 73 - Dec 75
Feb - March 76
Feb - March 76 w/o C.tripos
gCm-2
0
2
4
6
8
10
12
14
16
18
20
22
24
J
F
M
A
M
J
J
A
S
O
N
D
Date

Figure 14.


Bloom Periods
Netpl
Nanopl
○ Sept 73 - Dec 75
● Feb - March 76
△ Feb - March 76 w/o C.tripos
% Phytoplankton - C
0
10
20
30
40
50
60
70
80
90
100
J
F
M
A
M
J
J
A
S
O
N
D
Date

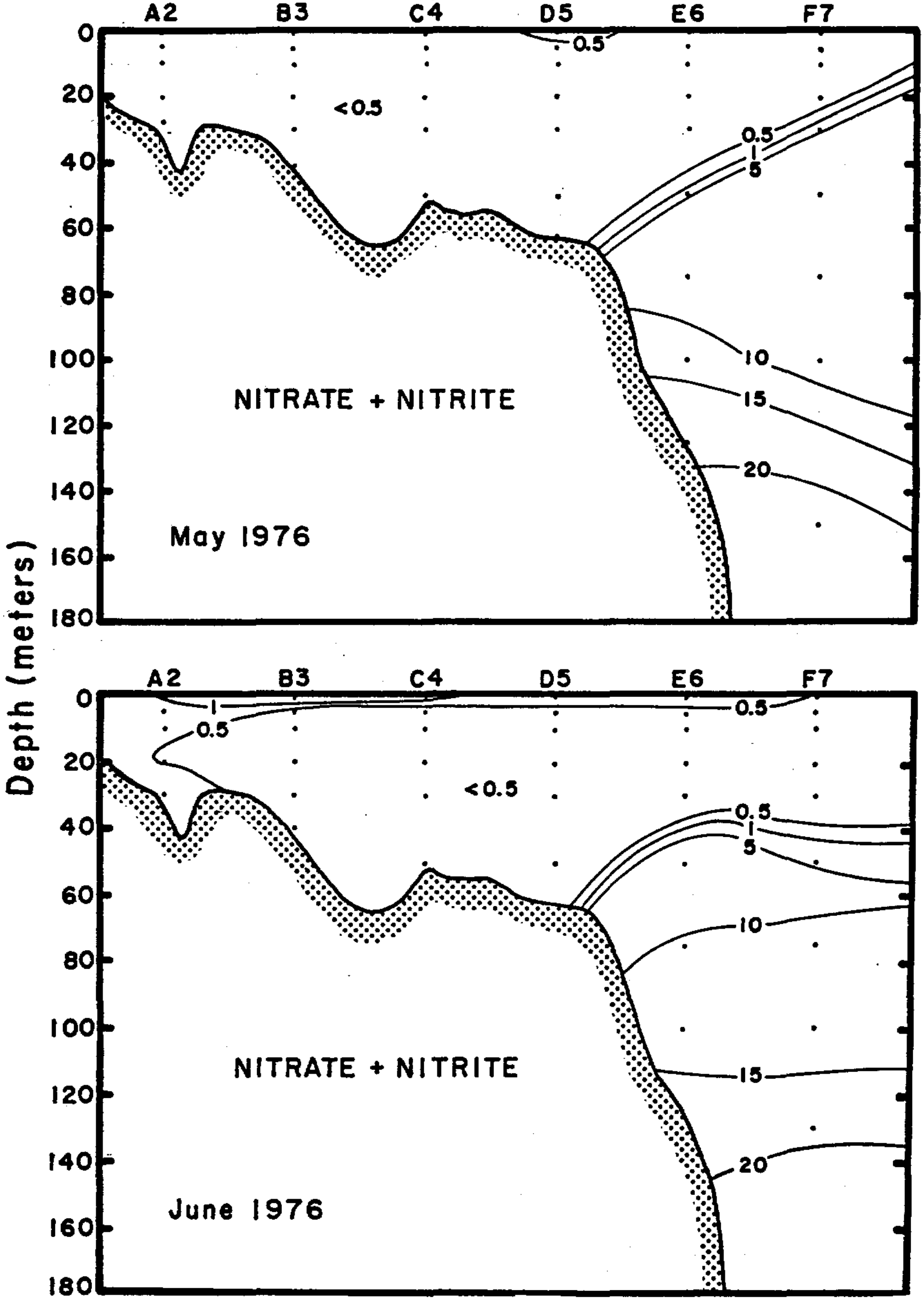

A2
B3
C4
D5
E6
F7
0
20
40
60
80
100
120
140
160
180
Depth (meters)
0.5
<0.5
0.5
1
5
10
15
20
NITRATE + NITRITE
May 1976
A2
B3
C4
D5
E6
F7
1
0.5
0.5
<0.5
0.5
1
5
10
15
20
NITRATE + NITRITE
June 1976

Figure 16.

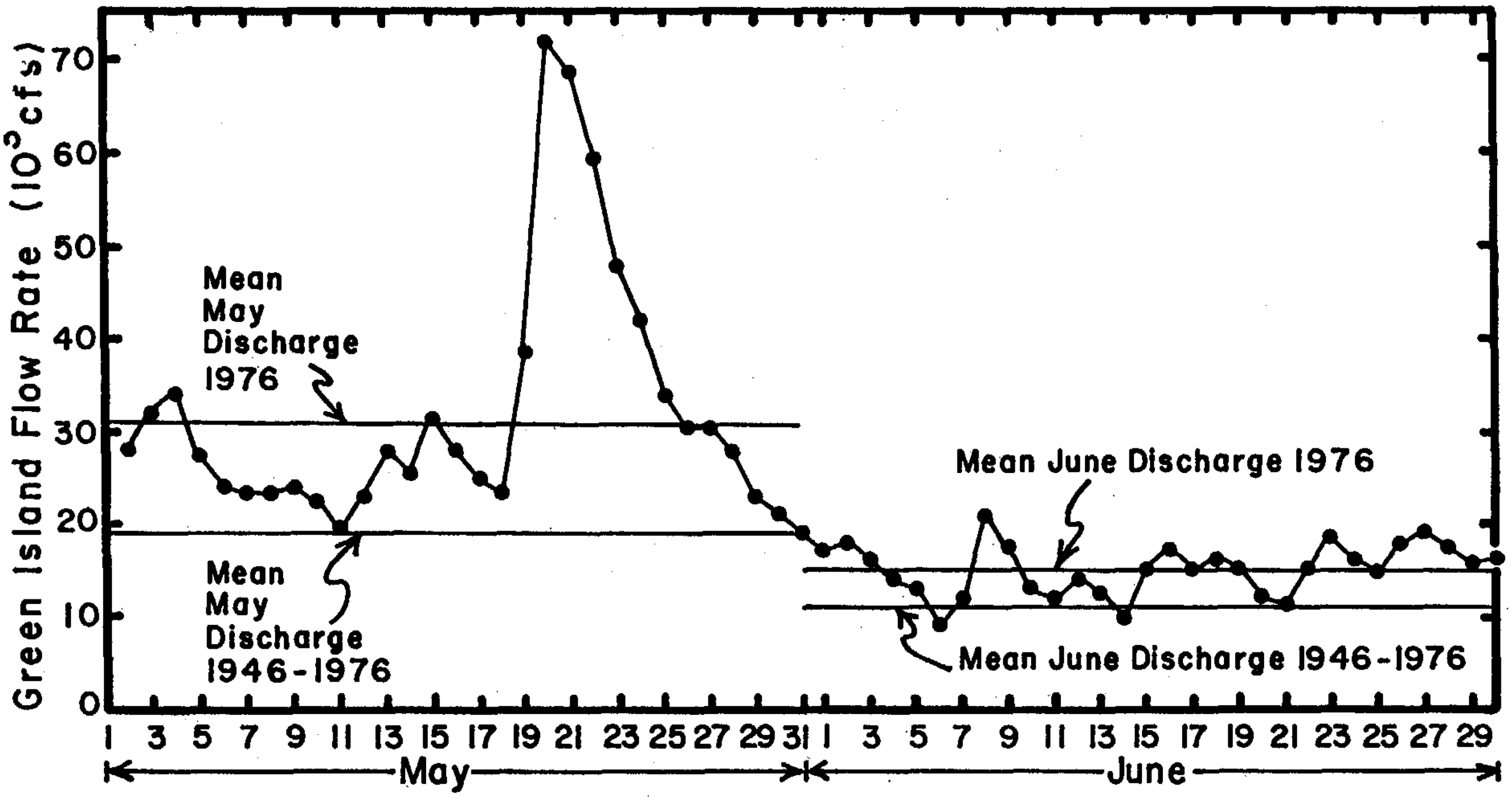

Green Island Flow Rate (10^3 cfs)
0
10
20
30
40
50
60
70
Mean May Discharge 1976
Mean May Discharge 1946-1976
Mean June Discharge 1976
Mean June Discharge 1946-1976
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
May
June

Figure 17.

APPENDIX I

OBSERVATIONS ON THE DECOMPOSITION OF A *CERATIUM TRIPOS* POPULATION IN NEW JERSEY COASTAL WATERS DURING JULY - AUGUST 1976

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Highlands, NJ 07732

Introduction

As already mentioned in the preceding Plankton Workshop report, an extensive layer of flocculent material was present on the bottom during the fish kill. Examination of initial samples of this material, diver-collected in early July, showed it was primarily an aggregate of cells of the dinoflagellate, *Ceratium tripos*. Since it was obvious that the decay of this material could contribute to the low oxygen situation then present, it seemed prudent to gather information on its composition and the decay process.

OBSERVATIONS

Sandy Hook Area

A surface sample collected on July 22, 3.7 km off Monmouth Beach, was dominated by *Prorocentrum redfieldi* but also contained abundant *Ceratium tripos*. A location 7.4 km south of Long Island, N. Y and 13 km east of Sandy Hook was sampled on July 30. In a sample from a depth of 4.5 m detritus bits were evident but this "floc" was different in composition from that seen earlier in the month in samples from other locales. In contrast to the previous *Ceratium* abundance, the dominant plankter in this material was the phytoflagellate *Olisthodiscus luteus*; some individuals were motile. A single live *C. tripos* cell and a fragment of another were seen. Diatoms were not abundant. In the mid-depth sample, at 11 m, "floc" was sparse; only a single bit which was reminiscent of that from the kill area was seen. In the bottom sample, at 27 m, "floc" was abundant. Although much of the material appeared unstructured, the diatom composition was similar to that seen in earlier samples. *Skeletonema costatum*, *Leptocylindrus danicus* and *Coscinodiscus* sp. were abundant. No *C. tripos* was evident except for possibly one individual which was difficult to positively identify because of advanced decay. Visible bacterial action was minimal.

The sludge dump area, approximately 20 km off Sandy Hook, was also sampled on July 30. In a sample collected at 5.5 m, a moderate amount of detritus material was present which contained a mixed collection of phytoplankters including some dinoflagellates, smaller nannoplankters, and diatoms, especially *S. costatum*; two ceratia, *C. tripos* and *C.*

lineatum were present. At 11 m, approximately the same amount of detrital material was collected. This again contained a mixed collection of plankters. C. tripos, both live individuals, and non-motile but apparently intact cells, were abundant. The bottom sample, at 27 m, contained the most amount of "floc" in this group of samples. The color was predominantly dark brown to black. Diatoms were the major component identifiable. Ceratium cells were not seen. Bacteria were present although not abundant. Two locations, 16 km off Monmouth Beach, N. J. and 20 km off Asbury Park, N. J., respectively, were sampled at 5 depths on August 4. Detritus bits were sparse in the surface samples. Small, non-motile nannoplankters were numerous; several species of diatoms were also seen. Little "floc", but a more abundant plankton occurred at 11-12 m. C. tripos, intact but non-motile, was numerous along with other flagellates, especially Dinophysis sp., and various diatoms and small nannoplankters. Basically the same plankton but in lesser abundance was present at 17-18 m. Ceratium was present at this depth only in the furthest offshore station. At 30 and 37 m, increased amounts of "floc" were found. The most significant changes in the plankton was the absence of Ceratium and the presence of numerous O. luteus. On the bottom, at 45-48 m, the "floc" was most abundant. O. luteus was again abundant; many of the cells were motile. Small nannoplankters were very abundant. Several species of diatoms, chiefly S. costatum, were present. Ceratium was not seen. Only minimal bacterial activity was evident.

Manasquan Area

On July 4, a diver obtained a sample of yellowish flocculent material from the bottom, 11 km off Manasquan, N. J. The dominant species in the aggregate, by biomass, at least, was *C. tripos*. *C. fusus* was also present as well as the diatoms *S. costatum*, *Coscinodiscus sp.*, *Nitzschia seriata*, *Thalassiosira nordenskioldii*, *L. danicus* and others. Most ceratia cells were disrupted in some way and empty of cytoplasm, although a few live individuals were also observed. Numerous bacteria, some motile, were also present in the mass.

Bottom samples from two locations in the same area (ca. 3 and 15 km off Manasquan, N. J.) collected on July 9 also contained a "floc" but, macroscopically, the color now appeared greyish. This material had the same general composition as the first sample but further decomposition of the *Ceratium* cells and a color change of much of the material from predominantly yellow to predominantly brown was evident. Live *Ceratium* were not seen. Bacteria appeared more abundant . Ciliates, apparently feeding on the decomposing mass, were also abundant. Three samples were collected from two bottom locations approximately 6.5 km off Manasquan on July 15. The "floc" retained the brownish appearance; *C. tripos* was still the dominant plankter. *Coscinodiscus excentricus* was second in importance. Approximately twice as many fragments as intact cells of *C. tripos* were seen. The *Ceratium* appeared to compose 25 to 50% of the volume of the "floc". Since these samples had been treated with preservative, bacterial activity could not be estimated. At a station 3.7 km off Manasquan Inlet, on August 2, the plankton from surface to bottom was dominated by *S. costatum* followed by *L. danicus*. In the surface sample there was also numerous *Ceratium minutum*, *Peridinium trochoidium*, *Dinophysis* sp. and *Prorocentrum micans*. A few *C. tripos* including intact and fragmented cells, and a single *C. fusus*, were also present. No "floc" was noted. At 10, 13 and 15 m, save for dominant diatoms, a sparser plankton was seen which included some of the species seen in the surface sample. Single intact *C. tripos* cells were seen at 10 and 15 m and none at 13 m. A small amount of "floc" was present at all three depths, more at 15 and 13 m than at 10 m. The bottom sample, at 18 m, contained the most "floc" but still in relatively low abundance. This looked whitish to the naked eye and approximately 50 percent black under the microscope. In addition to the diatoms, *P. trochoideum* and small nannoplankters were abundant. *Ceratium* was not seen. Bacterial presence was low. At a station 20 km off Sea Girt, N. J. on August 2, the surface sample contained a relatively sparse plankton dominated in numbers by *S. costatum* and small non-motile nannoplankters. *C. tripos*, whole cells and fragments, were fairly abundant as was *P. trochoideum* and *O. luteus*. Little "floc" was seen. At 8 m an increased plankton was evident and again *S. costatum* and the nannoplankters were most abundant. Intact and fragmented *C. tripos* cells were abundant. In some of the cells, bacterial attack was observed. Some detrital bits were observed. At 20 m, *S. costatum* remained in high abundance. An increased amount of intact, and in about half examples, motile, *C. tripos* was seen. At 22 m, the same diatom picture prevailed but the most striking observation was the presence of numerous, nearly all vigorously motile, *C. tripos*. A very different situation was revealed at 26 m where along with *S. costatum* the flagellate, *O. luteus* was very abundant and only a single non-motile *C. tripos* cell was seen.

Barnegat - Atlantic City Area

Three locations, ca. 18, 28 and 37 km, respectively, off Barnegat, N. J. were sampled on July 15. Because divers reported the "floc" to be primarily in the bottom waters, sampling was at 6 and 9 m off the bottom. At the 18 and 28 km stations, samples from both depths contained "floc" which was yellow or yellow-green with some blackish spots. Many of the *C. tripos* cells present were disrupted. Bacteria in chains or as motile individuals were most evident in the samples collected 6 m off the bottom. At the furthest offshore station, the decomposition did not appear as advanced. The "floc" was predominantly yellow in color. Most *C. tripos* cells were intact and when disrupted, were in large pieces. Some live *C. tripos* were observed. Again, bacteria were more evident in the lower depth sample.

At 10 m, 5 km off Barnegat on July 21, only a small amount of fine "floc" particles and a sparse plankton, including just a few *Ceratium* was present. At 15 m, however, a fairly abundant, by comparison, floc was evident. This was composed almost entirely of *C. tripos*.

On July 30, at a location 13 km off Barnegat, the surface sample contained a small amount of yellow-brown "floc" bits. There was a moderate abundance of free, intact *C. tripos* cells. The mid-depth sample, at approximately 11 m, contained a moderate amount of predominantly brown "floc". Some sections of the "floc" bits were yellow and other areas either very dark brown or black. *C. tripos* cells were numerous, most without cytoplasm; broken tests were more numerous than intact. *S. costatum* was the most abundant diatom. In the bottom sample, "floc" was abundant. Much of the material was unstructured; diatoms, especially *S. costatum* and *L. danicus* comprised most of the identifiable phytoplankton.

Some decaying *C. tripos* was seen. Moderate bacterial activity was evident. At a companion location 20 km off Barnegat, the surface plankton was sparse, consisting of a few centric diatoms. At mid-depth, approximately 11 m, numerous free, intact *C. tripos* cells dominated the phytoplankton which consisted also of a mixed group of dinoflagellates and diatoms. The bottom sample contained a moderate amount of "floc" which ranged in color from greenish-yellow to dark gold to brown. Intact and disrupted *C. tripos* were evident. Vigorous bacterial attack on *C. tripos* was observed. Apparent fungus attack on the "floc" was also observed. Various diatoms, especially *S. costatum*, were abundant.

In two locations, approximately 22 and 37 km, respectively, off Barnegat on August 16, bottom samples contained a sparse amount of "floc" and plankton. *Ceratium* was not present. Chains of *S. costatum* were numerous but these appeared to be in a state of advancing decomposition, judging from the apparent lack of cytoplasm in the cells. In some contrast, a bottom sample from 11 km off Atlantic City contained an abundant floc, yellow to greenish-brown in appearance. *S. costatum* dominated this material. Much bacterial presence was evident. *Ceratium* was again absent, however.

The surface samples from these locations showed a sparse plankton, dominated by *S. costatum* accompanied by mixed diatoms, dinoflagellates, and smaller nannoplankters. No *Ceratium* was seen. Only one mid-depth sample was collected, this at a depth of 12 m at the Atlantic City station. This contained a small amount of "floc". *S. costatum* was dominant. Some *C. tripos* plus other dinoflagellates and diatoms were seen.

Table 1 provides a synopsis of the Ceratium observations mentioned in these notes.

Figures 1 to 6 are a pictorial representation of the Ceratium bloom decomposition stages. The phytoplankton cells (Figure 1), in senescence or death (Figure 2), aggregated to form a flocculent sediment - Figure 3 shows the typical appearance of the "floc" seen in early July; Ceratium is obviously the major component. Figure 4 shows that the decomposition has advanced. Although Ceratium is present, its dominance is not as clear; increased disruption of the cell fragments is evident. The "floc" is darker in color. With further decomposition (Figure 5) there is additional darkening of the material and far less Ceratium fragments are identifiable. In a still later stage (Figure 6), diatoms but no Ceratium are seen in the "floc".

Figures 7 and 8 show bacterial and fungal attack, respectively, on Ceratium tripos.

Figures 9 and 10 show the gill of the mud shrimp, Axius serratus, partially clogged with "floc" material.

REMARKS

Although decomposition was advancing, C. tripos constituted a significant portion of the bottom "floc" in the area between Manasquan and Barnegat, at least until the middle of July. By August 2, Ceratium had almost disappeared from the bottom "floc" off Manasquan but it was still evident in the Barnegat area on July 30. None was seen in July 30 bottom samples from off Sandy Hook. The color of the "floc" from the Manasquan area at this time looked whitish to the eye and half-blackened under the microscope whereas the Barnegat "floc" at this time retained much of the earlier yellow-brown appearance. When the Barnegat area was next sampled, on August 16, bottom samples showed no Ceratium and little of the "floc", what was present had a generally decayed appearance. However, bottom samples from the Atlantic City area still contained abundant yellow-brown material. These observations suggest that decomposition proceeded earlier or at a more rapid rate in the Sandy Hook-Manasquan area and progressed in successively later stages to the south.

Some C. tripos were alive and apparently vigorous until at least late July-early August. Concentrations of these were found at 12 m on July 30, off Sandy Hook; at 20-22 m on August 2 off Manasquan; and at the same depth on July 15 off Barnegat. They were all at "offshore" stations. At the same time, intact but non-motile cells and also fragments of cells were found at various depths at all locales, "inshore" and "offshore". This may indicate that C. tripos survived better in waters greater than 10 km from shore.

Although some bacterial activity was seen associated with aggregates of phytoplankton material in the water column, it was primarily evident at the bottom where most of the "floc" was also found. Also, general bacterial presence seemed to be associated with the presence of Ceratium (the notable exception was in the August 16 Atlantic City bottom sample in which abundant bacteria but no Ceratium were seen). Direct bacterial attack on the Ceratium was observed several times. Therefore, bacterial digestion of the Ceratium is suggested as an explanation for its comparatively rapid disappearance in the floc. Diatoms did not appear so readily attacked. Bacterial activity associated with the decomposition of the Ceratium, as others have already suggested, should not be overlooked as a possible major factor in the bottom water anoxia.

The presence of numerous O. luteus, many individuals apparently in a senescent state, as a "floc" constituent in various locations in the Sandy Hook-Asbury Park area between July 30 and August 4, is interesting. This species bloomed intensely over the southern half of Lower New York Bay between June 6 and 13, 1976. Tidal action gradually washed the red water to the ocean. A dense patch of O. luteus was observed 5 km off Sandy Hook on July 28. If the assumption can be made that the Olisthodiscus concentrations in the bottom "floc" originated in the bay, then it is likely that the bottom off the New Jersey coast was the recipient of large quantities of phytoplankton from the bloom in Lower New York Bay. The Olisthodiscus bloom may not have contributed significantly to the 1976 bottom anoxia since, compared to the Ceratium bloom, it was relatively small. However, a perhaps more important implication is that material from chronic seasonal blooms would contribute to annual bottom water oxygen sag in at least the coastal area nearby the bay.

Figures 9 and 10 show degrees of clogging of the gills of mud shrimp, *Axius serratus*, with "floc" material. A concentration of these animals was found out of the substrate approximately 18 km off Barnegat on July 15. The clogging suggests that these animals may have suffered some debilitation from physical occlusion of gill surfaces.

Table 1. *Ceratium tripos* presence in July-August 1976 samples from off the New Jersey coast.

Designations: NS, not sampled; O, not observed; +, *C. tripos* fragments; ++, intact but non-motile cells; +++; motile cells; A, abundant; F, few. Unless otherwise noted the deepest samples were at the bottom.

A.

Sandy Hook-
Asbury Park
area

Date	July 22	July 30		August 4	
Distance from shore (km)	3.7	13	20	16	20
Depth (m)					
S	+F * ++A	NS	NS	O	O
4-6		+F +++F	+F ++F	NS	NS
11-12		O	+F ++A +++A	+A ++A	+A ++A
17-18		NS	NS	O	+F ++F
22		NS	NS	↑	↑
27		O	O	NS	NS
30				↓	O
37				O	NS
45-48				O	O

* Preserved sample

B.

Manasquan area								
Date	July 4	9		15	20	24	August 2	
Distance from shore (km)	11	3	15	6.5	1	14	3.7	20
Depth (m)								
S					NS		+F	+A
	↑	↑	↑	↑		↑	++F	++A
8	NS	NS	NS	NS	O	NS	NS	+A
								++A
10							++F	↑
13						↓	O	NS
15						+F		
		↓		↓		++F	++F	
18		+A		+A *				
		++F		++A *			O	↓
20								++A
	↓							+++A
22	+A							++A
	++A							~~+++A~~
	+++F		↓					
24			+A					
			++F					NS
26								++F

* Preserved sample

C.

Barnegat-Atlantic City area								
Date	July 15		July 21		July 30		August 16	
Distance from shore (km)	18 *	28 *	37 *	5	13	20	22	37
Depth (m)								
S	↑	↑	↑	NS	+A			
					++A	O	O	O
10-12	NS	NS	NS	+F **	+A		↑	
			↓	++F	++A	++A		++
13	+A	+A			↑	↑		↑
	++F	++F		+F **			↓	
				++A	NS	NS	NS	NS
15-17	+A	+A			↓	↓	↓	↓
	++F	++F						
19-20		+A	+F					
		++F	++A					
			+++F					
22			+F					
			++A			+A		
			+++F		++F	++F	O	O

* The deepest sample was at 6 m above bottom.

** Preserved sample

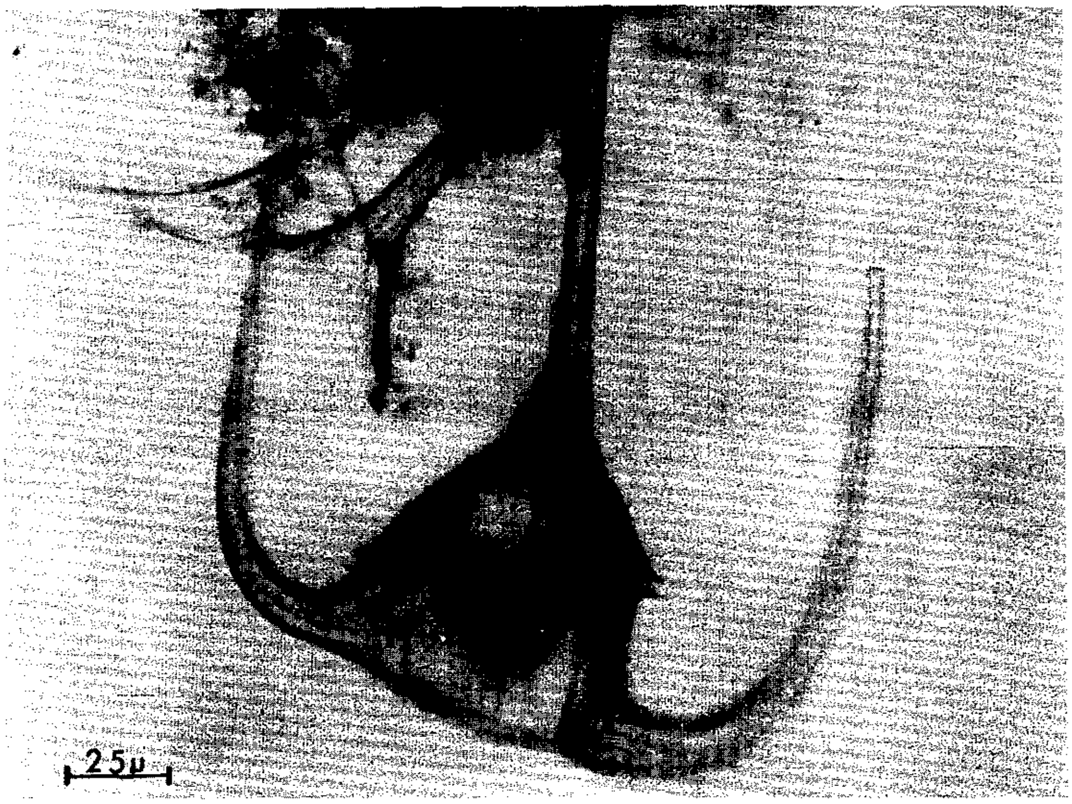

Figure 1. An intact Ceratium tripos cell; a fragment of another individual is adjacent.

Figure 2. A newly-disrupted C. tripos cell.

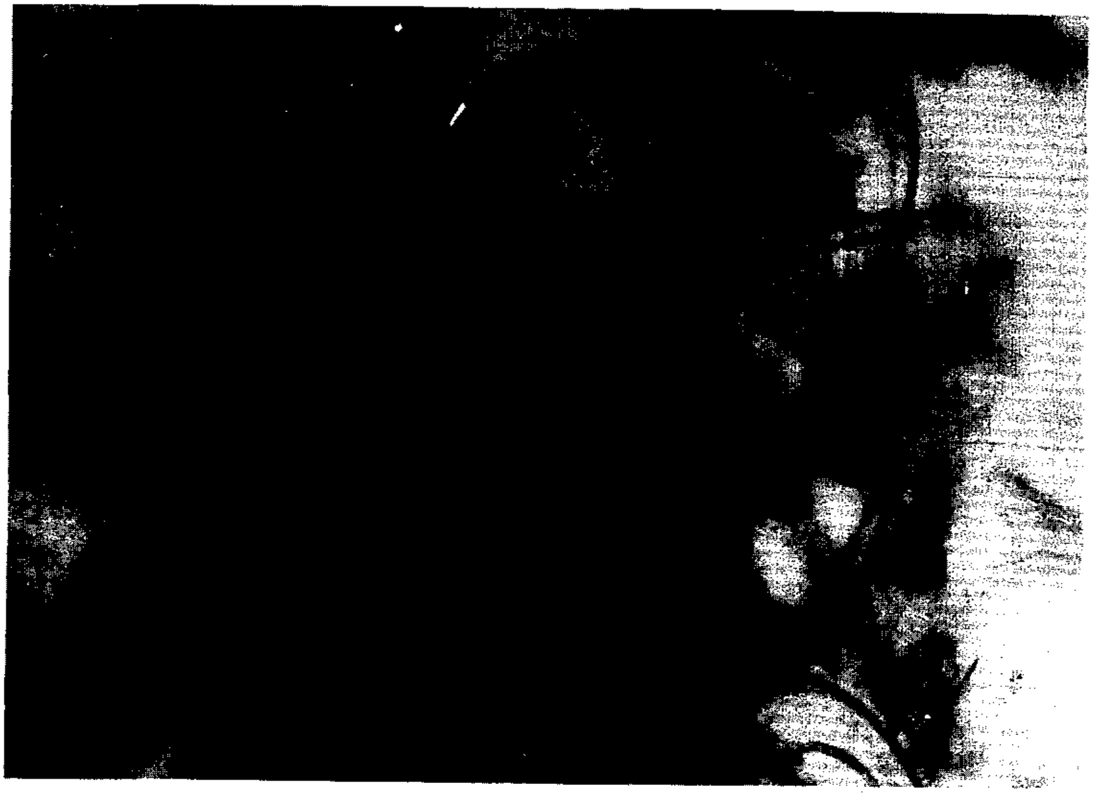

Figure 3. *Ceratium* is the obvious major component of the aggregate; most of the material relatively light in color.

Figure 4. *Ceratium* still a major component of this "floc" but increased disruption of the cell fragments is evident. The "floc" has darkened in spots.

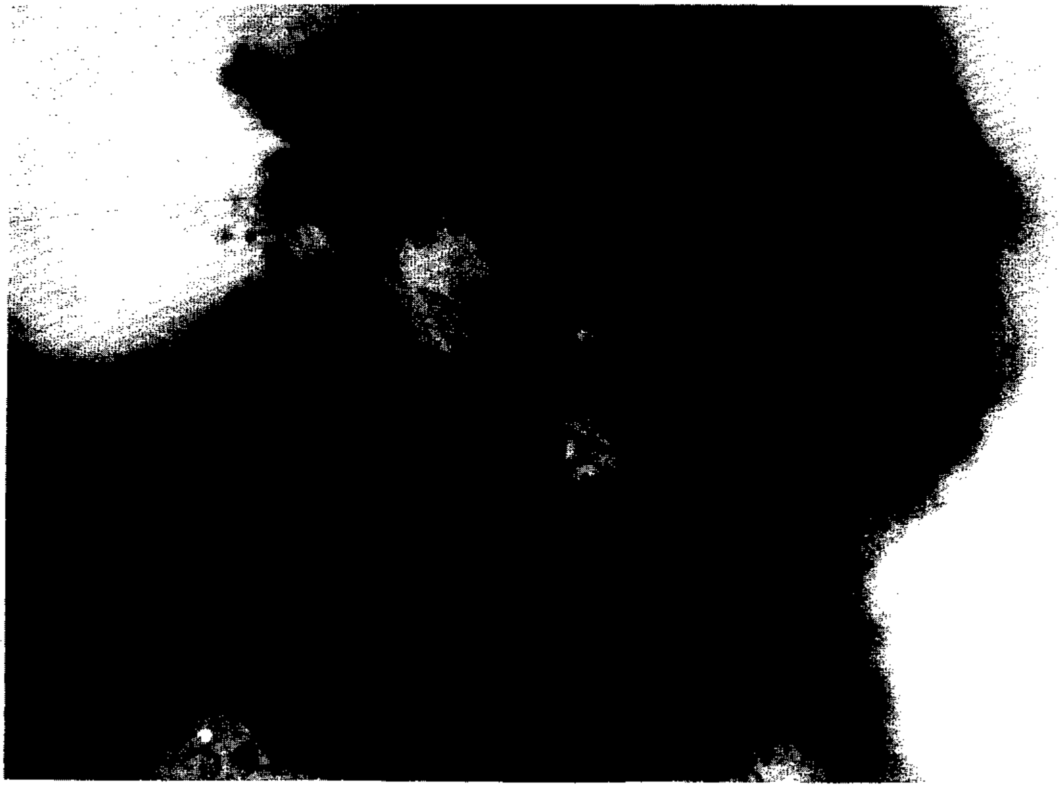

Figure 5. A few *Ceratium* fragments are identifiable but most of the material appears structureless. Most of the "floc" is dark in color.

Figure 6. *Ceratium* not identifiable in the "floc". Diatoms are the only evident phytoplankters.

Figure 7. Motile rod bacteria attack on Ceratium horn. Horn is bristling with bacteria; the area being digested is largely eaten away.

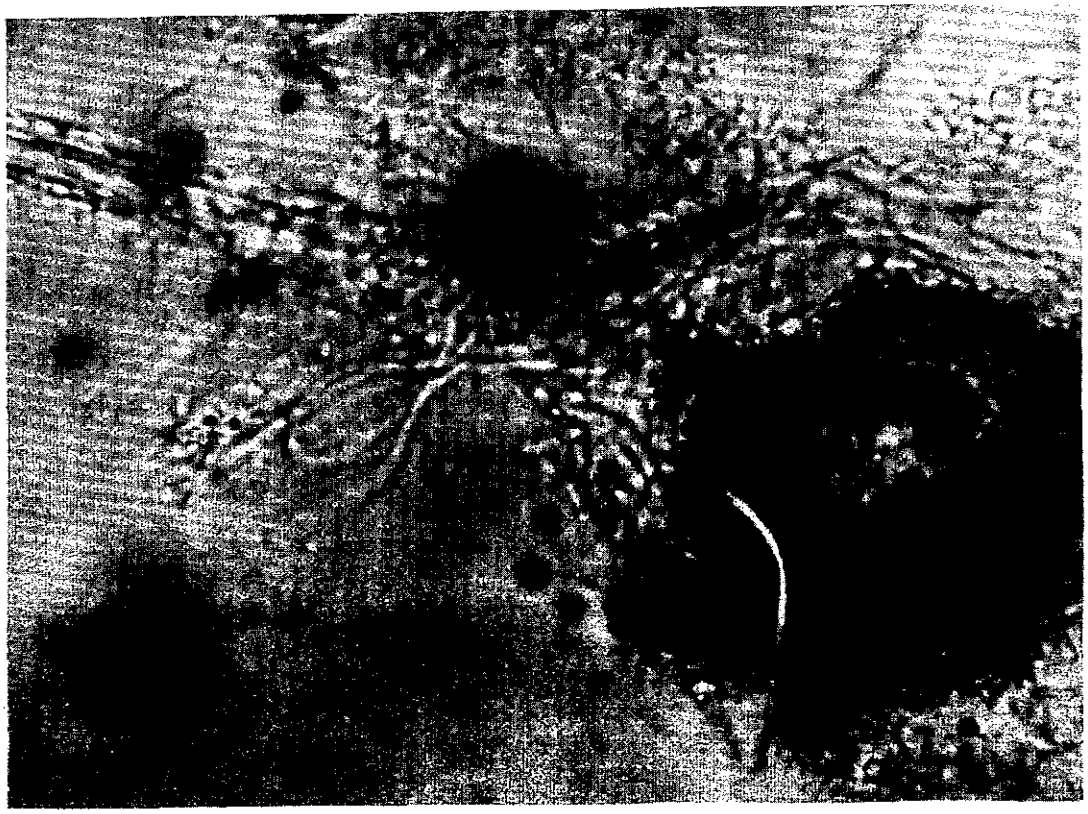

Figure 8. Fungus attack on "floc". Ceratium cell being attacked.

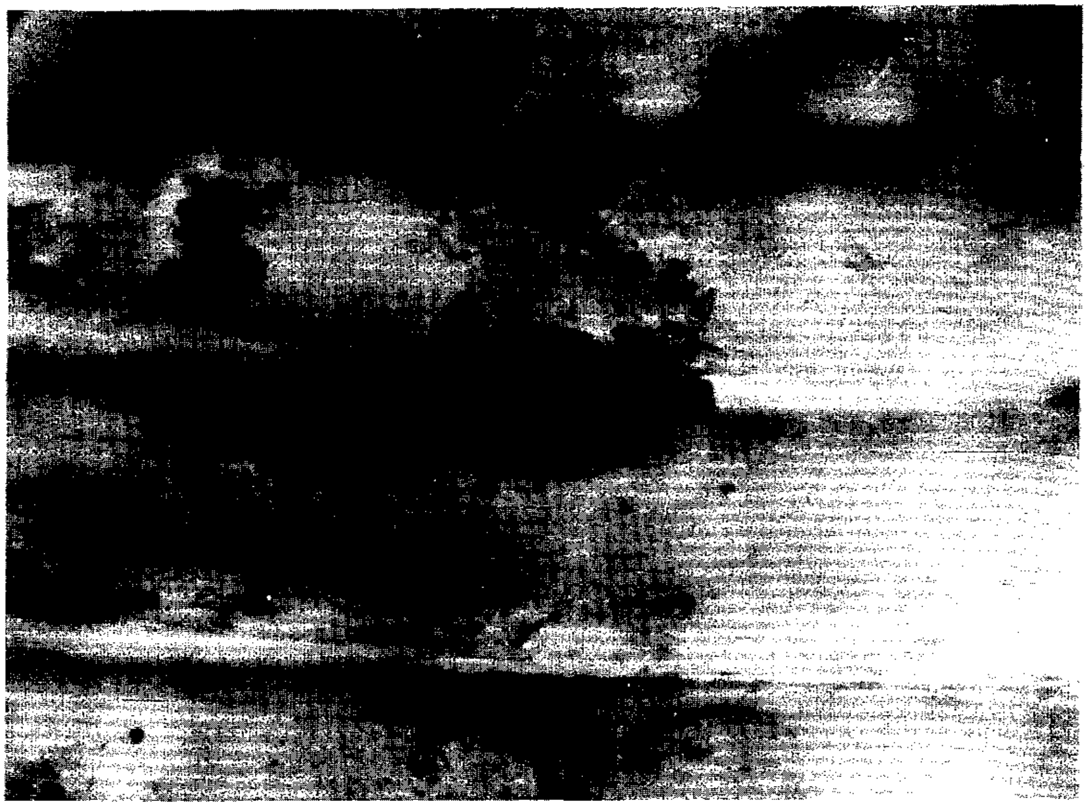

Figure 9. "Floc" fragment lodged between gill filaments of mud shrimp, Axius serratus.

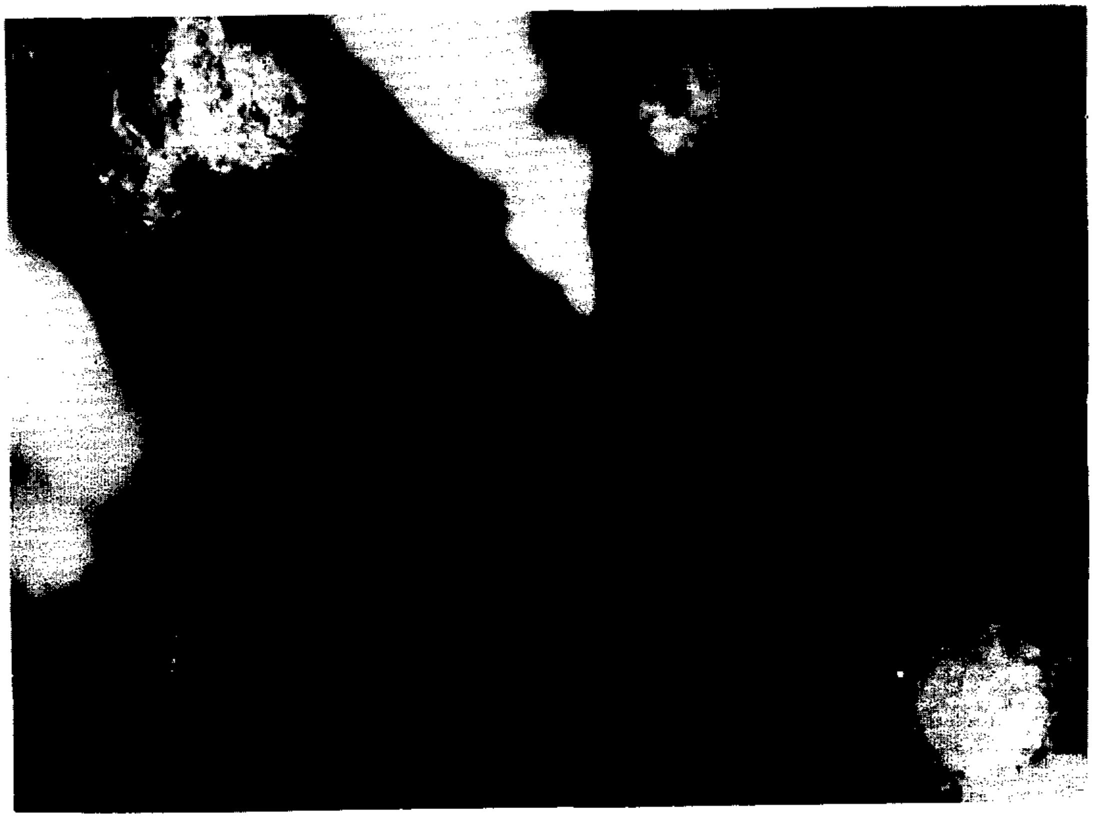

Figure 10. Mud shrimp gill choked with "floc" material.

FISH AND SHELLFISH WORKSHOP --

SUMMARY REPORT

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1.0 Introduction

The Fish and Shellfish Workshops were held on November 9 and 30, 1976, and on January 24, 1977, at the National Marine Fisheries Service's Sandy Hook Laboratory. Our discussions were restricted to the effects of the anoxic ocean water condition on economically important organisms. This summary was prepared from the minutes of the workshops as recorded by Anthony Pacheco, rapporteur, and from the papers subsequently submitted by the principal contributors. The complete papers are to be found in the Appendices. These papers should not be regarded as the last word on their respective subjects, but rather an attempt to make available information as quickly as possible without the time consuming analyses which are still being conducted.

2.0 Bivalves

2.1 Surf Clams

Reports of surf clam stress and mortality were received from divers, trawlers and clammers. From August through October, the National Marine Fisheries Service monitored mortalities in and beyond the impact area. For a detailed description of the surveys and observations, the reader is referred to the paper by John W. Ropes and Sukoo Chang in Appendix.

Samples of clams were taken by otter trawl and dredge and classified as whether individual animals were stressed, early mortality, late mortality or old mortality.

The loss estimates were made by subtracting observed mortalities from the results of this April-May 1976 assessment cruise. Data from that cruise were separated into depth ranges as follows: 0 to 18.3 meters, 18.4 to 36.6 meters and 36.7 to 54.4 meters. Mortality observed during the April-May cruise was 7.09% for 25 stations in and near the impact area. All of these dead clams consisted of paired shells. During the August cruise, mortality at 25 stations comparable to those occupied in April-May was 7.52%, consisting of 4.11% dead clams and 3.41% paired shells. Mortality was greatest in the 18.4036.6 meter depth range (10.64%) only 5.10% in the 0-18.3 meter range and none in the 37.7-54.4 meter range. In September total mortality over the area had increased to 53.49%, mostly paired shells. By depth ranges it was 60.51% at 18.4-36.6 meters, 23.33% at 0-18.3 meters and none beyond the 36.3 meter depth ranges. A further increase in loss was found in October with a total of 92.12%. Mortality in the 0-18.3 and 18.4-36.6 meter ranges was 97.44% and 98.15%, respectively, while the 37.7-54.4 meter range showed mortality for the first time at 54.84%.

The estimated biomass of surf clams within the area of the 25 stations occupied in the April-May survey was 145.5 million pounds in the 0-18.3 meter range, 176.86 million pounds in the 18.4-36.6 meter range and none at 37.7-54.4 meter range, totaling 322.4 million pounds of meats. These values were reduced by the mortality values obtained from the August through October surveys. Of the 322.5 million pounds of meats in the area in April-May, only 7.00 million pounds remained, representing a loss of 69.0% of the total New Jersey surf clam biomass (456.4 million pounds) and 16.1% of the estimated Middle Atlantic Bight biomass (1,957 million pounds).

Inshore surveys by Harold H. Haskin first showed abnormal conditions on August 14 when an unusually large collection of Ovalipes was made in the area between Beach Haven and Atlantic City. Apparently they had been driven inshore by anoxic water further offshore. He found surf clam mortalities ranging from 19 to 80% in three stations off Little Egg Inlet and a third of the clams in the northern portion of the area were stressed. On August 13, three station off Corson's Inlet showed mortalities of 12, 16 and 20% in depths of 26 to 28 feet. During a survey conducted over September 2 and 3 from Altantic City southward, mortalities of 16.5 to 89% were found. A repetition of two Corson Inlet stations originally sampled on August 13 showed the mortality had increased to 27 and 89%. The southern limit of the surf clam mortality was off Townsend's Inlet. From the condition of the dead clams appearing in his last survey, he estimated that the mortality occurred during the last two weeks of August, killing an estimated 200,000 bushels of surf clams below Beach Haven, in an area estimated to contain four million bushels in about 140 square miles. The consistency of the Point Pleasant fishery is considered by him to be good evidence that no comparable kill had occurred there in the past 1 1/2 decades.

2.2 Ocean Quahogs

Biomass loss for this species was obtained in the same manner as the surf clam. The maximum mortality observed was 13.30%. However, the cruise did not cover the full depth range of the ocean quahog so the extent or total mortality could not be calculated.

2.3 Sea Scallops

From July through September, commercial scallopers from New Jersey and Massachusetts reported catches of dead and dying scallops off

New Jersey. Dead scallops were also found in the course of surf clam and finfish assessment cruises. The location of these occurrences showed that scallops were stressed and dying within the shallow area of their distribution off New Jersey. Scallops in this area generally occur in depths of 35 to 75 meters, but they are more concentrated in the deeper portion of this range. Cruises were conducted in October and November to determine the effect of anoxic water on the sea scallop resource. The reader is referred to the paper by Clyde L. MacKenzie for details of the report by fishermen, cruises and calculations.

The area occupied by sea scallops off New Jersey covers about 11,525 square kilometers (km^2); of this, live scallops cover about 7,225 km^2 or 63% and dead scallops about 4,300 km^2 or 37%. The area occupied by dead scallops lies in the shallow inshore part of the scallop range and along about 60% of its north-south length. Average numbers of scallops per station determined in two recent cruises were 6.2 and 4.0 times greater in what is now the live scallop area compared to the inner, dead scallop area, indicating that scallop concentrations were much denser in the deeper portion of the range. The percentage of the total New Jersey sea scallop resource killed by the anoxic water was 8.8 and 12.2 based on the results of two cruises.

2.4 Lobsters

The impact on the anoxic water on the lobster resource was estimated from landing statistics. For details, the reader is referred to the paper by Bruce Halgren in the Appendices.

New Jersey lobster landings for the period 1971 through 1974 were quite stable ranging from 1.19 to 1.37 million pounds. In 1975, they dropped to 850 thousand pounds. They appeared to recover during the first four months of 1976 when landings were 22% greater than during the same period in 1975. For May, 1976, landings were down about 3% as compared to May 1975. The months of June, July, August and September, normally the most productive months of the year, showed decreases of 27.5, 40.8, 29.7 and 16.3% respectively, compared to the same months in 1975. Most severely affected was the inshore pot fishery which operates within twelve miles of the coast. Inshore landings for Ocean County decreased from over 115 thousand pounds in the first nine months of 1975 to less than 26 thousand pounds for the same period in 1976. This is all the more remarkable when one considers that the catch was up 23% in the first six months of the year and down 75% after nine months.

In Monmouth County, the inshore lobster area was not so severely affected by the anoxic water, but apparently received some detrimental effect. Although that catch was up 52% over 1975, lobstermen in the area contend that few offshore migrants entered the area.

2.5 Finfish

While some finfish mortality was observed on wrecks by divers, and locally substantial kills occurred at several locations when the anoxic water mass engulfed fish trapped against a shoreline, no finfish mortality was revealed in a series of 8 survey cruises conducted in and near the anoxic water mass. Thomas Azarovitz described changes in finfish distribution which resulted from the oxygen depletion, and the subsequent recovery and repopulation of what had been the anoxic area.

Summer spawning and the anoxic condition were discussed by Wallace G. Smith. He lists 33 species of fish whose larval stages occur in the impacted area in June and August. Among the economically important species listed are the Atlantic menhaden, Atlantic cod, haddock, red hake, silver hake, black sea bass, bluefish, tautog, Atlantic bonito, Atlantic mackerel, butterfish, yellowtail flounder and witch flounder. While the effect that the anoxic water mass had on fish eggs and larvae is unknown, there is every reason to believe that spawning was affected and that the highly vulnerable eggs and larvae that were produced did not fare well.

The effect of the anoxic water mass on bluefish and summer flounder (fluke) was discussed by Bruce Freeman. Bluefish schools normally migrate northward in spring along the coast. They are distributed according to size, the smallest fish hugging the shore, medium fish further offshore, while the largest fish travel well offshore. During 1976, the smallest and largest contingents apparently followed the normal migratory routes and reached their normal summer range, based upon tag returns and anglers' catches. The medium sized contingent, whose normal migratory route would pass through the anoxic zone, exhibited unusual behavior in 1976. Fish tagged southeast of Manasquan in early June were recaptured later in the summer south of their release point instead of to the north as expected.

Discussions by Freeman and by Patrick J. Festa indicate that the distribution of summer flounder was drastically altered by the anoxic water mass. This bottom dwelling species appeared to be herded inshore and concentrated by the anoxic water, enabling anglers to make unusually large catches.

APPENDIX I

IMPACT ON OFFSHORE SEA CLAM POPULATIONS (SURF CLAM AND OCEAN QUAHOG) ASSOCIATED WITH ANOXIC BOTTOM WATER IN THE MIDDLE ATLANTIC BIGHT DURING SUMMER, 1976

John W. Ropes[1] and Sukwoo Chang[2]

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1. Introduction

During the summer of 1976, a large cell of cold bottom water, deficient in oxygen but high in hydrogen sulfide, developed off the central New Jersey coast. This condition caused mortalities of numerous finfish species by June and July. Soon reports of surf clams (Spisula solidissima) exhibiting stress reactions and mortalities were received from divers, otter trawl fishermen, and clam fishermen. On July 28, 1976, high mortalities of surf clams were confirmed during a trip on a commercial vessel. These reports foretold an impending disaster in this important Middle Atlantic shellfish resource.

During August through October, the National Marine Fisheries Service monitored surf clams in and beyond the suspected impact area. A survey in August with a chartered otter trawl vessel confirmed the reports of commercial otter trawl operations. The surveys assessed the extent of the adverse environmental conditions on the surf clam resource. Mortalities of other invertebrates and bivalves, such as the ocean quahog (Arctica islandica) and sea scallop (Placopecten magellanicus), were also recorded although the full extent of their range was not covered.

2. Methods

2.1 Types of Stress and Mortality

The types of stress and mortality encountered in bivalves can be described on the basis of visual observations.

Stress - clams and scallops out of their burrows lying on the bottom, some with their shells gaped open. The gaped condition was also seen in catches by dredge or trawl. Contact with the body tissues usually caused lethargic response.

Early Mortality - gaping clams and scallops with all or part of the soft body tissues attached to the shells, (in some instances only the adductor muscles remained attached to the shells) but body tissue contact caused no response.

2.2 Early Reports

In July, the earliest indications of surf clam stress and mortality were from operations by two SCUBA divers who made direct visual observations of stress and mortality. Otter trawl vessels provided stress and mortality observations too, but only for the portion of the resource that had vacated their burrows, since the gear is not designed to sample benthic infauna. Surf clam dredges provided combined observations on survival, stress, and mortality of benthic epifauna and infauna. The hydraulic action of the surf clam dredges probably washed meats from the gaping shells of bivalves, as attested by meats hanging from parts of the dredge after a tow. Thus, accurate determinations of early and late mortalities were not possible, but the separated pairs of shells could be sorted based on the presence of a resilium and/or rim of periostracal covering at the ventral shell margin to give an accurate estimate of total recent mortality. Dissolved oxygen and temperature observations were taken during some of the dredging operations. These early exploratory observations were useful in defining the probable boundaries of the impacted area.

2.3 Fishermen Interviews

Surf clam fishermen operating out of Point Pleasant, Atlantic City, Cape May, and Wildwood, New Jersey and Ocean City, Maryland ports were interviewed. Information was collected about where they had observed mortalities and catches at locations free of mortality.

2.4 Assessment Surveys

2.4.1 Otter trawl surveys

Additional observations of stress and mortality of surf clams were provided from otter trawl samples for finfish taken by the research vessel Atlantic Twin during August 6-17, 1976. A cruise report outlined the objectives, operations and methods, and results of samples taken at 97 stations (Cruise Report - R/V Atlantic Twin - 76-01). The area covered by this cruise was from Sandy Hook, New Jersey to off Assateague Island (Delmarva Peninsula) and from nearshore to 117 km (65 nautical miles) offshore.

During September 28 to October 1, 1976, observations of stress and mortality of surf clams and ocean quahogs were provided from otter trawl samples for finfish taken by the NOAA research vessel Albatross IV.

During December 6-22, 1976, observations of stress and mortality among surf clams and ocean quahogs were provided from otter trawl samples for finfish taken by the NOAA research vessel Delaware II.

2.4.2 Dredge surveys

From August through early October, commercial surf clam vessels were chartered to assess the surf clam resource (Table 1). During each survey, stations were located on a grid spacing approximately 18.5 km (10 naut mi) apart. Three surveys in the impacted area off central New Jersey were at monthly intervals; one survey was to the north and east of the area off Long Island, New York. The dredge was towed for four minutes at each station. Shell length measurements of live, dead, and paired shells were recorded, as well as the numbers of each. Other live or dead invertebrates and finfish were recorded when found. At each station, a water sample was taken from near the bottom and prepared for onboard determinations of oxygen content; a thermistor probe was lowered to obtain temperatures at 2 meter intervals from surface to bottom.

3. RESULTS

3.1 Early Reports

On July 4, 1976, a SCUBA diver found surf clams out of their burrows and lying on the sea floor off Manasquan Inlet (Figure 1 and Table 2). He did not report gaping as an additional sign of stress or dead clams. Twenty days later (July 24, 1976), another SCUBA diver searched 5 square meters of bottom 6 km NE of Absecon Inlet. He found three siphon holes, no clams partly out of the bottom and alive, but one live clam was lying on the sea floor among 24 dead ones. These definite observations of surf clams experiencing stress and vacating their burrows are unusual, since the adult clam is normally a benthic, infaunal, and sedentary creature (Ropes and Merrill, 1973).

On July 9, 1976, two otter trawl samples were taken by the NOAA ship *Xiphias*. No surf clams were found at one location, but **a ½ bushel** of paired shells were caught at a location 17 km east of Belmar. The bottom temperature and dissolved oxygen were 9°C and 2.80 mg/l.

On July 9, 1976, the New Jersey Department of Environmental Protection dredged at three locations 4 to 11 km east of Barnegat Inlet. From one to 12 live surf clams were caught and three live gapers were caught at only one station.

On July 13 and 15, 1976, the commercial otter trawl vessel *Grand Larson* reported gaping surf clams in four tows 19 and 28 km east of Ship Bottom, Barnegat Inlet, and Bayhead. The distressed clams amounted to 3/4 and $1^{1}/2$ bushels (about 55 clams for 1 bushel). Low temperatures ($\leqslant$10.8°C) and low oxygen levels ($\lesssim$0.3 mg/l) were recorded at the bottom. Dead crabs, lobsters and fish were also in the catches.

On July 20 and 21, 1976, the NOAA ship *Rorqual* took two otter trawl samples 18.5 km east of Bayhead and Barnegat Inlet. Thirty-three clams were out of their burrows, seven were dead, and eight paired shells were in the catch. Separated clam meats were also found in the net. Other dead invertebrates, including a sea scallop and a crab (*Cancer* sp.) were found with a live crab and six live moon snails, *Lunatia heros*. Bottom temperatures were low ($\lesssim$ 9.0°C), as were oxygen levels ($\leq$1.25 mg/l).

On July 28 and 30, 1976, three otter trawl samples were taken by the NOAA ship Xiphias. No surf clams were found at a location 20.4 km east of Manasquan Inlet, but two live and two dead sea scallops were in the catch with live finfish. A low bottom temperature (11.1°C) and slightly depressed oxygen level (2.55 mg/l) were recorded. At stations 13 and 24 km east of Barnegat Inlet, 20 dead surf clams and 25 paired shells were in the catches with seven gaping, live clams. Separated meats hung in the netting and many other dead invertebrates were found (Table 2). Both bottom temperatures and dissolved oxygen levels were low ($\leq$12.2°C and $\leq$1.85 mg/l).

On July 28, 1976, the commercial surf clam vessel Harold E. Snow dredged at six locations from Seaside Park to Barnegat Inlet. Four locations were 5 to 11 km offshore at sites where the captain had found extensive mortalities a week earlier; two were within 2 to 4 km off the beach. Catches at offshore locations amounted to 129 to 262 live surf clams; while inshore, 234 and an estimated 9,000 clams were caught. Mortalities of offshore clams were 10 to 56 percent, but there were none in clams from the two inshore sites. Other invertebrates and fish were absent or scarce at the offshore stations; live lady crabs, Ovalipes ocellatus, spider crabs, Libinia sp., moon snails, Lunatia heros, and horseshoe crabs, Limulus polyphemus, were present at the inshore sites.

3.2 Fisherman Interviews

Interview data were collected from commercial surf clam vessels operating out of Point Pleasant, Atlantic City, and Cape May -

Wildwood. Catch and effort, location, and date of capture of live clams are presented in Table 3 and Figure 2. Locations of clam mortalities indicated by the vessel captains are also listed and plotted.

Mortalities reported by Point Pleasant captains were concentrated from Barnegat Inlet to Manasquan, whereas mortality reports of Atlantic City vessels ranged from off Atlantic City to Beach Haven.

Catch per effort (bu /hr) of live clams did not change significantly over the range of dates sampled.

3.3 Otter Trawl Assessment Surveys off Central New Jersey

Of the 97 stations sampled during the Atlantic Twin cruise on August 6-17, 1976, evidence of stress and mortality in surf clams was recorded for 28. The latter stations were off Barnegat Inlet, Little Egg Inlet, and Townsend Inlet at 14 to 38 m depths (Figure 3 and Table 4). Most of the 127 surf clam specimens caught were either dead (26.8 percent) or paired shells (33.1 percent) although the remaining live 40.1 percent had obviously vacated their burrows as an indication of stress. No demersal finfish, dead or alive, were caught in the area containing stressed or dead surf clams.

Of the 39 stations sampled during the Albatross IV cruise September 28 to October 1, 1976, evidence of stress and mortality in surf clams was recorded for only two. At one station, one live surf clam was caught; at the other station, meats alone were in the net (Table 5). Live Ovalipes ocellatus and Limulus polyphemus were in the catch with the live surf clam; dead sand dollars and paired shells of razor clams, Ensis directus, were found, along with separated meats. Stress and mortality of ocean quahogs were also noted for both stations. At one station, one dead specimen was found with 735 paired shells; at the other, only the presence of live and dead clams was recorded. The bottom temperature and oxygen level was lowest (13.2°C and 1.77 mg/l) at the station where meats alone were found.

Of the 45 stations sampled during the Delaware II cruise on December 6-22, 1976, evidence of mortality in surf clams was recorded for 12 (Table 6). About 127 paired shells were in the catches, but no live or dead specimens or meats alone were in the net. At one station, 1½ bu. (ca. 78 clams) of paired shells were caught. Evidence of stress and mortality in ocean quahogs was recorded at 9 stations. Only one live clam was caught, no dead clams, but from one to 109 paired quahog shells per station.

3.4 Dredge Assessment Surveys off Central New Jersey

3.4.1 Station location information

Within less than a month, an alarming increase in surf clam mortalities occurred after the stresses seen early in July. The approximate boundaries of the affected area were from Manasquan Inlet (40°06'N lat.) to Absecon Inlet (39°22'N lat.) and from about 5 km off the beach to 48 km offshore and 36.6 m (20 fathom) depths. Surf clams were relatively unaffected within 3 to 5 km of the beach. The affected area was about 4,459 square km (1,300 sq naut mi).

During the 48-hour (August 6-8, 1976) dredge assessment survey, 25 stations were sampled in a 6,174 square km (1,800 sq naut mi) area including depths of 13 to 41 m from nearshore to about 56 km offshore (Table 7). From three to four stations were spaced on the following transects:

TRANSECTS

1. Manasquan Inlet, Pt. Pleasant
2. Seaside Heights
3. Barnegat Inlet
4. Ship Bottom
5. Little Egg Inlet
6. Absecon Inlet, Atlantic City
7. Great Egg Inlet

During the September 9-14, 1976 dredge assessment survey, 31 stations were sampled in a 9,604 square km (2,800 sq naut mi) area and included depths of 8.5 to 42.1 m from nearshore to about 74 km offshore (Table 8). From three to five stations were spaced on the following transects:

TRANSECTS

1. Manasquan Inlet, Pt. Pleasant
2. Seaside Heights
3. Barnegat Inlet
4. Ship Bottom
5. Little Egg Inlet
6. Absecon Inlet, Atlantic City
7. Great Egg Inlet
8. Cape May Inlet

During a single trip on October 7-8, 1976, only 11 stations were completed (Table 9). Stations located on transects given for trips on August 6-8 and September 9-14 were to be sampled. Depths of 9.8 to 45.4 m were sampled; only one station was nearshore, 10 were to about 74 km offshore.

3.4.2 Mortality

3.4.2.1 Surf clam

During the August 6-8, 1976 cruise, a total of 787 live surf clams was taken in the samples; from three to 365 live clams taken at 19 stations; and mortalities ranged from one to 23 dead and/or clappers at 11 stations (Figure 4, Table 7). Mortality rates of from 4.5 to 34.3 percent were observed at individual stations. To locate areas of more or less intense mortality, data were separated into the three depth ranges: 0-18.3, 18.4-36.6 and 36.7-54.4 m. An overall mortality rate for 25 stations was 7.52 percent (Table 10) comparable to 3.78 for the April-May cruise (Table 11). The proportion of dead and/or clapper clams in the study area was 5.10 percent at the shallowest range of stations (≤18.3 m), and 10.64 percent at the mid-depth (18.4-36.6 m) range of stations. No mortality was observed at the deepest (>36.6 m) range of stations. Nevertheless, clam abundance was low at all stations in the study area.

During the September 9-14, 1976 cruise, a total of 4,263 live surf clams was observed in 34 samples; from three to 3,700 live clams were collected at 13 stations; mortalities ranged from one to 90 dead and/or clappers at 17 stations; and no surf clams were found in the samples at nine stations (Figure 5, Table 8). At eight stations, nothing but clappers were observed, which would be the evidence of 100 percent mortality; at nine stations, live clams and clappers and/or paired shells containing all or part of the rotting soft body tissues were found. No mortalities were observed at 5 stations, and one of them (#10) was an inshore location. The very high catch at this latter station (3,700 clams) was excluded from subsequent analyses in the study area because no mortalities were observed and the dissolved oxygen value (7.20 mg/l) was high. An overall mortality rate for the study area surveyed was 53.49 percent (Table 12). Mortality was again greatest (60.51 percent) at 18.4-36.6 m, 23.33 percent at ≤18.3 m, and none at > 36.6 m depths in the study area.

During the October 7-8, 1976 cruise, a total of 19 live surf clams was observed in the 11 samples; from one to 10 live clams were collected at five stations; mortalities ranged from one to 152 clappers (no dead clams containing rotting meats were found) at eight stations; and no clams were found in the samples at two stations (Figure 6, Table 9). Clappers alone were at 4 stations as evidence of 100 percent mortality. No mortalities were observed at one station, but only two live clams were caught indicating a low density. An overall mortality rate for the study area surveyed was 92.12 percent (Table 13). Mortalities of 97.44 and 98.15 percent at the shallow and mid-depth ranges respectively were the highest observed during any of the three dredging periods. An additional mortality of 54.84 percent at the deepest range of stations in the study area was observed for the first time. This indicated a progressive spread of the clam kill phenomenon toward deeper water offshore areas.

3.4.2.2 Ocean quahog

In the study area, ocean quahog samples were from the inner margin of the population. More extensive beds occur in deeper waters.

During the August 6-8, 1976 cruise, a total of 847 live ocean quahogs was taken at 17 stations in the study area (Table 7). Only seven clappers were observed in the samples, indicating a relatively low (0.8 percent) mortality for this species during this period (Table 10). A paired shell mortality of 1.21 percent was greatest at depths > 36.6 m, only 0.28 percent at 18.4-36.6 m depths, and none at ≤ 18.3 m.

During the September 9-14, 1976 cruise, a total of 1,361 live ocean quahogs was taken at 15 stations (Table 8). Thirty-five dead clams and 71 paired shells were in the samples. Evidence of stress and mortality in this species was seen in three of the offshore stations (see Station 4, 6 and 22 in Figure 7 and Table 8) where the measurements of dissolved oxygen were low (see Figure 20). The mortality was almost 40 percent for those three stations. Overall mortality rate in the study area surveyed increased to 13.30 percent.

Dead clams and clappers were found only at 18.4-36.6 m depths and amounted to 5.75 and 12.80 percent of the samples. Total mortality at this mid-depth range was 18.55 percent (Table 12).

During the October 7-8, 1976 cruise, a total of 404 live ocean quahogs was taken in the 11 sample stations; from one to 219 live clams at six stations; mortalities ranging from two to 20 clappers were at four stations (Figure 8, Table 9). Two clappers and no live clams at one station were evidence of 100 percent mortality and low density. No mortalities were observed at two stations. An overall mortality rate for the study area was 9.21 percent (Table 13) which was slightly less than seen for September. Mortalities by depths were 7.19, and 12.57 percent for the deeper and mid-depth ranges of stations respectively, and none was observed at shallow depth range stations.

3.4.3 Biomass Loss

3.4.3.1 Surf clam

The relative biomass loss of surf clams in the study area is expressed in terms of the biomass estimated from the April-May 1976 assessment cruise. The loss was determined by substracting the percent mortality rates for August, September and October from the biomass estimates obtained during the April-May, 1976 Delaware II assessment survey. Table 14 summarizes relative biomass changes in the study area.

The estimated biomass of surf clams for the 25 stations in the study area in April-May, 1976 survey was 66 thousand mt of meat at 18.3 m depths, 80.2 thousand mt at 18.4-36.6 m depths, and a negligible quantity at 36.7 m depths, totaling 146.2 thousand mt meats (Table 14). After the October survey, when environmental temperatures and dissolved oxygen had risen, only 3.2 thousand mt of meats remained in the study area. Thus, 143 thousand mt of meats were lost in the study area. This loss represented 69 percent of the total New Jersey surf clam biomass (207 thousand mt) and 16.3 percent of the estimated total Middle Atlantic Bight biomass (875 thousand mt) (Chang, Ropes and Merrill, 1976).

3.4.3.2 Ocean quahog

Estimates of relative ocean quahog loss were determined as for surf clams. The estimated biomass of ocean quahogs for the 25 stations in the study area in the April-May, 1976 assessment survey was 29.8 thousand mt of meat at 18.4-36.6 m depths, 45.6 thousand mt at 36.7 m depths, and none at 18.3 m depths, totaling 74.9 thousand mt of meats (Table 14). These values were reduced by the percent mortality rates obtained during the August through October assessment surveys. After the October survey, 68.4 thousand mt of meats remained. Thus, 6.6 thousand mt of meats were lost in the study area. This loss was 0.8 percent of the total New Jersey ocean quahog biomass (818.7 thousand mt) and 0.3 percent the estimated total Middle Atlantic Bight biomass (unpublished NMFS data). It should be pointed out that this loss was only for the inner margin of the population fringing the study area since surveys were not made in the deeper waters with the surf clam dredge.

3.5 Dredge Assessment Survey off Long Island, New York

3.5.1 Station Location Information

During trips off Long Island, New York, between September 15-25, 1976, 35 stations were sampled in about a 11,319 square km area (3,300 sq naut mi). A grid of stations (spaced approximately 18.5 x 18.5 km apart) included depths of 7.3 to 57.6 m from nearshore to about 56 km (Figure 9, Table 15). Table 16 summarizes mortality rates of surf clams and ocean quahogs off northern New Jersey and Long Island, New York in the April-May assessment surveys.

3.5.2 Mortality

3.5.2.1 Surf clam

A total of 6,573 live surf clams was in the samples; from one to 6,440 were at eight stations; no dead or dying clams were found, and only two clappers were at two stations (Figure 9). The data, separated into three depth ranges, show no mortalities at the shallow range of stations, only a low mortality (1.6 percent) at mid-depth stations, and no surf clams at station depths greater than 36.6 m (Table 17). An overall surf clam mortality rate for 35 stations of 0.26 percent was negligible.

3.5.2.2 Ocean quahog

A total of 5,744 live ocean quahogs was in the samples; from one to 1,059 were at 30 stations; no dead or dying clams were found; and only 206 clappers were at 21 stations (Figure 10). Clappers were most numerous (84) at Station 51, together with an unusual abundance of starfish. These clappers may have resulted from starfish predation. The data, separated into three depth ranges, show no coean quahogs at the shallow range of stations, a 18.15 percent mortality at mid-depth stations, and a low, 2.04 percent at the deepest stations (Table 17). An overall ocean quahog mortality for 35 stations was 3.59 percent.

3.5.3 Biomass Loss

3.5.3.1 Surf clam

Since an overall mortality rate for 35 stations in the study area was so low (0.26 percent), biomass loss of surf clams in the Long Island region was not estimated.

3.5.3.2 Ocean quahog

Estimates of relative ocean quahog biomass loss in the Long Island region were determined as for the clams in the New Jersey study area (see previous section). Table 18 summarizes relative biomass changes in the study area. The study area encompassed about one half of the total area populated by ocean quahogs in the Long Island region.

The estimated biomass of ocean quahogs for the study area in the April-May, 1976 assessment survey was 4.8 thousand mt of meats at 18.3 m depths, 64.7 thousand mt at 18.4-36.6 m depths, and 674.2 thousand mt at 36.7 m depths, totaling 743.7 thousand mt of meats (Table 18). These values were reduced by the percent mortality rates obtained during the September survey for the same study area. The September assessment survey indicated a 25.4 thousand mt loss in the study period. This loss represented less than four percent of the biomass in the Long Island study area, which is about the usual mortality found on routine assessment cruises. (Unpublished NMFS data)

3.6 Environmental Water Measurements

3.6.1 Temperature

Measurements of water temperature were recorded at the surface and at two meter intervals to the bottom at all stations (Tables 19 to 22).

During the August 6-8, 1976 survey, a strong thermocline occurred at all except close to shore stations. Plots of the surface and bottom isotherms are shown in Figures 11 and 12. In general, surface waters were cooler inshore and in the north than offshore and in the south. Bottom waters were cooler along northern transects than those along southern transects; inshore stations had higher temperatures than those offshore. The thermocline began about 10 meters below the surface in the northern transects and 14 meters in the southern ones. At each station throughout the surveyed area, temperatures between the surface and the thermocline were similar, 20° to 24.7°C, and those between the thermocline and the bottom were also similar, 7.7° to 15.0°C.

During the September 9-14, 1976 survey, surface temperatures were virtually similar over the entire survey area, ranging from 19.0° to 22.6°C. Bottom temperatures were more variable, ranging from 9.0°C to 19.8°C. A strong thermocline was observed at all except close to shore stations. At each station throughout the surveyed area, temperatures between the surface and the thermocline ranged from 9.0° to 15.0°C (Figures 13 and 14).

During the October 7-8, 1976 survey, surface temperatures ranged from 16.7° to 18.6°C; bottom temperatures ranged from 13.6° to 18.1°C (Figures 15 and 16). Surface and bottom temperatures varied as little as 0.1°C and as much as 4.0°C. The strong thermocline observed during the early September trip was weak during the October trip.

During the September 15-25, 1976 survey off Long Island, New York, surface temperatures ranged from 17.5°C to 20.1°C over the entire surveyed area; bottom temperatures varied widely from 8.1°C to 20.1°C (Figures 17 and 18). A strong thermocline was most evident at offshore stations. At each station throughout the survey area, temperatures between the surface and the thermocline varied about 4.5°C, and those between the thermocline and the bottom varied about 6.9°C.

3.6.2 Dissolved oxygen

During the August 6-8, 1976 survey, dissolved oxygen levels (mg/l) were measured at the bottom at all stations within each transect (Figure 19). Low oxygen levels, from 0.00 to 2.00 mg/l, were observed on six transects, and at 13 of the 25 stations. These data characterized a large mass of bottom water extending 60 km from a point mid-way between Manasquan and Barnegat Inlets and Atlantic City. The distribution of this water began 10 km from shore in the north and 2 km from shore off Little Egg Inlet. Low oxygen levels at some oceanward stations indicated that this condition extended beyond the area sampled.

During the September 9-14, 1976 survey, dissolved oxygen levels (mg/l) were measured at the bottom at all stations within each transect (Figure 20). Low oxygen levels, from 0.00 to 2.00 mg/l were observed on eight transects and at 22 of the 34 stations. These data characterized a large mass of bottom water extending 90 km from Manasquan Inlet to Ocean City, New Jersey. The distribution of this water was as close as 2 km from shore off Beach Haven. Low oxygen levels at all but one oceanward station indicated that this condition extended beyond the area sampled.

Measurements of dissolved oxygen at a few stations were made at the following four vertical levels: surface; top of thermocline; bottom of thermocline; and bottom. As was true for temperatures, oxygen levels between the surface and top of the thermocline were similar, 6.8 to 7.3 mg/l, and those between the bottom of the thermocline and sea bottom were also similar, 0.00 to 1.91. Thus, the deficient oxygen layer extended from below the bottom of the thermocline to the sea floor. The oxygen deficient layer was as much as 60 meters deep at some stations away from shore.

During the October 7-8, 1976 survey, dissolved oxygen levels (mg/l) were measured at the bottom at all stations (Figure 21). A low oxygen value of 0.75 mg/l was observed at Station #8, all other values were 2.75 mg/l or higher. The latter values were an indication of the breakdown of the thermocline.

During the September 15-25, 1976 survey off Long Island, New York, dissolved oxygen levels (mg/l) were measured at the bottom at all stations (Figure 22). Low oxygen levels, from 0.65 to 2.00 mg/l were observed at five stations all of which were within a 74 km (40 mile) radius of Ambrose Lightship and near the New York dumpsite. Surf clams were in the catch at only one of these stations (#40), ocean quahogs were in the catch at four stations (#38, 39, 40, and 69) and sea scallops were in the catch at three stations (#38, 40, and 69). Only two ocean quahog clappers were in these samples, as an indication of mortality. Oxygen levels at the remaining 30 stations were 2.25 to 7.10 mg/l.

4. DISCUSSION

The cold bottom water and low levels of dissolved oxygen associated with early mortalities (June and July) of finfish and invertebrates characterized a relatively large stagnant cell off central New Jersey in early August and September. Finfish were absent from the cell, but the much less mobile benthic invertebrates could not escape the apparent anomalous drastic depletion of life-sustaining oxygen. With each mortality in the affected area, the demand on the available oxygen increased through natural decay processes. The condition persisted for at least 13-weeks (July 1 to September 30) and had probably developed to some degree before July, since a commercial fisherman reported dead fish in his trawl catches on June 30.

Some past temperature and dissolved oxygen measurements are available to compare with the values observed in the impacted area. Churgin and Halminske (1974) documented such measurements for July to September off Atlantic City, New Jersey. The average temperature values for the 3-month period progressively decreased with depth from 22.27°C at 0 m to 13.24°C at 30 m. Their minimum value of 4.78°C at 30 m was 3.62°C lower than any recorded bottom temperature during August and September 1976 in the affected area; their maximum value of 22.83°C at 30 m was 9.73°C higher. Colder and warmer bottom temperatures than were seen during the clam cruises, then, have occurred off the Central New Jersey coast. Bumpus (1973) reviewed knowledge about the circulation of the Middle Atlantic Bight. He included several references to studies describing the pool of cold bottom water than can develop during the summer from south of Long Island to off Chesapeake Bay. Although the pool can be warmed by mixing warmer and fresher surface water or warmer and more saline slope water of similar depth and density, the process may be delayed to September, October, or even November. In 1976, mixing was apparently in progress during the October 7-8 clam cruise, since surface temperatures had decreased and bottom temperatures had increased.

Churgin and Halminske (1974) listed average dissolved oxygen values for July to September off Atlantic City, New Jersey. At 0 to 50 m depths all were 5.00 mg/l or higher; average values for the August 6-8 and September 9-14 clam cruises were 1.62 and 1.73 mg/l, respectively. One minimum value of 1.73 mg/l for 20 m depths was the lowest listed by Churgin and Halminske (1974); other minimum values were all 2.42 mg/l or higher. During the August and September clam cruises, 6 and 10 minimum values of 0.00 mg/l were obtained. Clearly, low dissolved oxygen was the most anomalous condition measured during the clam cruises. An increase in dissolved oxygen levels during the October 7-8 clam cruise to an average of 4.99 mg/l (max. 6.70; min 0.75; and standard deviation 1.97 mg/l) was an almost three-fold increase over the average for the September cruise. This increase, together with the changes in surface and bottom water temperatures, was more definite proof of mixing.

Mortalities of marine organisms off the New Jersey coast were reported twice in the recent past. In the most recent (Young, 1973), lobster (Homarus americanus) and rock crab (Cancer irroratus) mortalities were seen by SCUBA divers during October 1971, but clams were not mentioned in the report. Although accurate diagnosis was not possible, low dissolved oxygen, high temperature, and flocculated material in the water were suspected conditions affecting the lobsters and crabs. Ogren and Chess (1969) listed numerous observations around ship wrecks, reefs, and bottom communities during September and October 1968. Ogren (1969) summarized the event. Several species of finfish and invertebrates were seen in the live, dying and dead condition. Surf clams (Spisula solidissima) were found lying on the sea floor. Water temperatures taken at one site (the Delaware wreck) were considered normal for the season. Dissolved oxygen levels, however, were abnormally low (range 0.34 ml/l to 0.72 ml/l) and were believed responsible for the unusual behavior and mortalities of the finfish and invertebrates. Oxygen levels as low and lower were recorded during 1976.

Low dissolved oxygen thresholds producing some physiological, behavioral, or other response in marine invertebrates are poorly known and determinations are complicated by the ability of many to survive anaerobically (Davis, 1975). Some invertebrates have a tolerance for very low levels of oxygen and even exhibit an independence above a low critical tension. Davis, in his Table 5, included the soft clam (Mya arenaria) as an oxygen independent species with critical oxygen tension (Pc) values of 40-50 mm Hg. Although the experimental conditions under which the values for Mya were obtained may not be strictly comparable, Savage (1976) found that the median burrowing time of the surf clam (S. solidissima) was significantly slower at an oxygen concentration of 1.4 mg/l (ca 123 mm/Hg) and at 11°C. Burrowing of surf clams ceased after three days at 15.4 to 15.8°C and 0.8 mg O_2/l (ca 68-77 mm Hg). By increasing the ambient temperature about 6°C in one experiment and during experiments at seasonally high temperatures of 20.8° and 21.0°C in July and August, mortalities also occurred in water of the lowest oxygen content (0.88 mg O_2/l; ca. 92-93 mm Hg). Oxygen depletion, then, had the greatest effect on burrowing, and, coupled with high temperatures, on survival too. Since it is not known whether surf clams exhibit independence, like Mya, a comparison of oxygen tension values may not be justified. The generally higher values for Spisula may be the result of experimental or species specific differences.

Studies have been made relating the reactions of the ocean quahog (Arctica islandica) to low oxygen levels. Brand and Taylor (1974) reported on pumping behavior. In well oxygenated water (160 mm Hg), currents in and out of the siphons to fulfill respiratory and digestive requirements of ocean quahogs were periodic, alternating with periods of inactivity. The pumping activity was independent of shell movements. Complete closure of the shells often resulted in quiescence for several hours. For ocean quahogs, and some other subtidal species, the periods of pumping were variable, but amounted to 40-60 percent of the observation time. In water of low oxygen (30-35 mm Hg), pumping time increased to over 95 percent, and at lower oxygen tensions it stopped and the shells closed. Taylor and Brand (1975) investigated the effect of hypoxia on the rate of oxygen consumption in ocean quahogs held in water at 10°C and 34 o/oo salinity. Oxygen consumption by large ocean quahogs (2.9 - 16 g dry weight) was more or less constant to levels of 40-50 mm Hg, the values considered to be critical oxygen tensions (Pc) for the species. Above the critical levels, the clams exhibited respiratory independence, but smaller sized clams ($\leq$1 g dry weight) showed respiratory dependence under hypoxic conditions. The differences in response to oxygen was believed also to be modified by temperature and the physiological condition of the clams, other factors which complicate clearly identifying a species as an oxygen regulator or oxygen conformer. The critical oxygen tension (Pc) values for A. islandica compare with those given above for M. arenaria (Davis, 1975) and are lower than those for S. solidissima (Savage, 1976). As reported by Brand and Taylor (1974), A. islandica can comepnsate for oxygen levels lower than the Pc values by greatly increasing pumping activity or closing its shells. Both activities are reactions to stress conditions.

The relatively greater capacity for A. islandica than S. solidissima to function during low oxygen conditions appears to be species specific. Theede et al. (1969) compared the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulfide. Spisula solida, a European relative of S. solidissima, and A. islandica were among several bivalves used in the experiments. Resistance was measured in terms of time (in hrs) at which 50 percent (LD-50) survived experimental conditions. All A. islandica survived for 55 days in water of 10°C, 15 o/oo salinity and 0.15 ml O_2/l (ca 0.22 mg/l) and for 33-41 days in water of similar oxygen deficiency but which had been treated to create a H_2S condition. These survival times were the longest for any of the invertebrates tested, but S. solida was not among the species listed in their Table 2. In experiments with isolated gill pieces tested in water of a similar oxygen deficiency and H_2S level, but higher salinity (30 o/oo), the survival of S. solida tissues was affected 3-7 days earlier than those of Mytilus edulis, M. arenaria, and Moliolus modiolus. For S. solida, ciliary activity ceased and cell damage was irreversable after 24 hr in oxygen deficient water treated to create H_2S. The tissue pieces survived the experimental conditions for 3-4 days. Under similar oxygen and H_2S conditions, but lower salinity (15 o/oo), isolated gill tissue pieces of A. islandica survived for eight days, although ciliary activity also ceased and was irreversible after 8-24 hr. Lower experimental temperatures and higher salinity greatly increased survival and recovery of ciliary activity for A. islandica. A. islandica was a species considered to have a high resistance to oxygen deficiency and hydrogen sulfide.

As Davis (1975) has pointed out, many invertebrates may tolerate low levels of oxygen, but intolerant or less tolerant species may be lost from communities resulting in possible invasion of new species into the community and/or an increase in some species present in the community. The changes in community structure may or may not be bad, but the outcome of such changes is generally unpredictable. Relative to the surf clam fishery, which is at present faced with a low supply of the resource and a low recommended annual yield (Chang, et al., 1976), the loss of a significant portion of the clam biomass and problematical nature of re-colonization in the affected area has a particularly serious socioeconomic impact. Relocation of vessels to fish the remaining stock increases the effort on the already low supply of the resource. Some of the vessels in the fleet may not be able to fish stocks at greater depths and farther from shore. The biological implication of this loss is that a sizeable brood stock, which may be essential to produce larvae and recruitment to the fishery, is missing.

5. SUMMARY

From July through September 1976, a wide-spread kill of surf clams occurred off central New Jersey. Assessment survey data indicate an almost complete kill in about half of the New Jersey surf clamming area.

From an April-May 1976 assessment survey, the estimated total surf clam resource in 14,406 square km (4,200 sq naut mi) off New Jersey was 207 thousand mt of meat. Based on biomass estimates and the observed mortalities during assessment cruises in August through October 1976, 143 thousand mt of meats or 69 percent of the New Jersey resource has been lost. In the Middle Atlantic Bight, the total surf clam resource was estimated at 875 thousand mt of meat. Thus, the loss from mortalities off New Jersey is about 16.3 percent of the total resource.

Six thousand six hundred mt (0.8 percent) of an estimated 818.7 thousand mt of ocean quahog meat were lost from the New Jersey and only 0.3 percent from the total Middle Atlantic Bight resource of 2,457.8 thousand mt. However, since the study area did not extend to waters deep enough to fully assess the total population of ocean quahogs, the results pertain only to the inner, shallow water margin of the population. Additional observations in deeper water are planned during an early 1977 shellfish cruise for a full assessment of the ocean quahog stocks.

Low dissolved oxygen on the bottom over the beds was the immediate cause of the clam mortalities. The low oxygen condition was present in a cell of cold bottom water which was sustained during July through September.

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TABLE 1. Commercial surf clam vessels, survey areas, and number of stations sampled in August through early October, 1976.

Date in 1976	Vessel Name	Survey Area	No. of Stations Sampled
Aug. 6-8	*Valerie E.*	Manasquan Inlet to Great Egg Inlet; nearshore to about (56 km (30 naut. mi) offshore	25
Sept. 9 to 14	*Gail Snow* and *Cora May Snow*	Manasquan Inlet to Cape May Inlet, nearshore to about 74 km (40 naut. mi) offshore	34 + 10 special stations
Sept. 15 to 25	*Cora May Snow*	Manasquan Inlet north and east to off Montauk Point, N.Y.; nearshore to about 56 km (30 naut. mi) offshore	11
Oct. 7-8	*Margaret* and *Nancy*	Manasquan Inlet to Absecon Inlet; nearshore to about 74 km (40 naut. mi) offshore	

TABLE 2. Summary of data on surf clams and other invertebrates reported from diver, otter trawl and dredge operation, in July, 1976.

Information Source	Date in 1976	Location of Observation		Depth m	Bottom		Number of Surf Clams			REMARKS
		N.Lat.	W.Long.		Temp. °C	D.O. mg/l	Live	Dead	Clapper	
SCUBA DIVER	7/4	40 06	74 01	-	-	-	*	0	0	*Clams lying on the sea floor
"	7/24	39 23	74 21	-	-	-	1	24	0	Clams lying on the sea floor, 3 siphon holes found, no clams out of bottom
OTTER TRAWL	7/13	39 38	73 56.5	23	10.8	0.00	*	0	0	*1½ bu.live but gaping clams; dead crabs, starfish, moon snails & fish.
Ship, *Grand Larson*	7/13	39 48	73 54	27	10.5	0.00	2	0	0	*3/4 bu live but gaping clams; dead crabs, mud shrimp, starfish and moon snails
	7/13	39 58	73 15.5	29	10.1	0.30	*	0	0	*1¼ bu.live, but gaping clams, dead crabs
	7/15	39 51.5	73 45	29	10.5	0.05	12	1	0	1 dead sea scallop, crabs, lobsters and fish dead
OTTER TRAWL (Ship, *Rorqual*)	7/20	40 01	73 50.5	23	7.6	1.25	7	2	6*	1 recent & 5 older clappers, surf clam meats alone in net, 1 dead sea scallop, crab, starfish and sand dollars.
	7/21	39 49	73 52	24	9.0	0.00	26	5	2	Dead crab, mud shrimp & worms
OTTER TRAWL (Ship, *Xiphias*)	7/9	40 11	73 48.5	30	9.0	2.80	0	0	*	1/2 bushel
	7/28	40 06	73 48	29	11.1	2.55	0	0	0	2 live and 2 dead sea scallops, fish alive.
	7/30	39 48	73 57	24	12.2	1.85	2	9	13	Surf clam meats alone in net; dead *Cancer* sp. Mantis shrimp, sand dollars & other vertebrates;1 live clearnose skate.
	7/30	39 48	73 49	26	11.6	1.60	5	11	12	Surf clam meats alone in net; 29 dead *Cancer* sp. 12 dead razor clams, 3 dead bivalves.

TABLE 2 (continued)

Information Source	Date in 1976	Location of Observation		Depth m	Bottom		Number of Surf Clams			REMARKS
		N.Lat.	W.Long.		Temp. °C	D.O. mg/l.	Live	Dead	Clapper	
DREDGE N.J.D. E.P.	7/9	39 46	74 03	-	-	-	12	0	0	
	7/9	39 46	74 01	-	-	-	10	0	0	3 of the live clams were gaping open
	7/9	39 46	73 59	-	-	-	1	0	0	
DREDGE (Ship, *Harold F. Snow*)	7/28	39 52	74 01	17	14.5	-	129	1	12	No other invertebrates or fish caught.
	7/28	39 51	74 01	17	21.0	-	262	13	0	10 surf clam meats alone in catch. No other invertebrates or fish caught.
	7/28	39 49	74 01	20	17.5	-	225	85	88	100 ± surf clam meats alone in catch; 1 live *Limulus*; 1 live *Cancer* sp.; 6-8 live Sipunculids; no fish.
	7/28	39 44	74 00	22	12.5	-	165	213	0	No other invertebrates or fish.
	7/28	39 49	74 05	11	20.5	-	234	0	0	6 live *Limulus*; 5 live *Ovalis* sp.; 2 live *Librinia* sp., 1 live windowpane flounder.
	7/28	39 51	74 03	9	20.5	-	*	0	0	*60.0 bu. live clams; 1 live *Lunatia*; 1 live *Ovalipes*, no fish.

TABLE 3. Locations fished from interviews with captains of surf clam vessels.

		Live Clams					Dead Clams	
Port	Date 1976	Lat.	Long.	Depth	Hours Fishing	Bu.	Lat.	Long
Pt.Pleasant, N. J.	8/1	39 52	73 56	18	10.0	176	39 53	73 55 [2]
	"	40 01	73 58	21	10.0	170	39 21	73 51
	8/2	40 04	73 56	24	6.5	109	40 02	73 59
	"	39 52	73 56	19	10.0	196	39 48	73 56
	8/4	39 55	73 57	20	8.0	86	39 59	73 59
	8/11	39 55	73 58	20	8.5	103	39 54	74 00
	8/26	39 55	73 59	18	5.0	86	39 22	74 08 [3]
	"	39 57	73 60	18	4.5	66	39 22	74 07
	"	39 58	73 57	21	11.0	130	39 24	74 07
	"	39 58	73 58	18	10.0	96	39 22	74 04
							39 22	74 03
Atlantic City, N.J.	8/25	39 11	74 36	13	10.00	352	39 21	74 03
	"	38 19	74 23	14	9.00	152	39 18	74 04
	"	39 12	74 35	11	11.0	128	39 15	74 06
	"	38 19	74 23	14	9.0	120	39 12	74 05
							39 11	74 06
Cape May-Wildwood	8/10	38 33	74 31	32	8.0	256	39 10	74 06
	8/18	38 34	74 22	34	30.0	256	39 10	74 05
	"	38 58	74 24	26	30.0	280	39 10	74 04
	"	38 33	74 41	20	6.0	128	39 13	74 30
	"	38 36	74 43	--			39 15	74 23
	"	39 01	74 35	--	12.0	189		
	"	38 40	74 44	--	25.0	416		
	"	38 40	74 44	--	30.0	448		
	8/19	38 34	74 28	31	15.0	289		
	"	38 49	74 48	24	15.0	345		
	7/12[1]	38 49	74 36	--	7.0	150		
	7/16	38 49	74 36	--	40.0	1000		
	7/21	38 34	74 32	--	24.0	640		
	7/23	38 49	74 36	--	30.0	704		
	7/27	38 35	74 31	--	18.0	618		
	8/2	38 44	74 45	--	28.0	320		
	8/4	38 32	74 30	--	28.0	992		
	8/6	38 30	74 34	--	17.0	600		
	8/12	38 30	74 34	--	30.0	768		

[2] Six locations provided by captains at Pt. Pleasant, N.J.

[3] Fifteen locations provided by captains at Atlantic City, N. J.

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[1] This and subsequent entries to 8/12 from the log of one vessel.

TABLE 4. Summary of data on surf clams from otter trawl catches of the vessel <u>Atlantic Twin</u>, August 6-17, 1976

Station Number	Location		Depth	Bottom		Number of Surf Clams		
	Lat.	Long.	m	Temp. °C	O_2 mg/l	Live	Dead	Clapper
17	39 50	73 33.2	34	7.7	1.59	0	2	0
18	39 50	73 38.5	33	8.3	1.46	1	1	0
19	39 50	73 45.2	28	8.1	1.48	0	1	3
20	39 52.2	73 52.2	27	9.5	2.25	0	4	0
21	39 50	73 58.3	23	10.4	2.66	0	*	0
23	39 30	74 08.5	17	11.1	0.00	1	2	3
24	39 30	74 02	28	10.8	0.00	1	1	7
25	39 30	73 55,7	25	11.1	0.00	2	3	3
28	39 30	74 14.8	14	18.3	4.91	0	0	3
29	39 30	74 08.5	18	17.4	4.80	0	*	0
32	39 31.2	73 48.3	34	11.8	0.37	11	0	2
33	39 30	73 42.2	33	10.6	0.00	1	0	0
34	39 29.9	73 36.6	34	10.3	0.00	3	1	0
35	39 31	73 28.5	35	10.2	1.01	0	1	0
45	39 10.3	74 01	38	11.9	1.03	11	0	0
46	39 10.4	74 06.9	29	13.2	0.35	3	0	0
47	39 10.6	74 13	27	15.6	1.11	11	1	5
48	39 10	73 40	23	17.2	2.10	1	0	0
49	39 10	74 26.4	20	18.1	2.58	0	0	1
50	39 10	74 32.9	17	18.4	4.22	1	2	3
54	39 00	74 32.5	16	18.5	6.34	0	1	2
56	38 51	74 37.9	16	17.6	6.51	0	0	1
85	39 39.5	73 28.7	35	10.2	0.00	2	1	3
86	39 40	73 42	32	9.2	0.50	0	0	1
89	39 40	74 08	15	17.3	2.91	0	1	1
90	39 29	74 07.7	20	16.3	3.21	0	1	0
91	39 30	74 01.4	25	13.4	0.01	0	6	4
92	39 29.7	73 54.7	26	11.6	0.87	2	5	0

* Meats alone hanging in trawl net.

TABLE 5. Summary of data on surf clams and ocean quahogs from otter trawl [1/] catches of the research vessel <u>Albatross IV</u>, September 28 to October 1, 1976.

Sta. No.	Location Lat.	Location Long.	Depth m	Bottom Temp. °C	Bottom O_2 mg/l	Number of Surf Clams Live	Number of Surf Clams Dead	Number of Surf Clams Clapper	Number of Ocean Quahogs Live	Number of Ocean Quahogs Dead	Number of Ocean Quahogs Clapper
75	39 38.5	73 41	27	17.5	6.43				0	1	735
77	39 41.5	74 03	13	17.2	6.99				X	X	
82	39 13	74 24.5	15	17.3	6.60	1	0	0			
179	39 16	73 45	40	13.2	1.77	0	*	0			

[1/] Net was a #36 Yankee roller sweep trawl and 30 min. tows.

* Meats alone in net

X Not counted, only presence noted.

TABLE 6. Summary of data on surf clams and ocean quahogs from otter trawl [1] catches of the research vessel *Delaware II*, December 6-22, 1976

Sta. No.	Location		Depth m	Bottom		Number of Surf Clams			Number of Ocean Quahogs		
	Lat.	Long.		Temp. °C	O_2 mg/l	Live	Dead	Clapper	Live	Dead	Clapper
4	40 18.8	73 43.1	24	8.6	-				1	0	3
6	40 14.3	73 56.7	20	6.0	-	0	0	7			
8	40 04.5	73 53.2	22	7.3	9.31	0	0	2			
9	40 07.2	73 42.2	38	12.5	5.51				0	0	10
53	39 41.6	74 02.7	15	5.0	9.98	0	0	1			
54	39 44.9	73 50.5	22	7.2	-	0	0	24			
55	39 45.4	73 43.3	28	7.5	9.39	0	0	1			
56	39 48	73 27	37	7,8	-				0	0	1
61	39 15	74 21.2	18	7.6	-	0	0	1			
64	39 05.6	74 28.6	20	6.5	-	0	0	8			
65	38 51.5	73 58.8	42	10.8	8.25				0	0	109
66	38 44	73 40.7	57	11.2	-						44*
69	39 10.6	73 31.4	45	9.0	-				0	0	1
70	39 28.4	73 35	37	8.6	8.71				0	0	1
71	39 30.4	73 18	35	9.2	-	0	0	2	0	0	3
74	38 50.8	74 25.2	28	8.8	8.91	0	0	1			
76	39 00.2	74 42.8	14	5.6	-	0	0	1			
77	39 03	74 44.6	8	5.0	-	0	0	1			
78	38 54.3	74 53	10	5.2	-	0	0	X			
98	38 33.2	74 05	57	11.6	7.70				0	0	1
105	39 01.2	73 19	68	12.0	6.09				0	0	7

[1] Net was a #36 Yankee trawl with chain sweep ("Cookie Discs").

* Clappers with muscles in shells.

X 1½ bu. clappers (ca. 78 clams).

TABLE 7. Summary of data on surf clams, and ocean quahogs - chartered vessel Valerie E. - August 6-8, 1976. Four minute tows were made using a surf clam dredge with a 60 inch knife. Pump was operated at 80-90 p.s.i.

Station No.	Location Lat.		Long.		Depth m	Bottom Temp. °C	Bottom O_2 mg/l	Number of Surf Clams Live	Dead	Clapper	Number of Ocean Quahogs Live	Clappers
1	39	28	74	15.5	13	15.0	1.69	365	0	17	0	0
2	39	28	74	00.5	24	12.9	0.00	30	0	0	0	0
3	39	28	73	47.5	31	12.0		12	1	0	3	0
4	39	36	74	00.5	24	11.9	0.89	18	3	3	0	0
5	39	44.5	74	04	14	13.5	2.92	12	1	2	3	0
6	39	44.5	73	51.5	26	11.6	0.00	18	2	2	0	0
7	39	45	73	39	34	12.5	1.25	7	0	1	32	0
8	39	56	73	44	32	8.8	2.10	0	0	0	2	0
9	39	56	73	57	21	11.5	2.89	64	0	0	0	0
10	40	05	74	01	16	12.6	2.43	14	0	0	0	0
11	40	04.5	73	47	29	9.9	1.91	44	0	0	5	1
12	40	05	73	40.5	37	9.4	2.63	5	0	0	54	0
13	40	05	73	21.5	40	7.7	3.40	0	0	0	128	4
14	39	57	73	31	37	8.4	2.61	0	0	0	234	2
15	39	44.5	73	26	33	9.4	1.24	3	0	1	12	0
16	39	37.5	73	40	34	11.4	0.00	6	1	1	15	0
17	39	28	73	35	34	11.0	0.00	0	0	0	45	0
18	39	22.5	73	43	34	12.3	1.10	36	0	2	212	0
19	39	13	73	44	41	11.6	2.73	0	0	0	73	0
20	39	13	73	59	26	13.6	1.90	3	0	0	5	0
21	39	19,5	73	50.5	33	12.4	0.00	0	0	0	6	0
22	39	20.5	74	05.5	24	14.0	0.00	44	23	0	14	0
23	39	13	74	09	23	15.2	2.61	51	0	0	4	0
24	39	14	74	21.5	18	16.0	2.36	38	0	0	0	0
25	39	22,5	74	18	16	15.2	2.11	17	4	0	0	0

TABLE 8. Summary of data on surf clams and ocean quahogs - chartered vessels Gail Snow and Cora May Snow, September 9-14, 1976. Four minute tows were made using a surf clam dredge with a 60 inch knife. Pump was operated at 80-90 p.s.p.

Station No.	Location Lat.	Location Long.	Depth m	Bottom Temp. °C	Bottom O_2 mg/l	Number of Surf Clams Live	Number of Surf Clams Dead	Number of Surf Clams Clapper	Number of Ocean Quahogs Live	Number of Ocean Quahogs Dead	Number of Ocean Quahogs Clapper
1	39 31	74 13	8,5	17.0	1.15	39	0	10	0	0	0
2	39 29	74 00	23.8	14.9	0.10	0	0	49	0	0	0
3	39 29	73 47	29.3	12.6	0.00	0	0	51	0	0	0
4	39 30	73 34	33.2	11.4	1.45	0	0	1	22	3	9
6	39 37	73 32	37.8	10.7	1.00	0	0	10	80	15	39
7	39 45	73 27	39.3	10.4	0.90	7	0	2	80	0	0
8	39 44	73 40	25.6	18.0	1.50	5	0	0	8	0	0
9	39 44	73 53	24.7	15.1	0.00	0	0	62	0	0	0
10	39.44	74.04	11.9	19.3	7.20	3700	0	0	0	0	0
11	39 56	73.57	20.1	13.3	0.10	227	13	16	0	0	0
12	40 06	73 59	20.1	12.9	1.35	118	15	1	0	0	0
13	40 06	73 47	28.3	11.5	2.05	67	0	0	12	0	0
14	40 04	73 36	37.5	9.9	1.75	0	0	0	48	0	0
15	40 06	73 22	39.3	9.5	2.15	0	0	0	8	0	0
16	39 57	73 29	40.8	9.0	1.45	0	0	0	10	0	0
17	39 55	73 43	32.0	11.9	1.95	26	0	41	0	0	2
18	39 39	73 58	24.4	15.0	0.00	0	0	90	0	0	0
19	39 38	74 01	20.7	15.0	0.00	0	0	53	0	0	0
20	39 22	74 04	22.3	14.6	0.00	0	0	88	0	0	0
21	39 22	73 49	35.1	12.9	0.00	0	6	1	196	7	5
22	39 23	73 36	41.5	11.9	0.85	0	0	0	36	6	14
24	39 13	73 45	42.1	12.1	0.00	0	0	0	147	0	0
26	38 54	73 54	40.2	14.2	1.55	0	0	0	444	0	0
27	38 58	74 07	36.6	13.1	2.05	5	0	0	54	1	2
28	38 58	74 20	33.8	12.6	2.30	0	0	0	211	3	0
29	38 57	74 33	17.1	16.5	3.05	40	0	0	0	0	0
30	38 57	74 43	12.2	18.6	6.05	0	0	0	0	0	0
31	39 14	74 35	14.6	18.0	2.80	0	0	0	0	0	0
32	39 13	74 23	18.3	16.6	3.75	4	0	23	0	0	0
33	39 13	74 10	21.9	16.6	1.85	43	0	45	0	0	0
34	39 13	73 58	11.9	14.1	1.95	22	1	18	5	0	0

TABLE 8 (continued)

Station No.	Location Lat.	Location Long.	Depth m	Bottom Temp. °C	Bottom O_2 mg/l	Number of Surf Clams Live	Number of Surf Clams Dead	Number of Surf Clams Clapper	Number of Ocean Quahogs Live	Number of Ocean Quahogs Dead	Number of Ocean Quahogs Clapper
Special samples taken between transect stations											
S1	40 00	74 03	5.5*	19.6	8.70	2400	0	0	0	0	0
S2	39 41	73 50	23.5	17.6	3.50	40	1	43	0	0	0
S3	39 44	73 47	21.0	15.5	0.80	38	4	64	0	0	0
S4	39 49	74 00	18.3	14.2	0.00	51	8	16	0	0	0
S5	39 51	74 03	14.6	14.6	0.00	73	36	26	0	0	0
S6	39 31	73 41	32.0	12.3	0.53	0	0	16	0	0	0
S7	39 30	73 51	32.0	13.6	0.00	0	0	71	0	0	0
S8	39 14	73 51	29.9	13.5	0.75	14	5	2	0	0	0
S9	39 13	74 29	-	17.1	3.30	11	10	13	0	0	0
S10	39 21	74 18	17.7	17.7	3.00	0	0	16	0	0	0

* Special inshore station

(S1-10 = Special stations)

TABLE 9. Summary of data on surf clams, ocean quahogs, and other invertebrates - chartered vessel <u>Margaret and Nancy</u> - October 7-8, 1976. Four minute tows were made using a surf dredge with a 60 inch knife. Pump was operated at 80-90 p.s.i.

Sta. No.	Lat.	Long.	Depth	Bottom Temp. °C	Bottom O_2 mg/l	No. Surf Clams Live	No. Surf Clams Dead	No. Surf Clams Clapper	No. Ocean Quahogs Live	No. Ocean Quahogs Dead	No. Ocean Quahogs Clapper	Other Invertebrates
1	39 28	74 15.5	9.8	16.4	6.70	4	0	152	0	0	0	1 Busycon, 1 Limulus
2	39 28	74 00.5	23.8	17.7	6.50	0	0	32	0	0	0	No invertebrates or fish
3	39 28	73 47.5	29.3	18.1	6.25	0	0	9	0	0	2	No invertebrates or fish
7	39 45	73 39	24.4	17.4	5.75	1	0	3	3	0	0	2 Lunatia
8	39 56	73 44	28.7	13.6	0.75	0	0	0	142	0	17	No invertebrates or fish
12	40 05	73 40.5	45.4	14.8	2.75	2	0	0	38	0	0	2 Asterias
13	40 05	73 21.5	42.7	15.6	3.55	2	0	1	210	0	20	No invertebrates or fish
14	39 57	73 31	39.3	18.0	6.65	10	0	8	1	0	0	No invertebrates or fish
15	39 44.5	73 26	37.8	17.7	6.65	0	0	8	0	0	0	No invertebrates or fish
16	39 37.5	73 40	33.8	17.1	5.15	0	0	0	1	0	2	1 Lunatia
17	39 28	73 35	31.7	16.4	4.15	0	0	9	0	0	0	No invertebrates or fish

TABLE 10. Surf clam and ocean quahog mortality in the study area (Manasquan Inlet to Great Egg Inlet, New Jersey) August 6-8, 1976.

Depth Range (m)	Number of Stations	No. of Live Surf Clams	Percent Mortality			Number of Live Ocean Quahogs	Percent Mortality		
			Dead	Clappers	Total		Dead	Clappers	Total
≤18.3	5	466	1.06	4.04	5.10	3	0	0	0
18.4-36.6	16	336	7.98	2.66	10.64	355	0	0.28	0.28
>36.6	4	5	0	0	0	489	0	1.21	1.21
Total	25	787	4.11	3.41	7.52	847	0	0.82	0.82

TABLE 11. Surf clam mortality in the study area (Manasquan Inlet to Great Egg Inlet, New Jersey) April 6 to May 13, 1976.

Depth Range (m)	Number of Stations	No. of Live Surf Clams	Percent Mortality Dead	Percent Mortality Clappers	Percent Mortality Total
≤18.3	5	142	0	1.40	1.40
18.4-36.6	16	149	0	6.04	6.04
>36.6	4	0	0	0	0
Total	25	291	0	3.78	3.78

TABLE 12. Surf clam and ocean quahog mortality in the study area (Manasquan Inlet to Great Egg Inlet, New Jersey) September 9-14, 1976.

Depth Range (m)	Number of Stations	No. of Live Surf Clams	Percent Mortality			No. of Live Ocean Quahogs	Percent Mortality		
			Dead	Clappers	Total		Dead	Clappers	Total
<18.3	3	161	7.14	16.19	23.33	0	0	0	0
18.4-36.6	16	357	2.21	58.30	60.51	439	5.75	12.80	18.55
>36.6	4	0	0	0	0	213	0	0	0
Total	23	518	3.13	50.36	53.49	652	4.12	9.18	13.30

TABLE 13. Surf clam and ocean quahog mortality in the study area (Manasquan Inlet to Great Egg Inlet, New Jersey) October 7-8, 1976.

Depth Range (m)	Number of Stations	No. of Live Surf Clams	Percent Mortality			Number of Live Ocean Quahogs	Percent Mortality		
			Dead	Clappers	Total		Dead	Clappers	Total
≤18.3	1	4	0	97.44	97.44	0	0	0	0
18.4-36.6	6	1	0	98.15	98.15	146	0	12.57	12.57
>36.6	4	14	0	54.84	54.84	258	0	7.19	7.19
Total	11	19	0	92.12	92.12	404	0	9.21	9.21

TABLE 14. Estimated biomass (in thousand metric tons) changes of surf clams and ocean quahogs in the impacted area off central New Jersey 1976.

Depth Range (m)	1976 - Assessment Surveys - Surf Clam				1976 - Assessment Surveys - Ocean Quahog			
	April-May	Aug. 6-8	Sept. 9-14	Oct. 7-8	April-May	Aug. 6-8	Sept. 9-14	Oct. 7-8
≤18.3	66.00	62.63	50.60	1.69	0	0	0	0
18.4-36.6	80.21	71.67	31.67	1.48	29.85	29.77	24.31	26.10
>36.6	+	0	0	+	45.55	45.00	45.55	42.27
Total	146.21	134.30	82.27	3.17	75.40	74.77	69.86	68.37

+ negligible

TABLE 15. Summary of data on surf clams, ocean quahogs, and sea scallops - chartered vessel <u>Cora May Snow</u> - September 15-25, 1976. Four minute tows were made using a surf clam dredge with a 60 inch knife. Pump was operated at 80-90 p.s.i.

Sta. No.	Lat.	Long.	Depth (m)	Bottom		No. Surf Clams			No. Ocean Quahogs			No. Sea Scallops		
				Temp. °C	O_2 mg/l	Live	Dead	Clappers	Live	Dead	Clappers	Live	Dead	Clappers
35	40 22	73 53	20.1	13.3	0.90	70	0	1	0	0	0	0	0	0
36	40 15	73 39	25.9	14.0	2.25	0	0	1	158	0	11	0	0	0
37	40 17	73 28	30.5	12.4	3.45	0	0	0	13	0	0	0	0	0
38	40 21	73 19	32.6	12.6	1.40	0	0	0	19	0	1	2	0	0
39	40 27	73 41	22.9	15.0	2.00	0	0	0	35	0	1	0	0	0
40	40 26	73 27	21.9	15.1	0.65	46	0	0	5	0	0	3	0	0
41	40 35	73 31	11.9	17.7	4.90	2	0	0	0	0	0	0	0	0
42	40 34	73 44	12.8	19.0	5.85	2	0	0	0	0	0	0	0	0
43	40 33	73 53	7.3	20.1	6.40	6440	0	0	0	0	0	0	0	0
44	40 27	73 15	28.3	13.5	2.25	0	0	0	3	0	0	0	0	0
45	40 28	73 03	33.5	12.7	2.55	0	0	0	32	0	2	0	0	0
46	40 33	72 52	37.5	11.9	2.30	0	0	0	148	0	3	3	0	0
47	40 35	72 37	36.6	12.0	3.30	0	0	0	600	0	5	0	0	0
48	40 37	72 25	18.3	16.4	4.70	9	0	0	1	0	0	0	0	0
49	40 48	72 24	27.4	14.6	3.65	1	0	0	173	0	1	0	0	0
50	40 52	72 12	26.5	14.4	3.90	0	0	0	47	0	0	0	0	0
51	40 58	71 58	24.7	16.7	5.65	1	0	0	65	0	84	0	0	0
52	41 02	71 47	23.8	18.2	7.10	0	0	0	0	0	0	0	0	0
53	40 53	71 41	55.8	11.4	3.55	0	0	0	17	0	26	0	0	0
54	40 50	71 54	38.4	12.5	4.80	-	-	-	-	-	-	-	-	-
54	40 50	71.54	37.5	12.0	5.05	0	0	0	97	0	1	1	0	0
55	40 39	71 48	57.6	11.2	6.85	0		0	47	0	0	1	0	0
56	40 40	72 26	38.4	11.5	3.40	0	0	0	682	0	3	0	0	0
57	40 42	72 16	40.2	10.7	3.75	0	0	0	1059	0	2	9	0	0
58	40 44	72 06	43.0	11.4	4.25	0	0	0	61	0	2	6	0	0
59	40 34	71 59	54.9	10.6	4.50	0	0	0	60	0	0	2	0	0
60	40 32	72 12	54.9	10.0	4.30	0	0	0	201	0	3	2	0	0

TABLE 15. (continued)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom O_2 mg/l	No. Surf Clams			No. Ocean Quahogs			No. Sea Scallops		
						Live	Dead	Clappers	Live	Dead	Clappers	Live	Dead	Clappers
61	40 29	72 24	47.5	10.3	3.65	0	0	0	221	0	2	6	0	0
62	40 20	72 21	51.5	9.0	3.65	0	0	0	198	0	2	4	0	0
63	40 16	72 33	51.2	8.8	3.95	0	0	0	783	0	15	0	0	0
64	40 26	72 36	43.3	9.5	3.95	0	0	0	167	0	2	4	0	0
65	40 23	72 49	45.1	9.3	*	0	0	0	169	0	6	32	0	1
66	40 13	72 46	53.0	8.1	3.10	0	0	0	137	0	33	28	0	0
67	40 18	73 01	39.3	10.4	3.10	0	0	0	108	0	1	6	0	0
68	40 09	72 59	43.9	9.0	*	0	0	0	260	0	0	5	0	0
69	40 07	73 08	41.8	9.7	1.90	0	0	0	179	0	0	6	0	1

* Sample would not titrate clear. Dirty brown color persisted.

Special samples taken between transect stations
(not discussed in this report)

Sta. No.	Lat.	Long.	Depth (m)	Bottom Temp. °C	Bottom O_2 mg/l	Surf Clams Live	Surf Clams Dead	Surf Clams Clappers	Ocean Quahogs Live	Ocean Quahogs Dead	Ocean Quahogs Clappers	Sea Scallops Live	Sea Scallops Dead	Sea Scallops Clappers
Sandy Hook Pier			--	--	4.55									
Ambrose Channel			--	19.0	6.05									
3	40 13	73 58	13.7	15.4	3.00	0	0	0	0	0	0	0	0	0
6	40 27	73 43	11.0	19.5	7.15	46	0	2	0	0	0	0	0	0
12	40 06	73 59	20.7	14.5	2.15	0	0	0	0	0	0	0	0	0
5	40 30	73 24	19.2	15.5	0.70	0	0	0	0	0	0	0	0	0
4	40 18	73 57	16.5	15.1	2.80	0	0	0	0	0	0	0	0	0

TABLE 16. Surf clam and ocean quahog mortality off northern New Jersey and Long Island, New York April 6 to May 13, 1976.

Depth Range (m)	Number of Stations	Live Surf Clams	Percent Mortality			Number of Live Ocean Quahogs	Percent Mortality		
			Dead	Clappers	Total		Dead	Clappers	Total
≤18.3	2	0	0	0	0	40	0	0	0
18.4-36.6	10	117	0	1.71	1.71	538	0	2.79	2.79
>36.6	19	11	0	0	0	5,597	0	3.14	3.14
Total	31	128	0	1.56	1.56	6,175	0	3.09	3.09

TABLE 17. Surf clam and ocean quahog mortality off northern New Jersey and Long Island, New York, September 15-25, 1976.

Depth Range (m)	Number of Stations	No. of Live Surf Clams	Percent Mortality			No. of Live Ocean Quahogs	Percent Mortality		
			Dead	Clappers	Total		Dead	Clappers	Total
≤18.3	3	6,444	0	0	0	0	0	0	0
18.4-36.6	13	127	0	1.57	1.57	551	0	18.15	18.15
>36.6	19	0	0	0	0	5,193	0	2.04	2.04
Total	35	7,571	0	0.26	0.26	5,744	0	3.59	3.59

TABLE 18. Estimated biomass (in thousand metric tons) changes of ocean quahogs in the study area off Long Island, 1976.

Depth Range (m)	1976 - Assessment Surveys for Ocean Quahogs	
	April-May	Sept. 15-25
≤18.3	4.8	4.8
18.4-36.6	64.7	53.0
>36.6	674.2	660.5
Total	743.7	718.3

TABLE 19. Temperature measurements in centigrade at 2 meter intervals from surface to bottom aboard Valerie E., August 6-8, 1976

Sta. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Meters																									
0	22.7	22.7	24.5	22.9	22.0	22.3	23.0	22.0	21.9	17.2	21.7	22.0	21.4	22.1	23.5	24.1	24.0	24.7	23.7	24.0	24.0	23.9	24.1	24.4	21.7
2	-	23.0	24.0	22.9	21.5	22.0	22.4	21.5	22.0	17.0	21.7	22.0	21.3	22.0	23.0	24.1	24.0	23.6	23.7	23.5	23.9	23.9	24.1	24.2	21.7
4	22.7	23.0	24.0	22.6	20.0	22.5	22.4	22.0	21.7	15.5	21.8	22.0	21.4	22.0	23.0	24.1	23.9	23.6	23.6	23.5	23.9	23.9	24.1	24.2	18.4
6	22.7	23.0	23.9	22.6	19.5	22.3	22.5	21.9	21.0	14.0	21.6	22.0	21.5	21.8	22.5	24.0	24.0	23.6	23.6	23.5	23.7	23.9	24.1	24.1	16.8
8	21.6	23.0	23.9	22.4	15.5	15.0	22.1	21.0	19.5	13.5	21.1	21.6	21.1	21.6	22.5	24.0	24.0	23.6	23.6	23.6	23.8	23.5	24.0	24.0	16.0
10	20.0	23.0	23.7	18.5	13.0	13.2	22.0	17.0	13.9	13.0	18.5	21.5	16.7	20.4	21.5	23.9	24.0	23.6	23.6	23.5	23.8	23.5	24.0	19.5	15.4
12	17.2	22.5	23.6	12.5	13.5	12.3	19.5	13.4	12.0	12.8	15.0	19.6	13.4	14.9	14.0	22.6	24.0	23.5	23.6	20.3	21.0	21.0	24.0	16.5	15.3
14	15.6	13.5	22.0	12.0	-	11.8	18.6	11.0	12.0	12.6	12.0	16.0	12.8	13.4	13.7	17.0	23.8	23.5	21.0	16.7	18.0	15.5	21.5	16.1	15.2
16	-	13.0	17.0	12.0	-	11.8	-	10.0	12.0	-	11.0	13.6	11.7	12.6	11.2	15.0	23.4	19.5	17.7	14.1	14.0	14.4	16.0	16.0	15.2
18	-	13.0	15.0	12.0	-	11.6	-	9.8	11.5	-	10.5	12.5	10.8	11.6	10.5	14.2	20.5	14.6	14.7	13.9	13.2	14.4	15.4	16.0	-
20	-	12.9	12.5	12.0	-	11.6	-	9.2	11.5	-	10.0	11.5	10.0	10.6	10.0	13.2	18.5	13.6	13.8	13.8	13.0	14.4	15.4	-	-
22	-	-	12.1	11.9	-	-	-	9.0	-	-	10.0	10.6	9.3	9.6	9.9	12.5	16.5	12.7	13.2	13.8	13.0	14.1	15.3	-	-
24	-	-	12.0	-	-	-	-	9.0	-	-	9.9	10.5	8.1	9.4	9.3	12.0	14.0	12.5	12.8	13.8	13.0	14.0	15.2	-	-
26	-	-	12.0	-	-	-	-	9.0	-	-	9.9	10.2	7.9	9.4	9.2	11.6	11.5	12.4	12.6	13.6	12.9	-	-	-	-
28	-	-	-	-	-	-	-	8.8	-	-	-	10.0	7.8	9.2	9.4	11.5	11.2	12.3	12.6	-	12.5	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	9.9	7.6	9.0	9.4	11.4	11.1	12.3	12.5	-	12.5	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	9.9	7.6	8.6	9.4	11.4	11.0	12.3	12.5	-	12.5	-	-	-	-
34	-	-	-	-	-	-	12.5	-	-	-	-	9.5	7.6	8.6	-	-	11.0	12.3	12.5	-	12.4	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	9.4	7.6	8.5	-	-	-	-	12.4	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	7.6	8.5	-	-	-	-	12.2	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	7.7	8.4	-	-	-	-	12.1	-	-	-	-	-	-
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.0	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.6	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.6	-	-	-	-	-	-

TABLE 20. Temperature measurements (°C) at 2 meter intervals from surface to bottom, September 9-14, 1976

Sta. No. Meters	1	2	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	26	27	28	29	30	31	32	33	34
0	18.5	20.4	20.7	20.5	19.9	20.1	21.5	22.4	20.2	20.7	19.0	20.4	21.0	21.1	20.5	21.9	21.0	21.0	20.3	21.5	20.7	22.5	22.6	21.6	21.0	19.7	19.6	21.2	20.8	20.2	22.5
2	18.5	20.5	20.6	20.4	20.0	20.1	21.0	22.1	20.0	20.7	19.2	20.4	20.6	21.0	20.5	22.0	21.0	20.9	20.2	21.2	20.7	21.8	22.3	21.6	20.9	19.7	19.6	21.2	20.8	20.3	21.4
4	18.5	20.5	20.6	20.5	20.0	20.2	20.8	21.7	20.0	20.3	19.0	20.4	20.6	20.9	20.5	21.8	21.0	20.9	20.2	21.2	20.7	21.5	22.2	21.4	21.0	19.7	19.6	21.0	20.8	19.9	21.0
6	17.0	20.4	20.6	20.3	20.0	20.2	20.8	21.5	19.5	20.2	19.1	20.5	20.6	20.9	20.4	21.6	20.9	20.9	20.2	21.2	20.6	21.4	22.0	21.3	20.9	19.4	19.0	20.5	20.1	19.8	21.0
8		20.5	20.6	20.3	20.0	20.2	20.7	21.4	19.3	20.1	19.2	20.4	20.5	20.9	20.2	21.6	20.8	20.9	20.2	20.7	20.5	21.4	21.8	21.3	20.9	19.2	18.7	20.0	20.0	19.5	21.0
10		20.5	20.6	20.2	19.9	20.1	20.6	21.3	19.3	19.5	19.5	20.4	20.5	20.8	20.1	21.5	20.8	20.9	20.2	20.7	20.5	21.3	21.8	21.2	20.9	17.0	18.6	18.2	20.0	19.5	20.8
12		20.5	20.6	20.2	19.9	20.0	20.5	21.3	19.3	14.1	14.9	20.4	20.5	20.8	20.1	21.5	20.8	19.2	20.0	20.6	20.5	21.3	21.9	21.2	21.0	16.8		18.0	20.0	18.0	20.7
14		15.5	20.6	20.2	19.9	15.3	20.5	21.0		13.6	14.5	20.4	20.5	18.1	20.1	21.2	20.8	16.0	16.5	20.6	20.5	21.3	21.8	21.1	20.9	16.5			17.1	17.2	20.6
16		15.2	20.6	20.1	19.8	15.0	20.5	15.3		13.5	13.9	20.4	17.6	15.2	18.3	15.9	15.2	15.3	15.0	20.6	20.5	21.2	21.8	21.1	17.5				16.6	17.0	16.5
18		15.0	13.0	20.1	14.7	11.0	20.5	15.1		13.3	13.4	14.5	17.4	13.3	16.0	13.6	15.1	15.0	14.6	20.6	17.6	21.0	21.8	21.1	14.8					16.6	14.5
20		14.9	12.7	12.6	12.0	10.6	18.2	15.0			13.0	12.7	15.5	11.0	15.4	12.9	15.0			13.1	13.0	18.4	21.8	21.1	14.1						14.5
22			12.6	12.0	12.0	10.5	18.0				12.9	12.5	15.4	10.1	14.2	12.0				12.9	12.6	14.4	21.8	15.6	13.3						14.1
24			12.6	11.5	11.0	10.5						11.6	15.3	10.0	12.5	12.0				12.9	12.3	13.7	18.6	13.6	13.0						
26				11.5	10.8	10.4						11.5	13.6	9.8	11.1	11.9				12.9	12.0	13.3	15.3	13.3	12.6						
28				11.4	10.7							11.5	11.0	9.8	10.0	11.9				12.9	12.0	12.8	14.4	13.3							
30					10.7								10.3	9.7	9.5					12.9	11.9	12.6	14.2	13.1							
32					10.7								9.9	9.5	9.2						11.9	12.2									
34															9.1							12.1									
36															9.0																

TABLE 21. Temperature measurements at 2 meter intervals from surface to bottom aboard <u>Margaret</u> <u>and</u> <u>Nancy</u>, October 7-8, 1976.

Sta. No.	1	2	3	7	8	12	13	14	15	16	17
Meters											
2	16.7	17.8	18.6	18.4	17.6	18.2	18.2	18.1	18.0	18.5	18.6
4	16.7	17.8	18.5	18.4	17.6	18.2	18.2	18.1	18.0	18.5	18.5
6	16.7	17.7	18.5	18.4	17.6	18.2	18.2	18.1	18.0	18.4	18.3
8	16.5	17.7	18.5	18.4	17.6	18.2	18.2	18.2	17.9	18.3	18.3
10	16.5	17.7	18.5	18.4	17.6	18.2	18.2	18.2	17.9	18.3	18.2
12	16.5	17.7	18.5	18.4	17.6	18.2	18.2	18.2	17.9	18.3	18.2
14	16.5	17.7	18.5	18.3	17.5	18.2	18.2	18.2	17.8	18.3	18.1
16	16.4	17.7	18.4	18.2	17.5	18.0	18.0	18.2	17.8	18.2	18.1
18		17.7	18.4	18.1	17.5	18.0	17.8	18.2	17.7	18.2	18.1
20		17.7	18.4	18.1	17.5	18.0	17.8	18.1	17.7	18.1	18.1
22		17.7	18.4	18.1	17.5	17.9	17.8	18.0	17.7	18.1	16.9
24		17.7	18.4	18.1	17.5	17.6	17.8	18.0	17.7	18.1	16.7
26		17.7	18.3	18.1	17.4	16.8	17.8	18.0	17.7	18.1	16.7
28		17.7	18.2	17.6	17.3	16.8	17.8	18.0	17.7	17.9	16.7
30			18.2	17.4	17.3	16.8	17.0	18.0		17.7	16.6
32			18.1	17.4	15.0	16.4	17.0	18.0		17.2	16.5
34			18.1	17.4	13.8	16.3	16.6			17.1	16.4
36			18.1		13.8	15.5	16.0			17.1	16.4
38					13.6	15.0	15.6			17.1	
40					13.6	14.8	15.6				
42					13.6						
44					13.6						

TABLE 22. Temperature measurements in centigrade at 2 meter intervals from surface to bottom aboard <u>Cora May Snow</u> September 5-15, 1975

Sta. #	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Meters																				
2	20.4	20.6	20.6	20.4	20.5	20.5	20.9	21.0	20.7	20.6	21.6	21.4	21.1	19.0	19.8	19.7	20.5	19.7	21.0	20.2
4	20.4	20.6	20.6	20.4	20.5	20.6	20.8	21.0	20.5	20.6	21.6	21.4	21.0	19.0	19.9	19.6	20.5	19.4	21.0	20.2
6	20.4	20.6	20.6	20.2	20.5	20.5	20.7	20.3	20.6	20.6	21.6	21.1	21.0	19.0	19.8	18.4	19.8	19.4	20.2	20.2
8	20.1	20.5	20.6	20.1	20.4	20.5	20.4	20.1	20.2	20.5	21.6	21.0	21.0	18.6	19.2	18.2	19.7	19.5	19.9	20.1
10	20.0	20.5	20.4	19.8	20.5	20.5	18.6	19.6	20.1	20.5	21.6	20.8	19.9	18.0	19.1	18.0	19.2	19.4	19.9	19.5
12	20.0	20.4	20.0	19.7	20.5	20.5	18.0	19.5		20.5	21.5	20.7	19.9	17.8	19.0	18.5	19.1	19.4	19.8	19.3
14	19.4	20.4	19.8	19.7	20.5	19.3	17.7	19.0		20.5	21.3	19.5	19.5	17.4	18.6	18.7	19.0	19.3	19.7	19.0
16	16.2	20.2	19.3	19.7	20.5	15.5		19.0		18.0	20.0	19.6	19.3	16.9	18.0	18.3	19.0	19.1	19.6	19.0
18	15.0	20.1	17.8	18.5	20.1	15.5				16.7	19.2	19.5	19.0	16.7	17.5	18.3	19.0	19.1	19.0	18.5
20	13.6	17.4	17.3	18.0	18.9	15.3				14.9	18.3	17.5	18.2	16.5	16.2	18.2	18.7	19.0	18.1	18.2
22	13.3	16.4	16.5	17.6	15.6	15.3				14.3	17.0	17.0	17.0	16.4	16.0	18.0	18.2	19.0	18.0	18.0
24		14.3	16.0	15.2	15.2	15.3				14.0	16.1	16.5	16.3		15.4	17.0	18.0	19.0	17.5	18.0
26		14.1	15.4	14.1	15.0	15.0				13.8	15.5	16.0	15.9		15.1	15.5	17.0	19.0	16.9	17.8
28		14.0	14.6	13.3	15.0	15.1				13.7	14.8	15.3	14.9		15.0	15.0	16.7	18.8	15.4	17.0
30		14.0	14.1	12.9		15.1				13.6	14.4	13.7	14.8		14.8	14.5		18.2	15.1	16.7
32		14.0	13.3	12.7						13.5	14.3	12.3	12.5		14.6	14.4			14.5	16.7
34			13.0	12.7							14.0	12.1	12.1						13.8	16.6
36			12.6	12.7							14.0	12.0	12.0						12.7	16.5
38			12.4	12.6							13.7	12.0	12.0						12.6	15.2
40				12.6							13.5	12.0	12.0						12.4	14.5
42											13.1	11.9							12.4	14.0
44											13.0								12.3	13.4
46											12.7								12.2	12.8
48																			12.3	12.6
50																			12.0	12.5
52																			11.8	12.5
54																			11.5	12.5
56																			11.5	12.5
58																			11.5	12.5
60																			11.4	
62																			11.4	
64																			11.4	
66																				
68																				
70																				
72																				
74																				

TABLE 22. (continued)

54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	3	6	12	5	4	Hudson Channel Ambrose
18.6	19.4	18.6	18.2	17.9	17.5	17.6	18.5	18.4	18.7	18.5	18.7	18.7	19.2	19.4	19.6	19.5	20.3	20.5	20.2	19.3	20.4
18.6	19.4	18.6	18.2	17.9	17.5	17.6	18.5	18.4	18.7	18.5	18.7	18.8	19.2	19.4	19.6	20.0	20.3	20.6	20.2	19.3	20.3
18.6	19.4	18.6	18.3	17.9	17.5	17.6	18.5	18.4	18.7	18.5	18.7	18.8	19.2	19.4	19.6	20.0	20.1	20.6	20.1	19.3	20.3
18.6	19.4	18.6	18.3	17.9	17.5	17.6	18.5	18.5	18.7	18.5	18.8	18.8	19.2	19.4	19.6	20.3	20.0	20.5	20.1	19.3	20.3
18.6	19.4	18.6	18.3	17.9	17.5	17.6	18.5	18.5	18.8	18.5	18.7	18.8	19.2	19.4	19.6	20.2	19.7	20.5	20.0	19.0	20.3
18.6	19.4	18.6	18.3	17.9	17.5	17.6	18.6	18.5	18.8	18.5	18.8	18.8	19.2	19.4	19.6	20.2	19.5	20.5	16.6	17.0	20.2
18.0	19.4	18.6	17.6	18.0	17.5	17.6	18.6	18.5	18.8	18.5	18.8	18.8	19.2	19.4	19.6	19.9		19.8	16.0	16.6	20.1
17.2	18.1	18.6	17.3	18.2	17.5	17.6	18.6	18.5	18.8	18.5	18.8	18.8	19.2	19.4	19.6	16.4		18.9	15.8	16.4	20.0
16.7	17.6	18.6	17.2	18.2	17.5	17.6	18.6	18.5	18.8	18.5	18.2	18.8	19.2	19.4	19.6	15.4		16.6	15.5	15.6	19.0
15.8	16.2	18.6	17.2	18.2	17.5	17.6	18.6	18.5	18.8	17.6	15.3	16.6	17.1	19.4	19.6			15.2	15.5	15.1	19.0
15.3	16.5	18.6	16.2	18.2	15.8	17.6	18.6	18.5	18.8	16.8	14.7	16.0	16.6	19.4	18.6			14.8	15.4		
14.8	15.4	17.4	14.7	18.2	14.7	17.0	18.6	18.5	18.8	15.2	14.3	15.2	15.5	18.0	17.1			14.5	15.5		
14.2	14.5	15.3	14.2	18.0	14.1	16.0	14.7	18.1	16.2	14.3	14.3	14.9	14.5	17.9	16.2						
13.6	13.6	15.0	14.0	16.3	13.2	14.8	14.3	17.4	14.9	14.3	13.5	14.6	14.2	17.2	15.1						
13.3	13.2	14.6	13.3	14.2	12.1	13.5	14.3	15.3	14.3	14.0	12.4	14.1	14.0	15.6	14.3						
13.2	13.2	14.2	12.4	13.0	12.1	13.0	14.3	15.3	14.2	14.0	11.4	13.6	11.0	15.2	13.6						
13.0	13.0	14.1	12.1	12.3	11.8	12.5	13.8	14.3	14.0	13.8	9.9	13.2	10.6	14.6	12.3						
13.0	13.0	13.7	11.5	12.0	11.8	12.3	13.8	14.0	13.3	13.5	9.5	12.0	10.5	14.4	11.1						
12.8	13.0	12.1	11.1	11.7	11.9	12.2	13.8	13.8	13.0	13.2	9.5	11.1	10.5	14.2	10.1						
12.4	12.7	11.7	11.0	11.6	11.6	11.8	13.8	13.3	12.3	12.5	9.3	8.6	10.4	14.0	10.0						
12.2	12.6	11.6	11.0	11.6	11.5	11.3	13.8	12.5	12.0	9.9	9.3	8.4	10.4	13.2	9.9						
12.2	12.6	11.6	11.0	11.5	11.3	11.1	11.3	12.2	11.3	9.6	9.3	8.3		12.2	9.8						
12.1	12.6	11.5	10.7	11.5	11.3	11.0	10.7	12.2	9.4	9.6	9.3	8.3		10.0	9.8						
12.0	12.4	11.5	10.7	11.4	11.2	11.0	10.7	12.2	9.1	9.6	9.3	8.2		9.3	9.7						
	12.2		10.7	11.4	11.1	10.2	10.7	11.0	9.0	9.5		8.2		9.1							
	12.0		10.7		11.1	10.1	10.5	9.3	9.0			8.2		9.1							
	11.8		10.7		11.0	10.0	10.5	9.3	9.0			8.1		9.1							
	11.8				10.7	10.0	10.3	9.3	8.8			8.1		9.0							
	11.6				10.6	10.0	10.3	9.3	8.8			8.1		9.0							
	11.6				10.6	10.0		9.3	8.8												
	11.5				10.6	10.0		9.0	8.8												
	11.5				10.6																
	11.3				10.6																
	11.3																				
	11.2																				
	11.2																				
	11.0																				

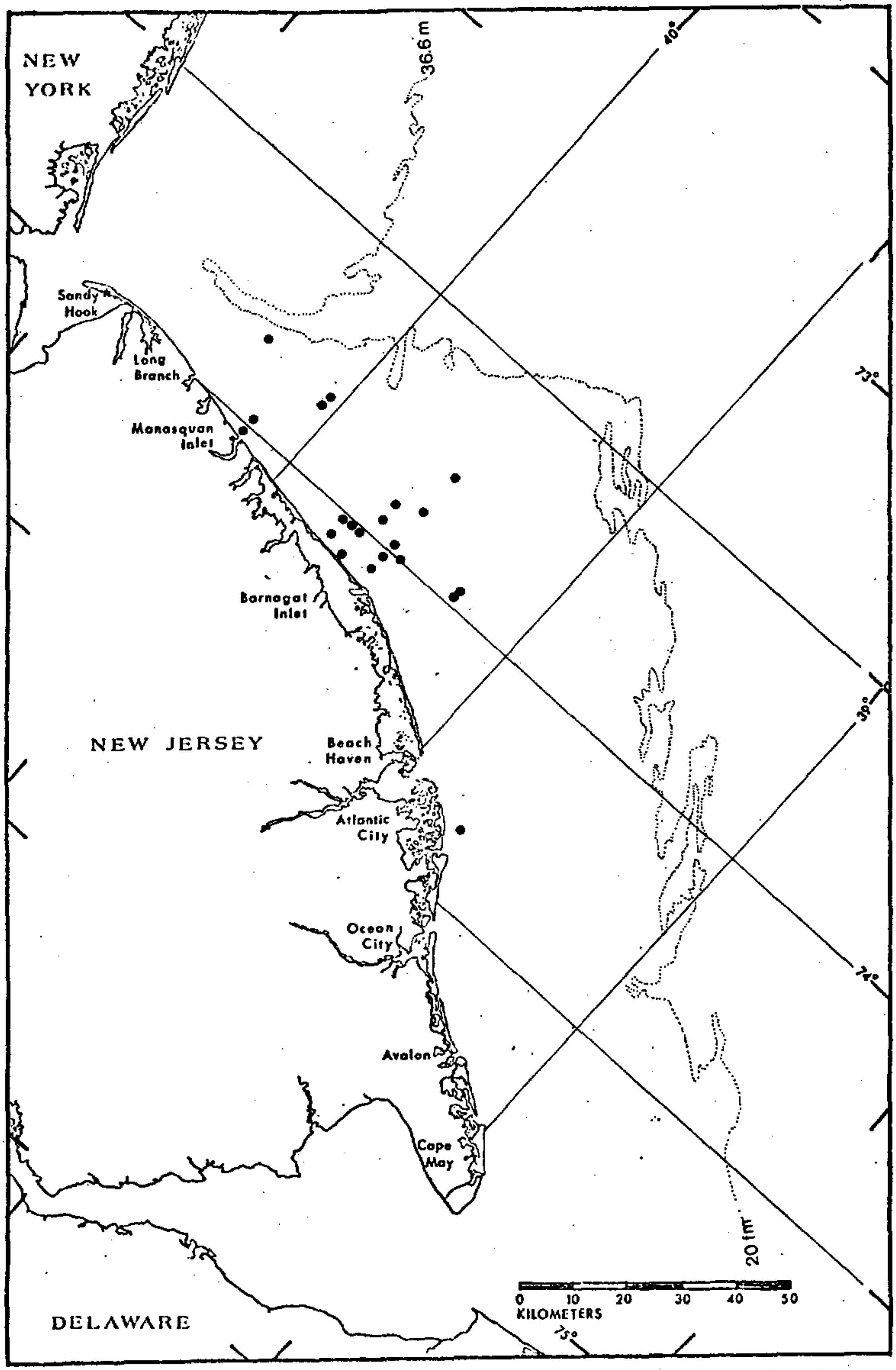

Figure 1. Chart shwoing positions (.) for stressed and dead surf clams and other invertebrates (Sources from SCUBA divers, otter trawl and dredged operations in July 1976).

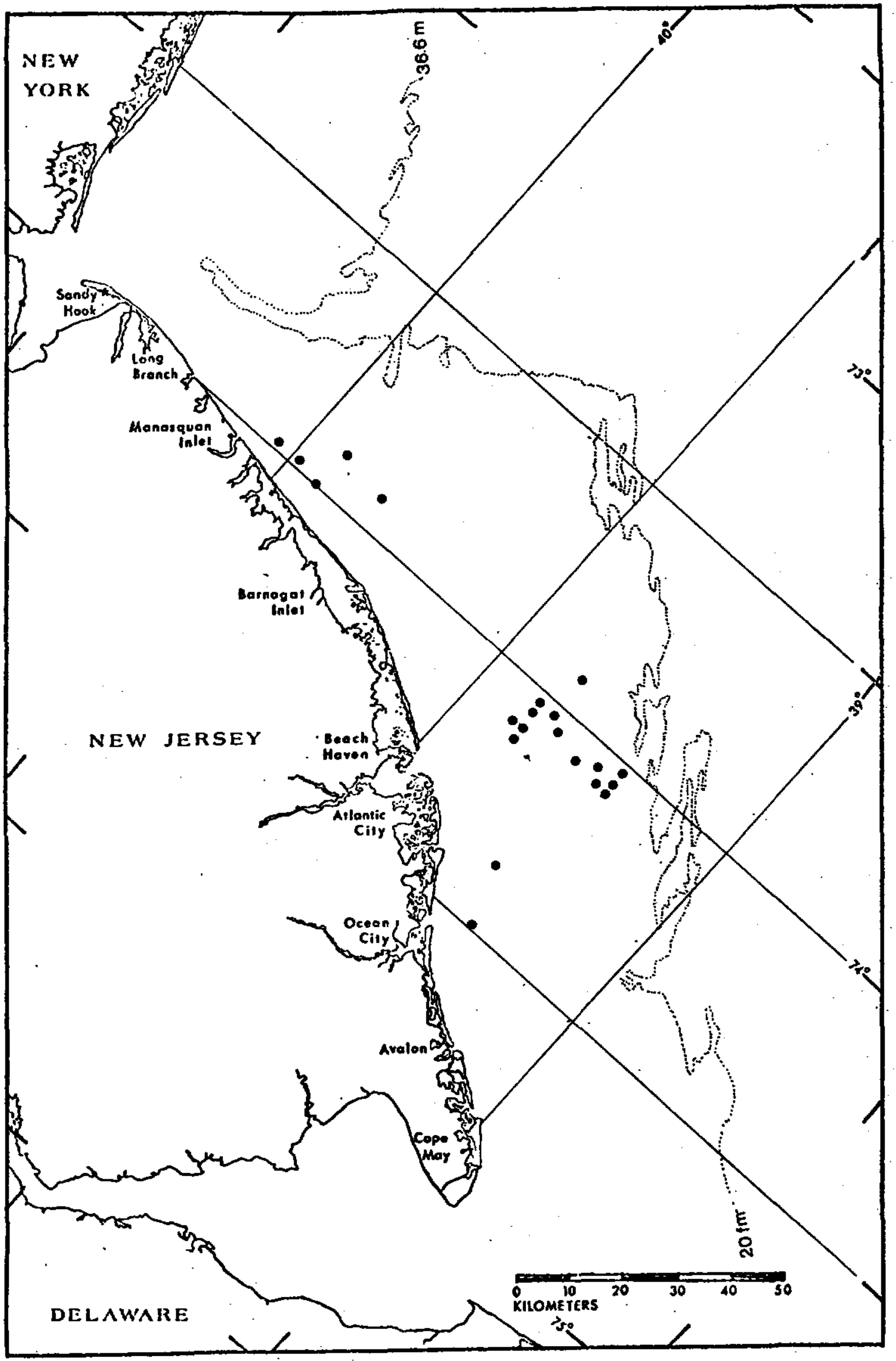

Figure 2. Chart showing positions (.) of dead clams as reported by captains of surf clamvessels.

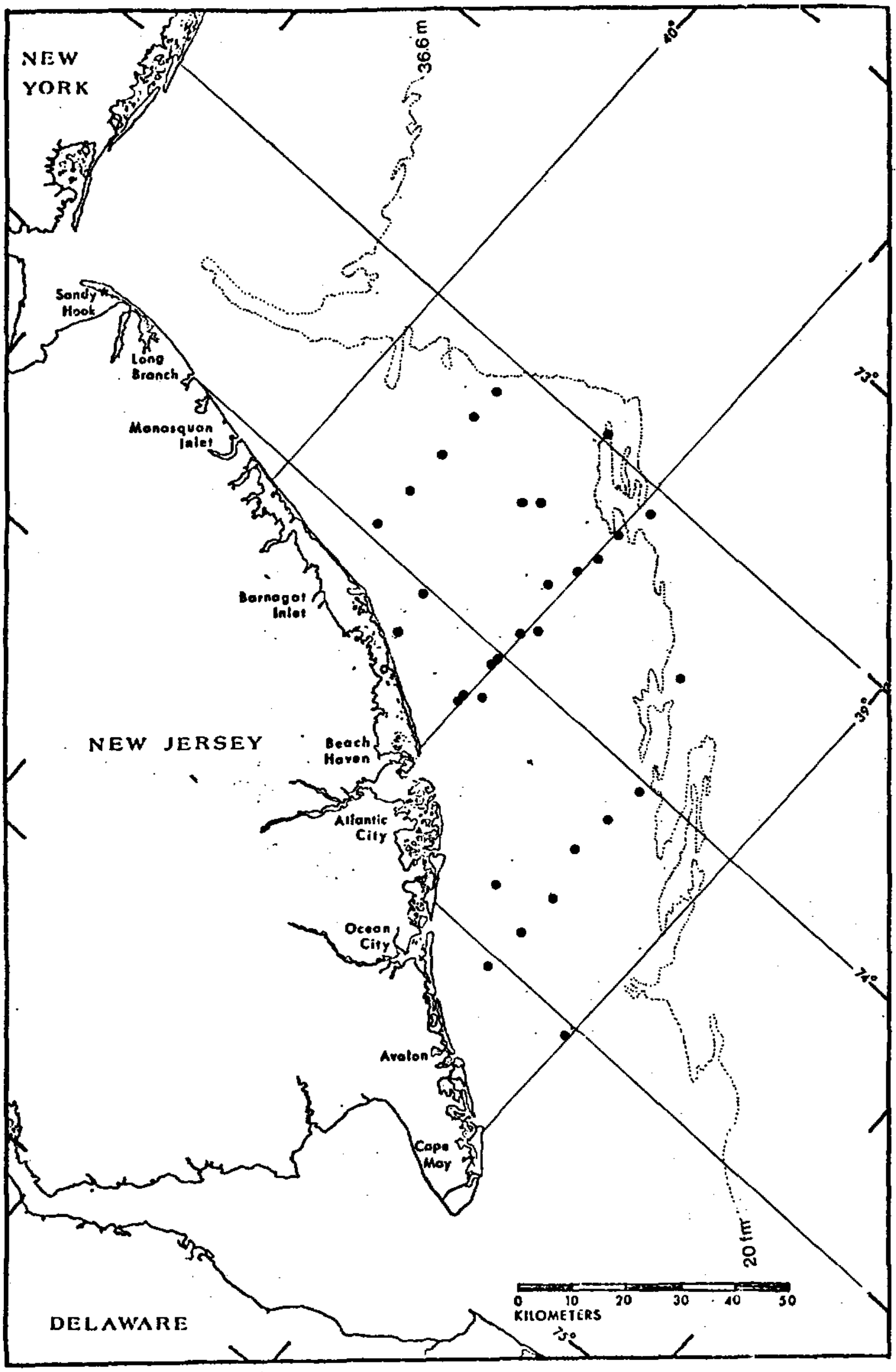

Figure 3. Chart showing position (.) of stressed and dead surf clams from ottor trawl catches of the vessel Atlantic Twin, August 6-17, 1976.

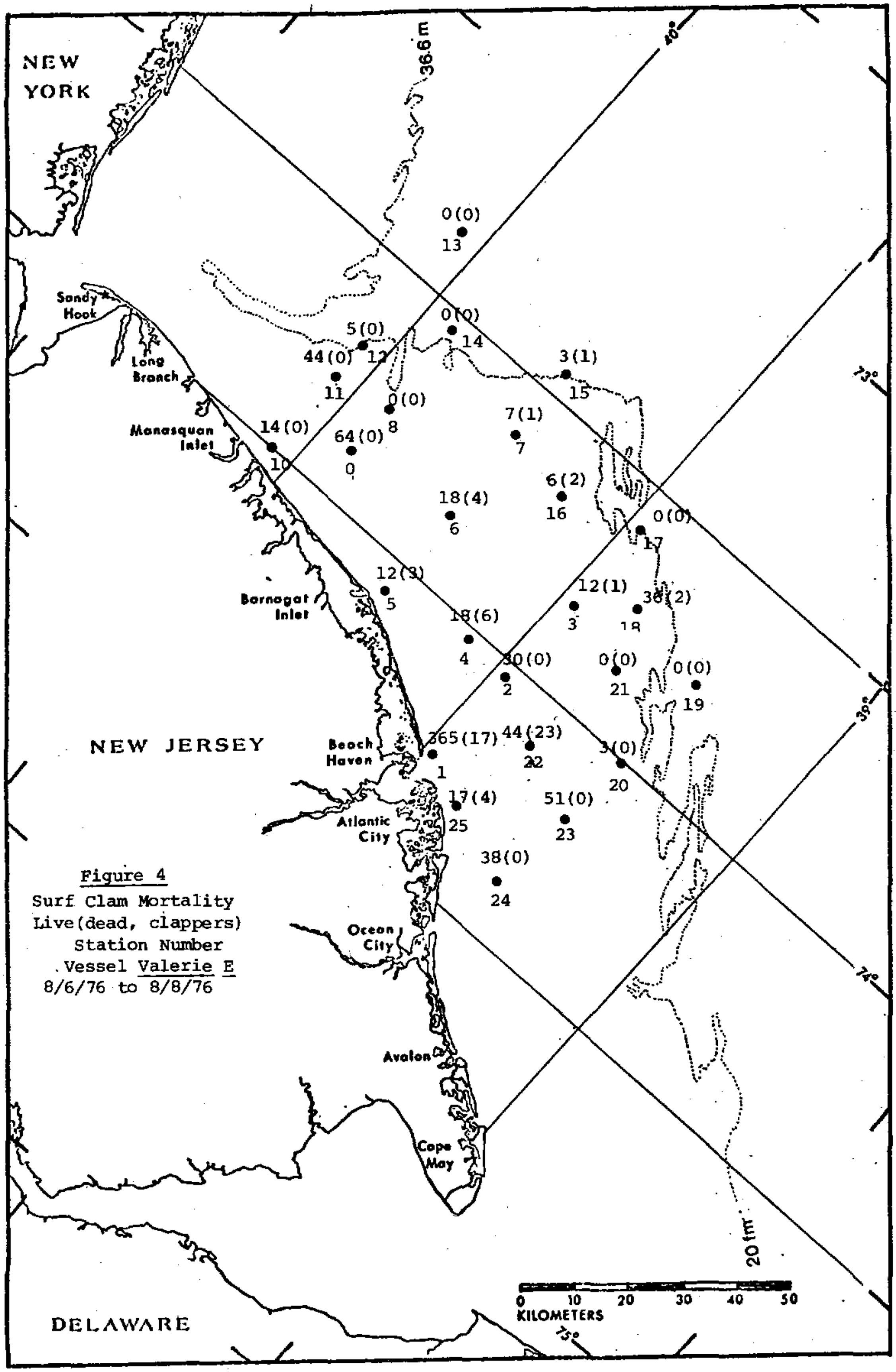

Figure 4
Surf Clam Mortality
Live(dead, clappers)
Station Number
Vessel *Valerie E*
8/6/76 to 8/8/76

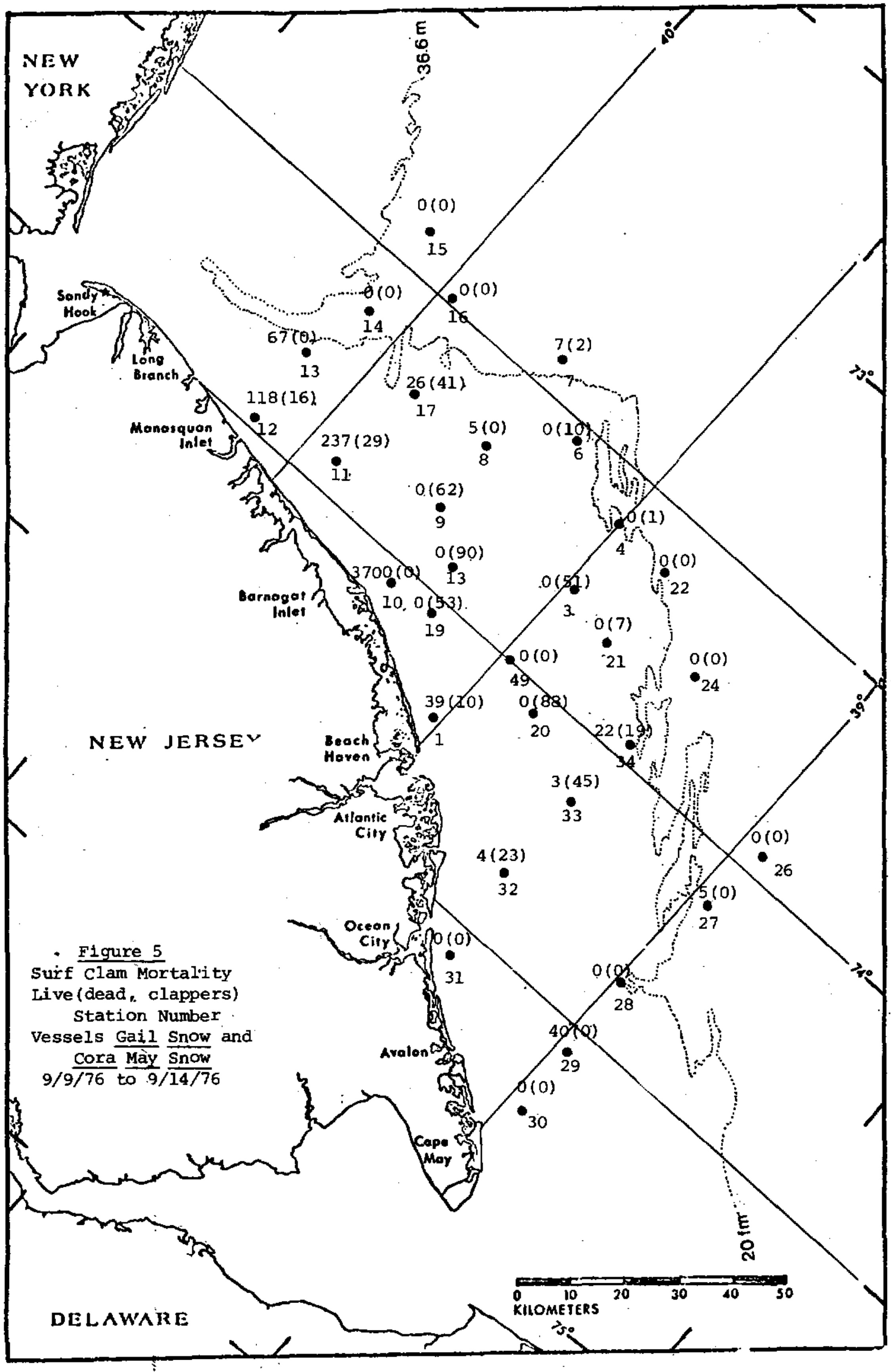

Figure 5
Surf Clam Mortality
Live(dead, clappers)
Station Number
Vessels Gail Snow and
Cora May Snow
9/9/76 to 9/14/76

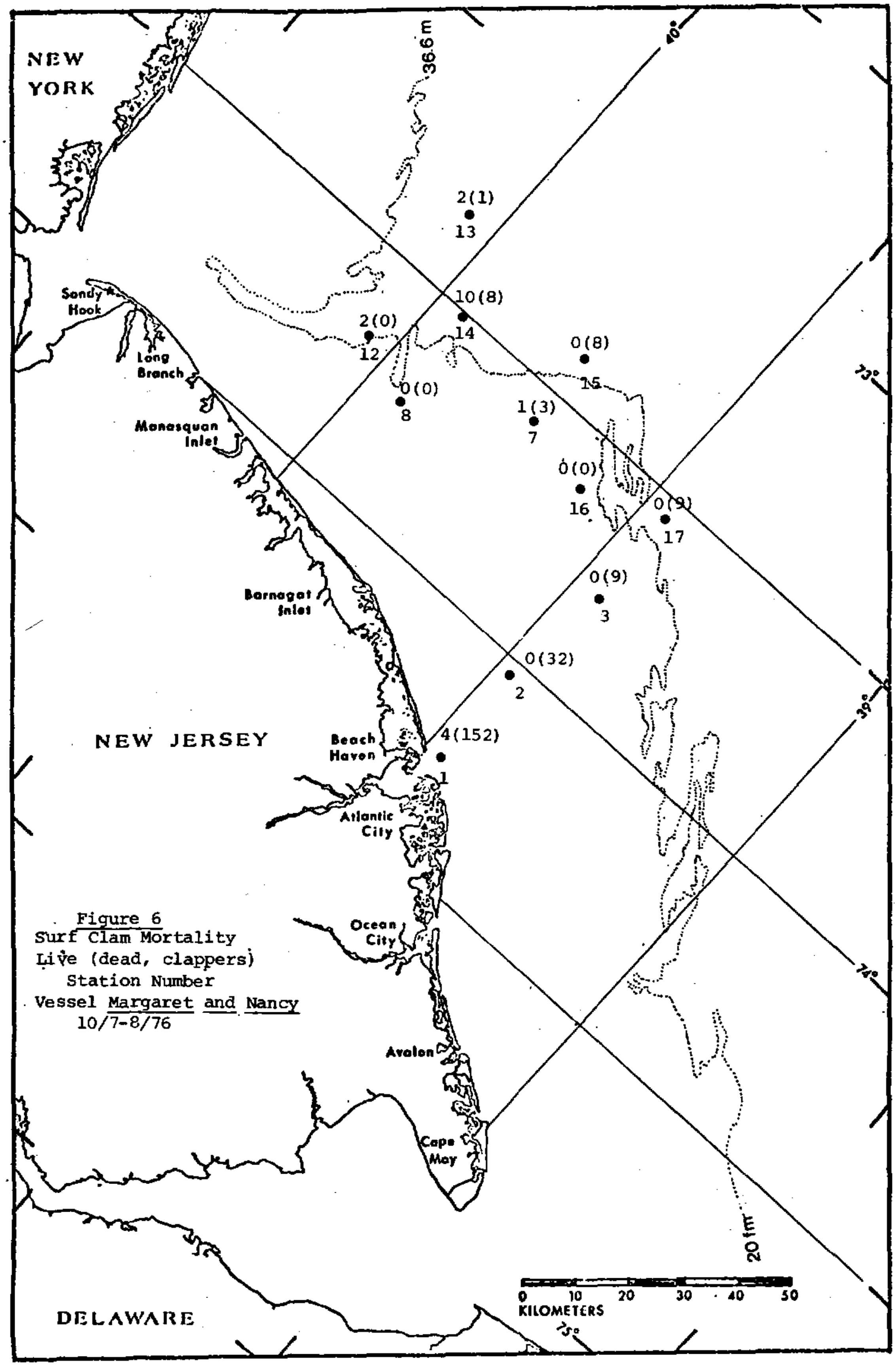

Figure 6
Surf Clam Mortality
Live (dead, clappers)
Station Number
Vessel Margaret and Nancy
10/7-8/76

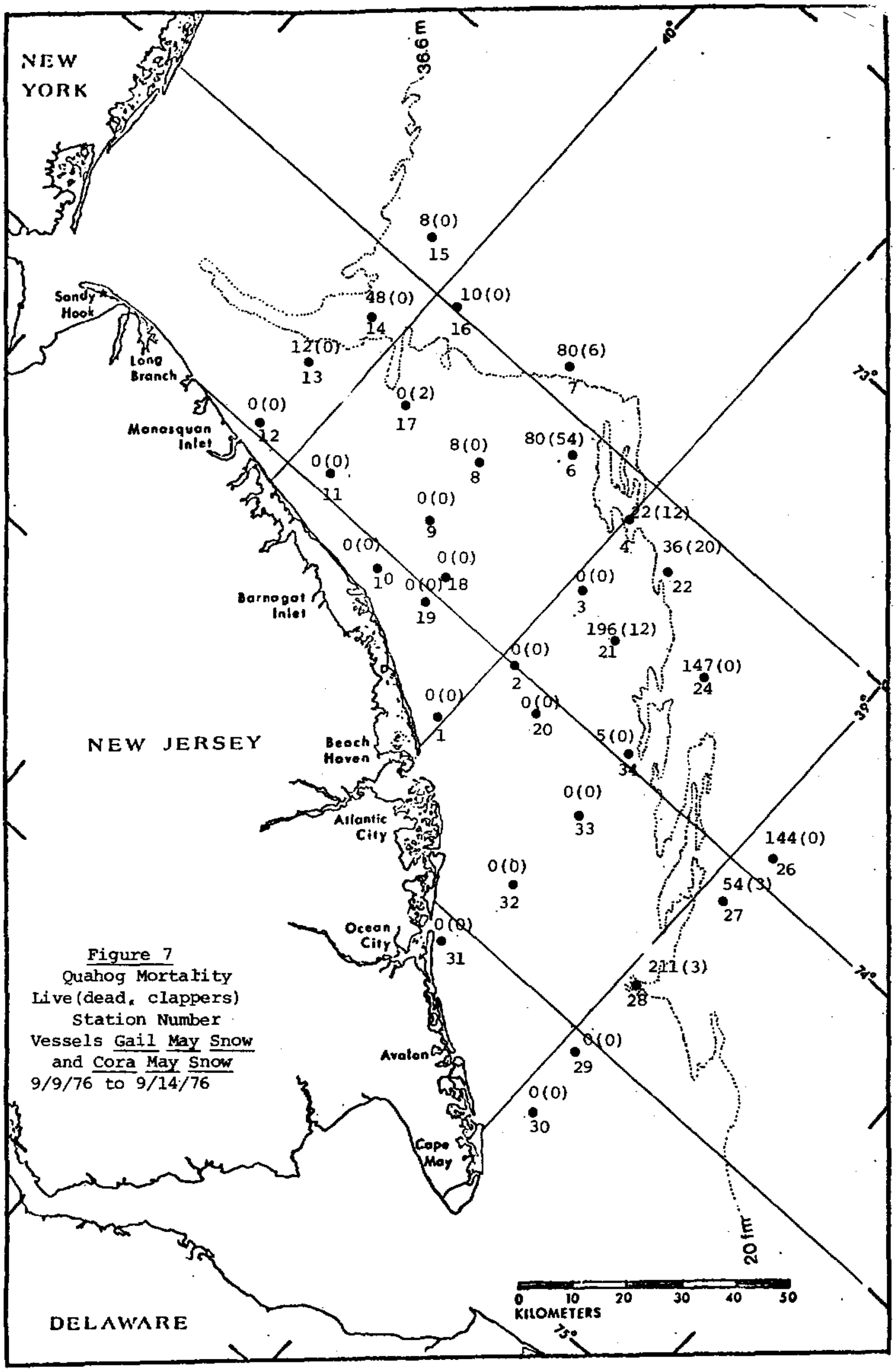

Figure 7
Quahog Mortality
Live(dead, clappers)
Station Number
Vessels *Gail May Snow*
and *Cora May Snow*
9/9/76 to 9/14/76

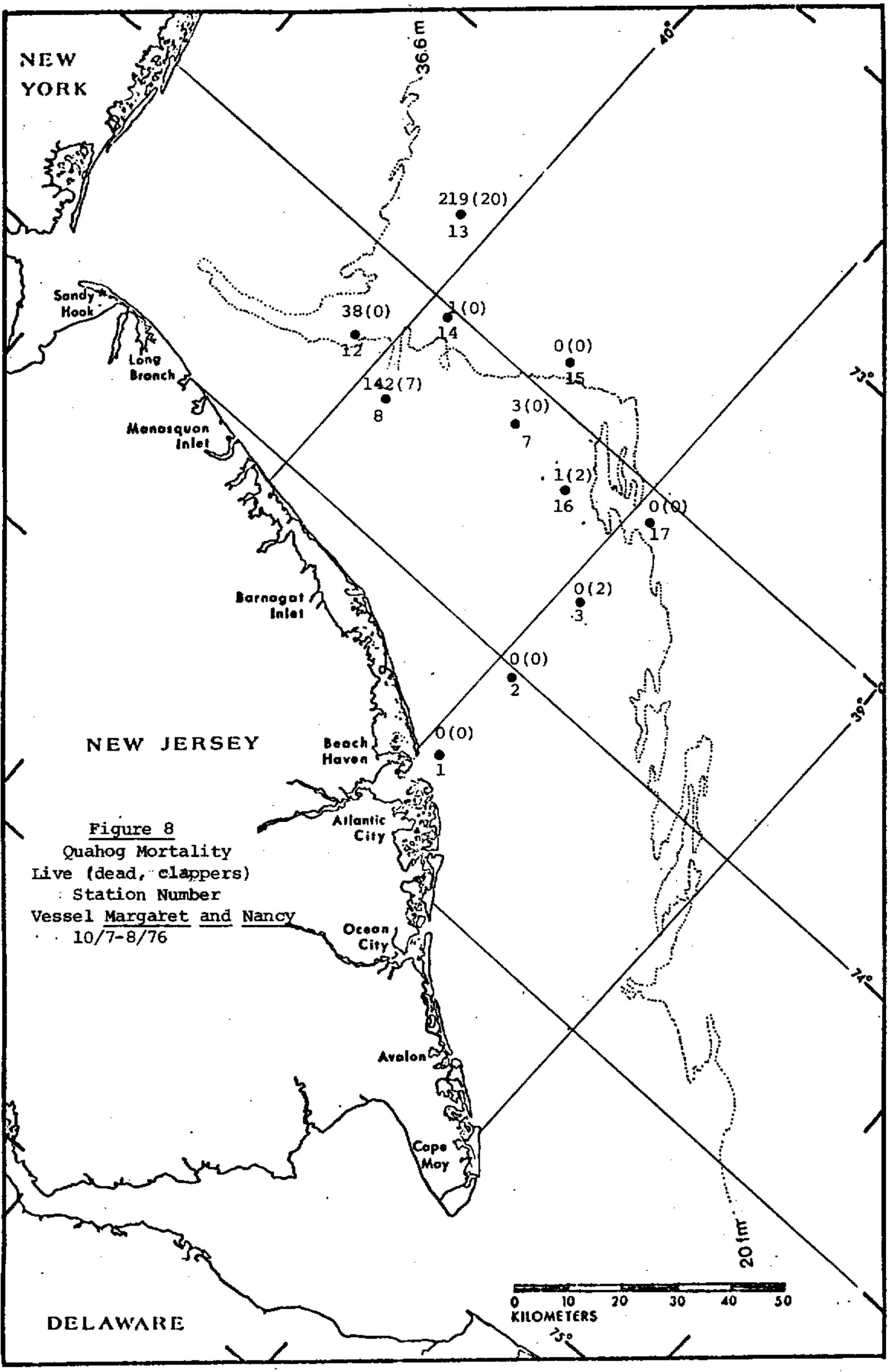

Figure 8
Quahog Mortality
Live (dead, clappers)
Station Number
Vessel *Margaret and Nancy*
10/7-8/76

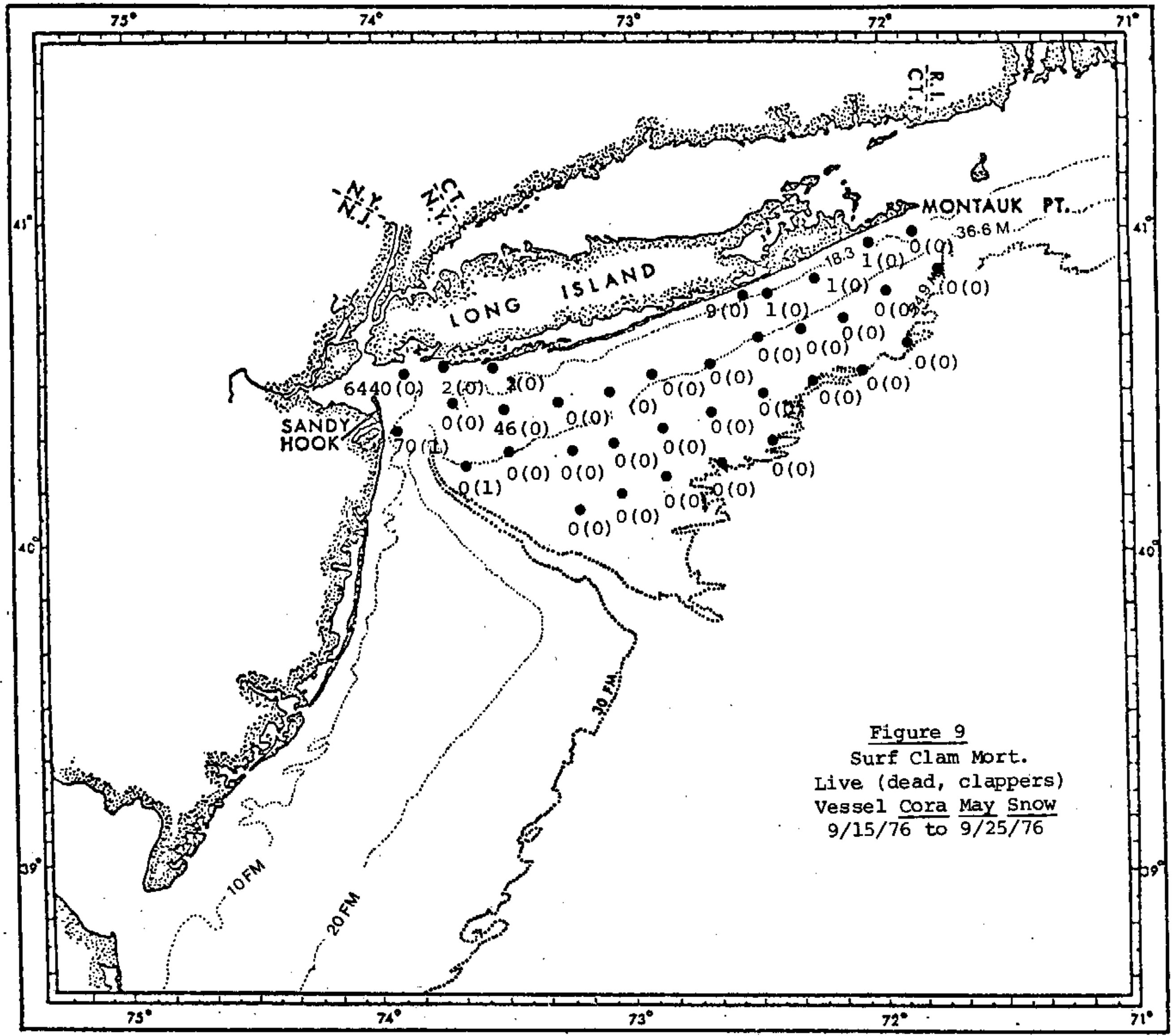

Figure 9

Surf Clam Mort.

Live (dead, clappers)

Vessel Cora May Snow

9/15/76 to 9/25/76

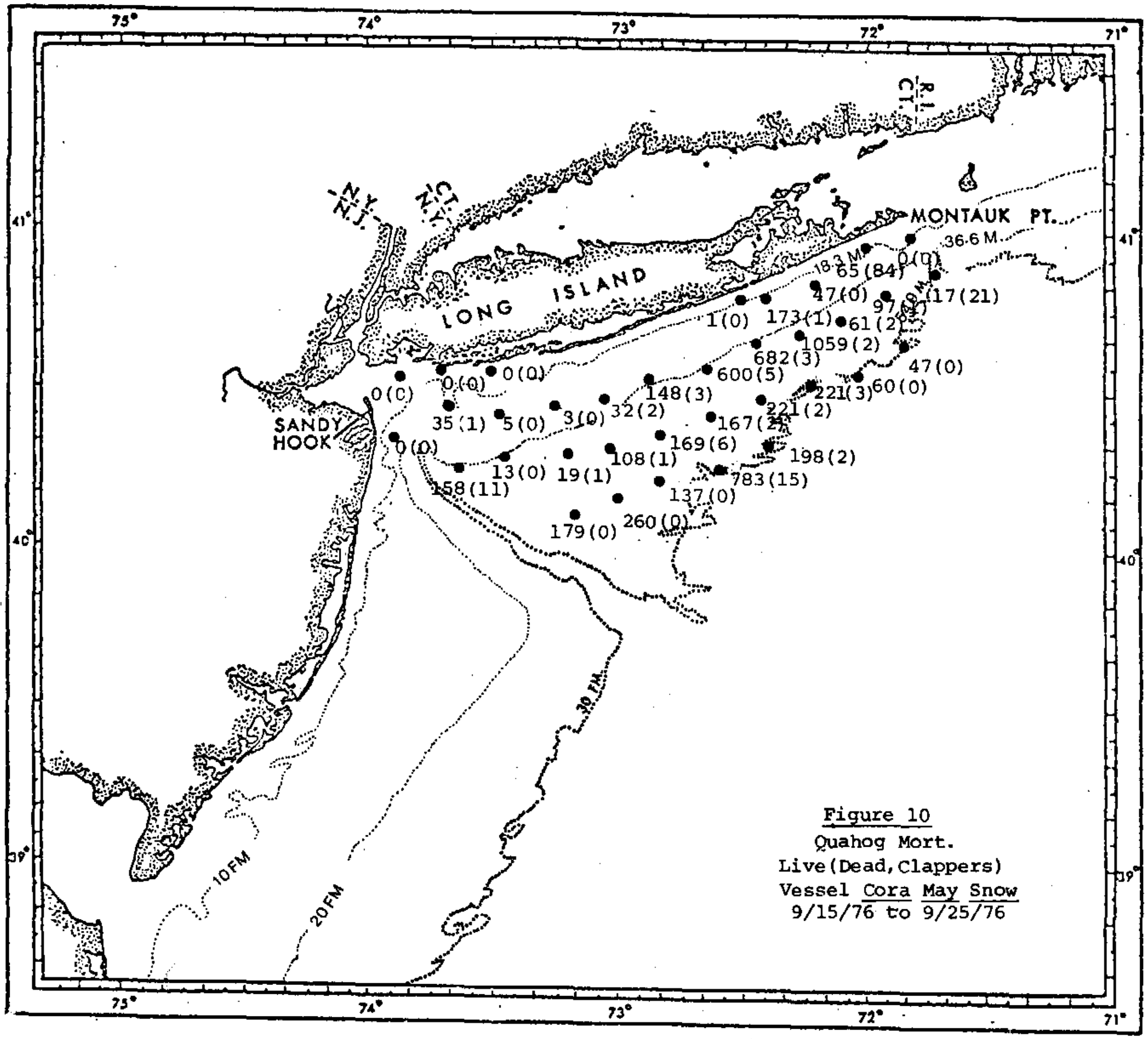

Figure 10
Quahog Mort.
Live(Dead,Clappers)
Vessel Cora May Snow
9/15/76 to 9/25/76

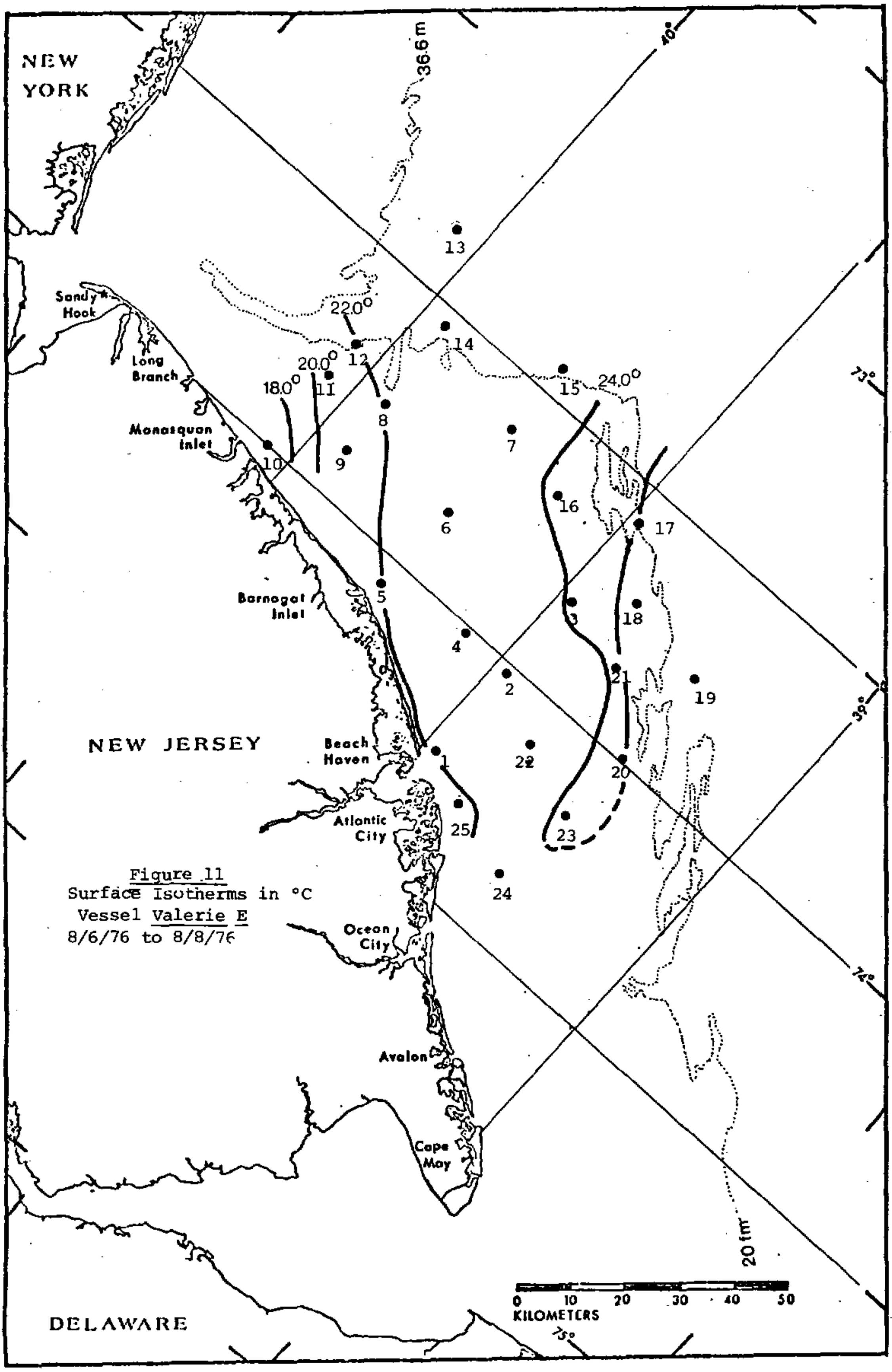

Figure 11
Surface Isotherms in °C
Vessel Valerie E
8/6/76 to 8/8/76

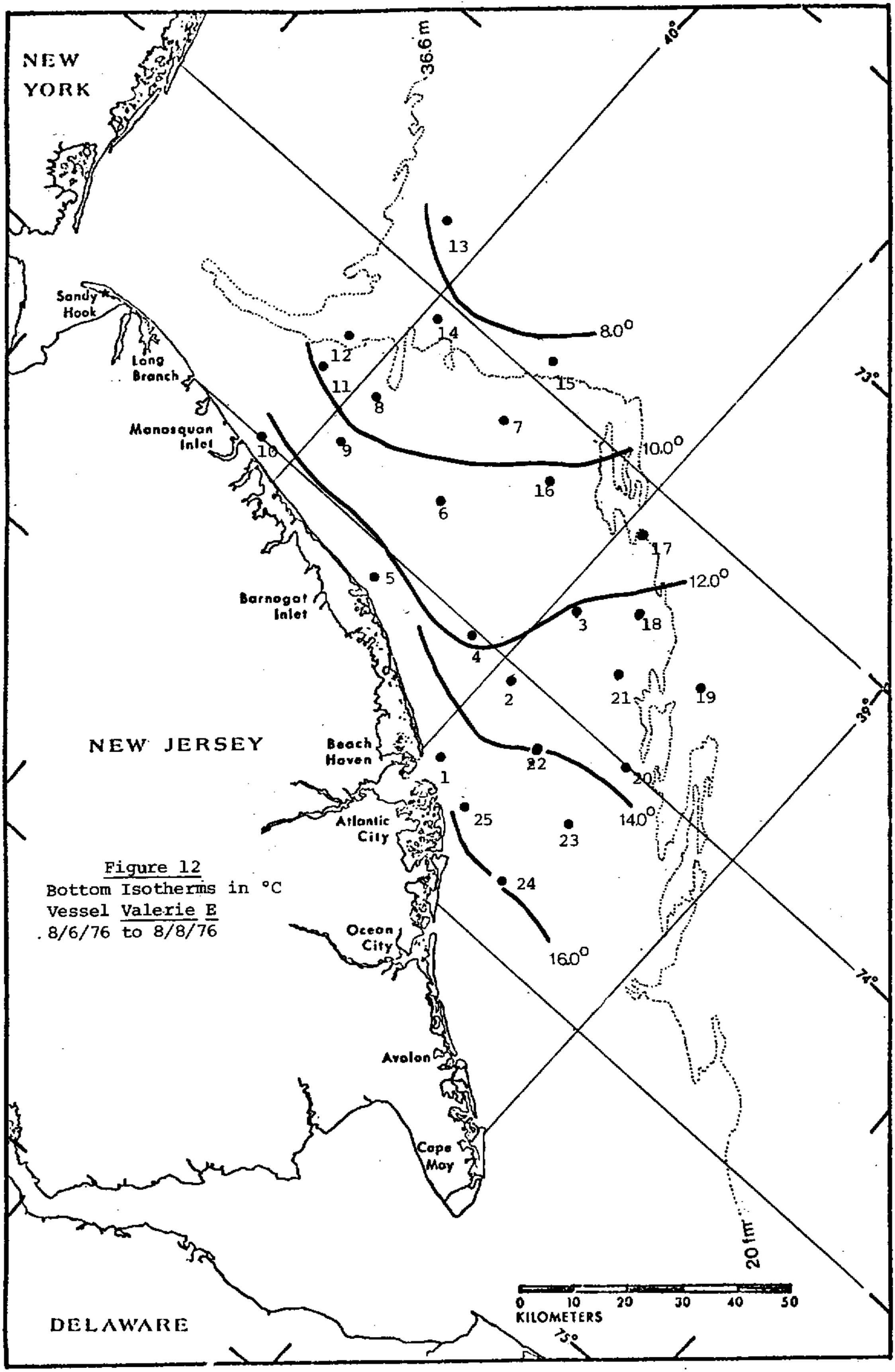

Figure 12
Bottom Isotherms in °C
Vessel Valerie E
8/6/76 to 8/8/76

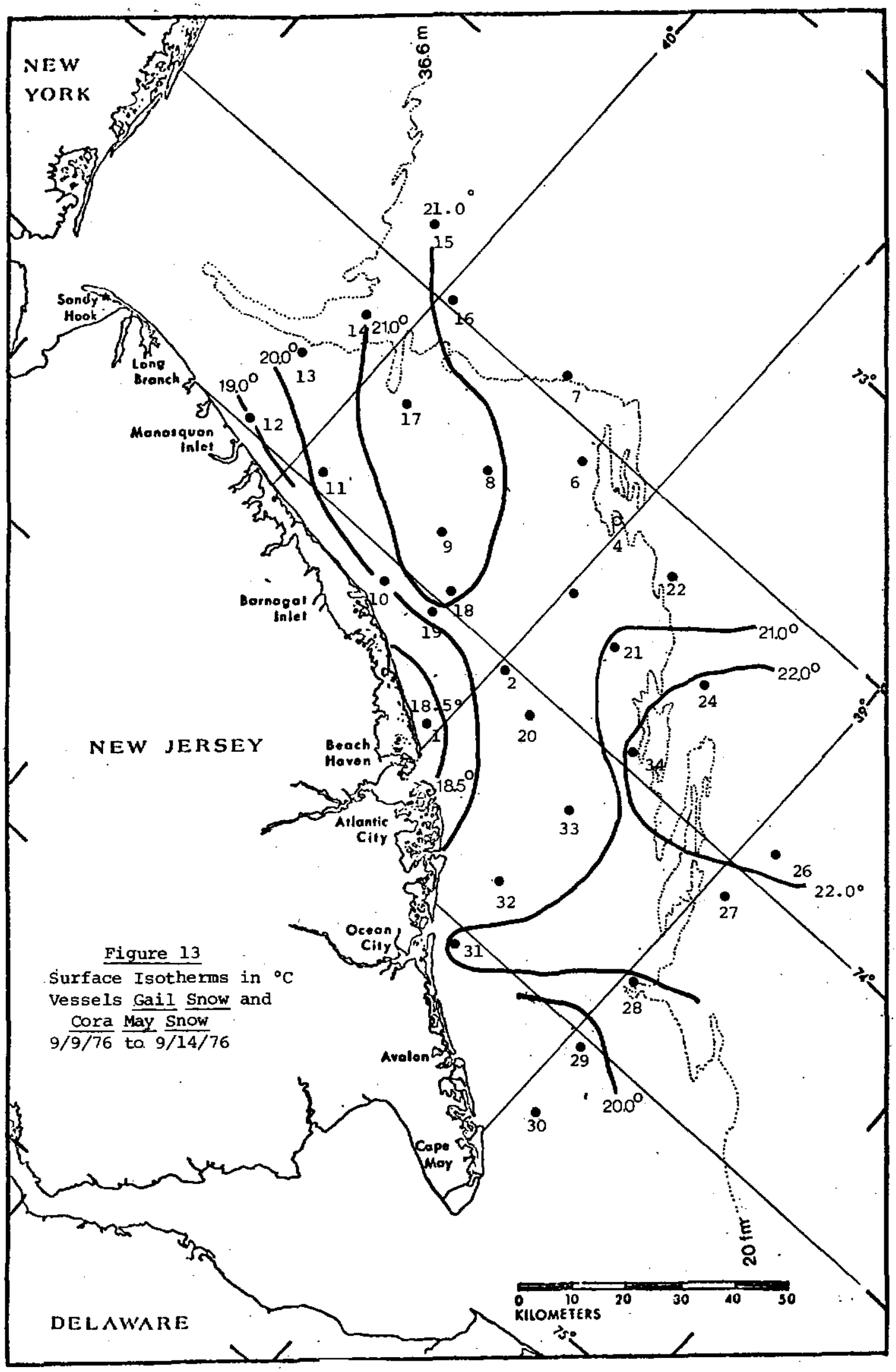

Figure 13
Surface Isotherms in °C
Vessels *Gail Snow* and
Cora May Snow
9/9/76 to 9/14/76

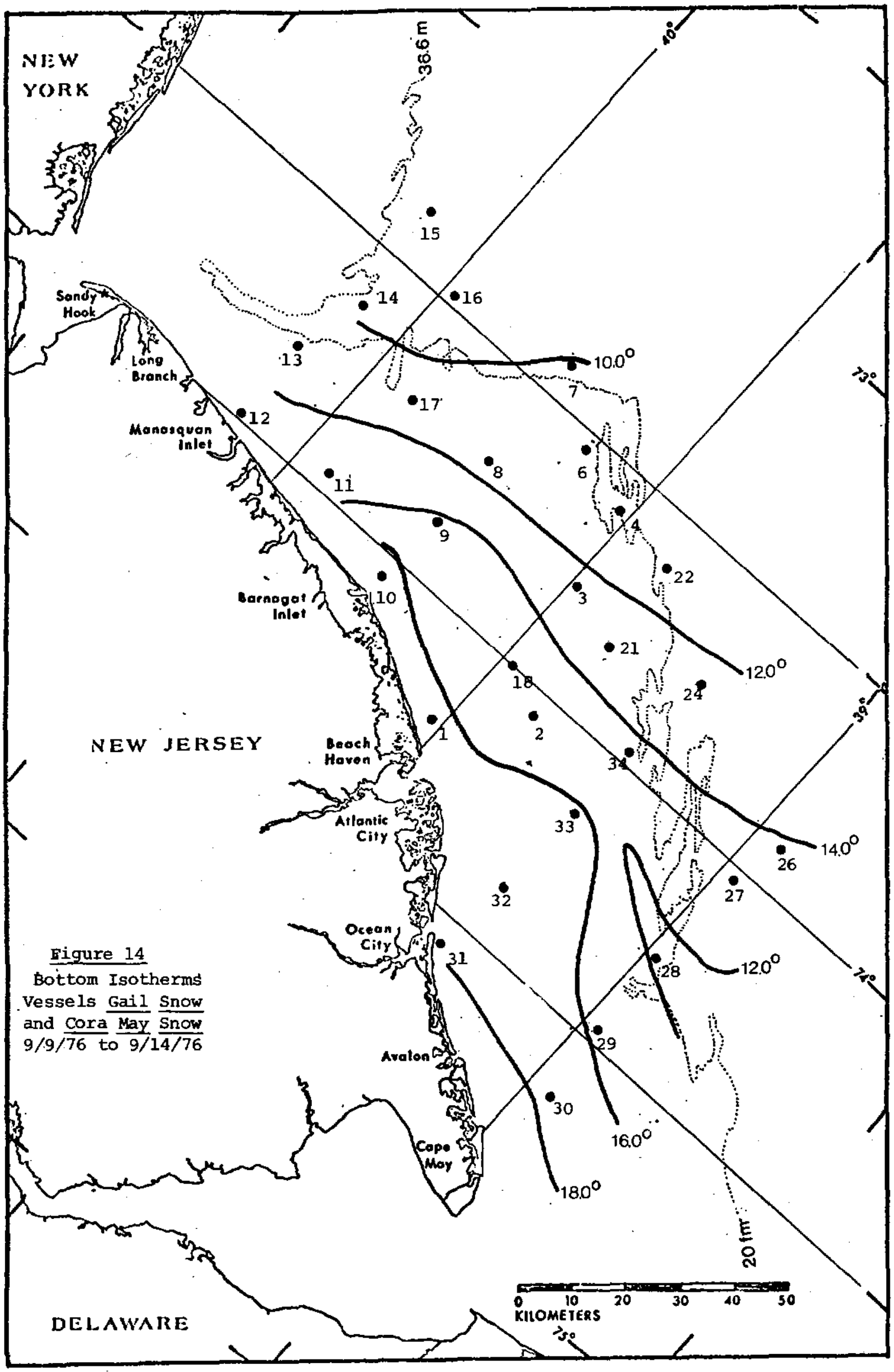

Figure 14
Bottom Isotherms
Vessels *Gail Snow*
and *Cora May Snow*
9/9/76 to 9/14/76

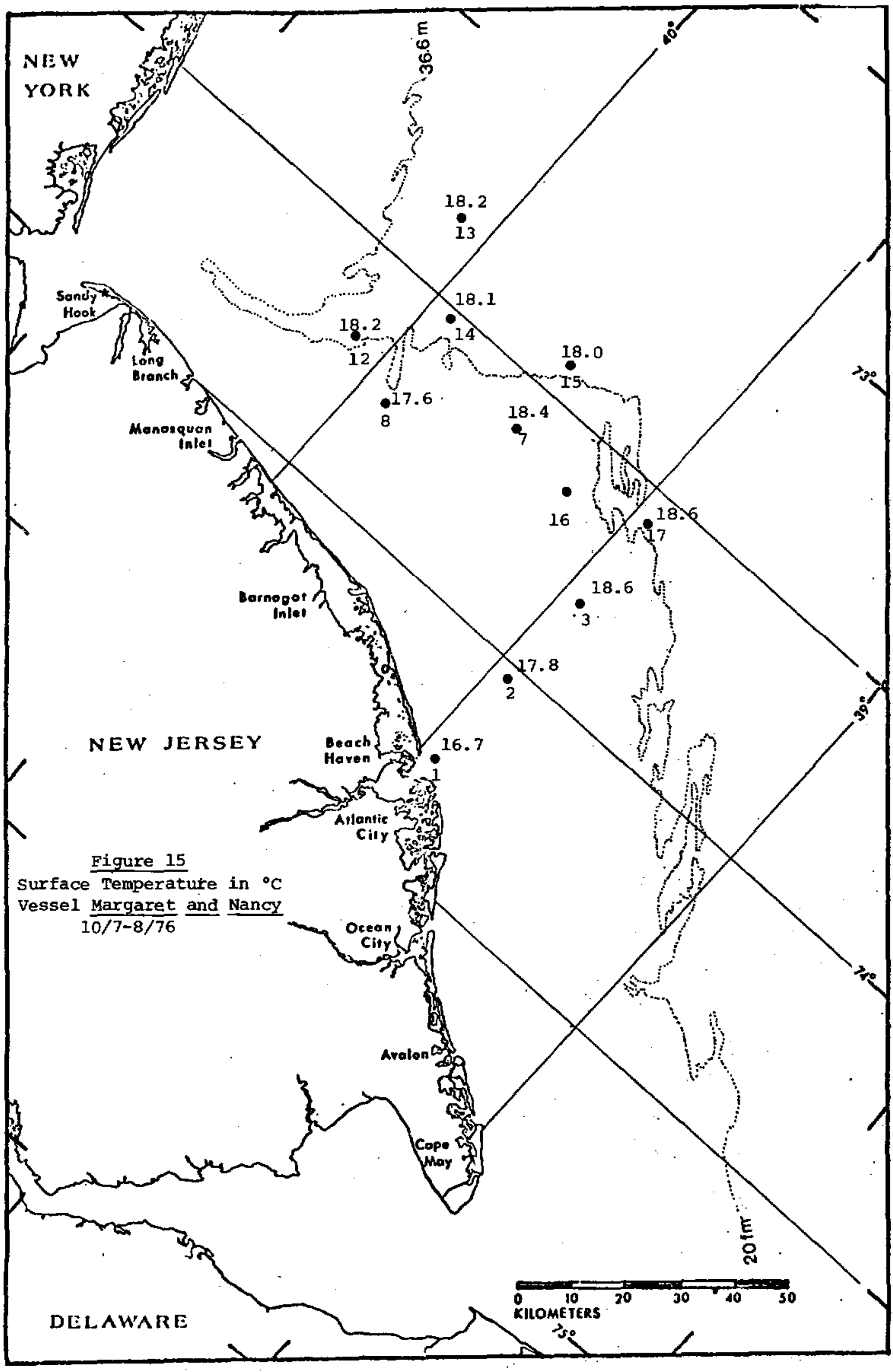

Figure 15
Surface Temperature in °C
Vessel Margaret and Nancy
10/7-8/76

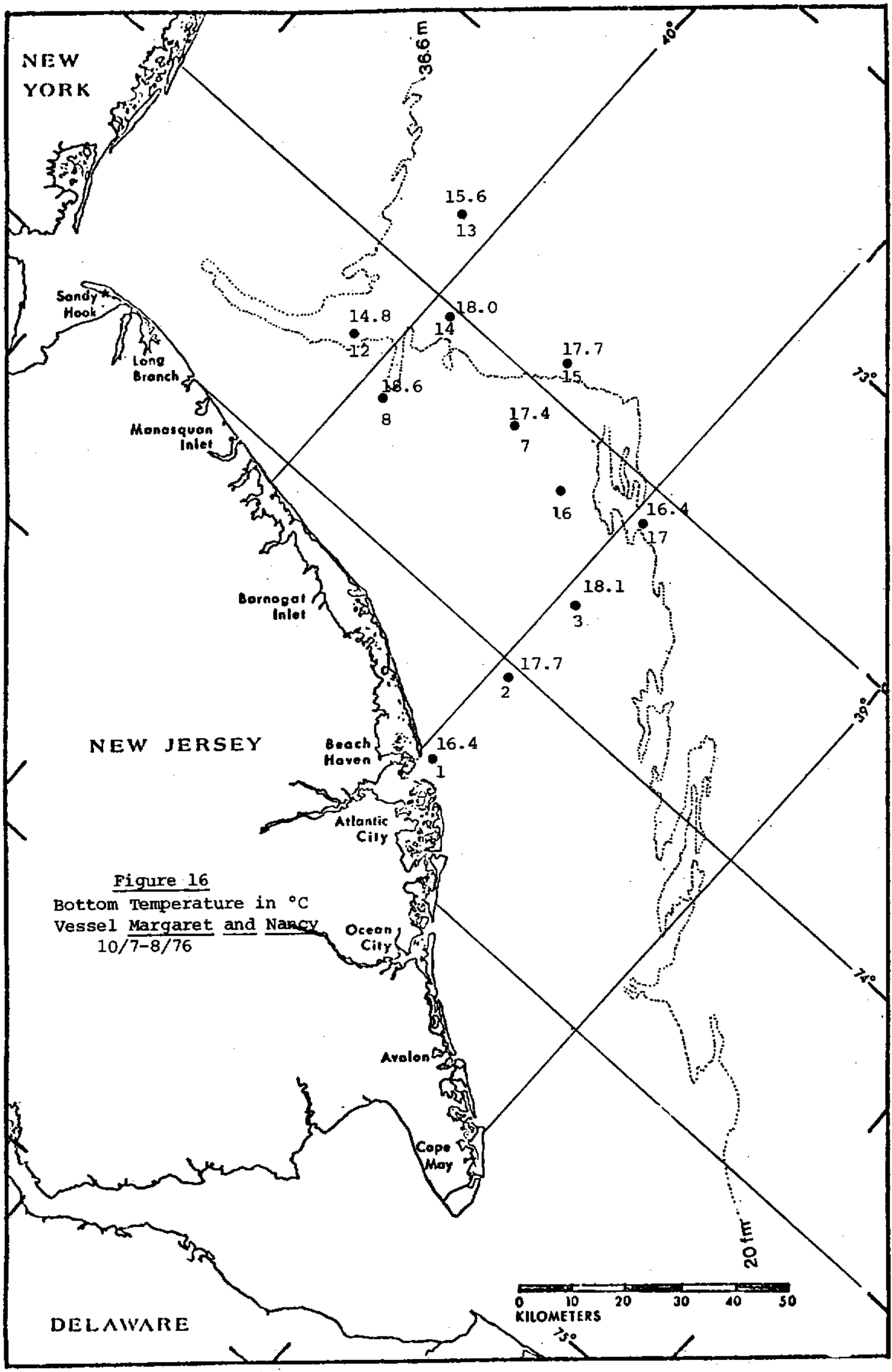

Figure 16
Bottom Temperature in °C
Vessel *Margaret and Nancy*
10/7-8/76

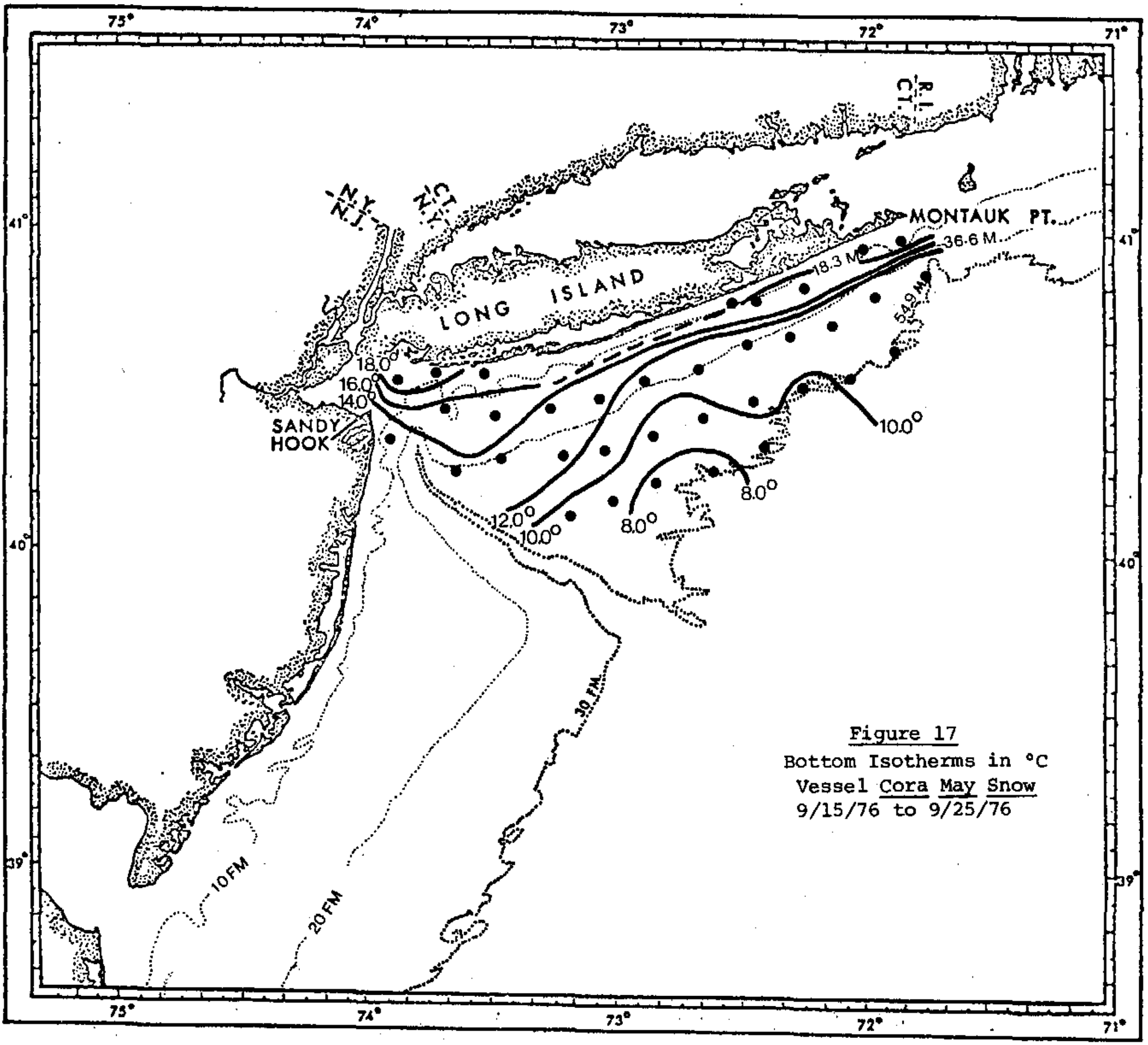

Figure 17
Bottom Isotherms in °C
Vessel Cora May Snow
9/15/76 to 9/25/76

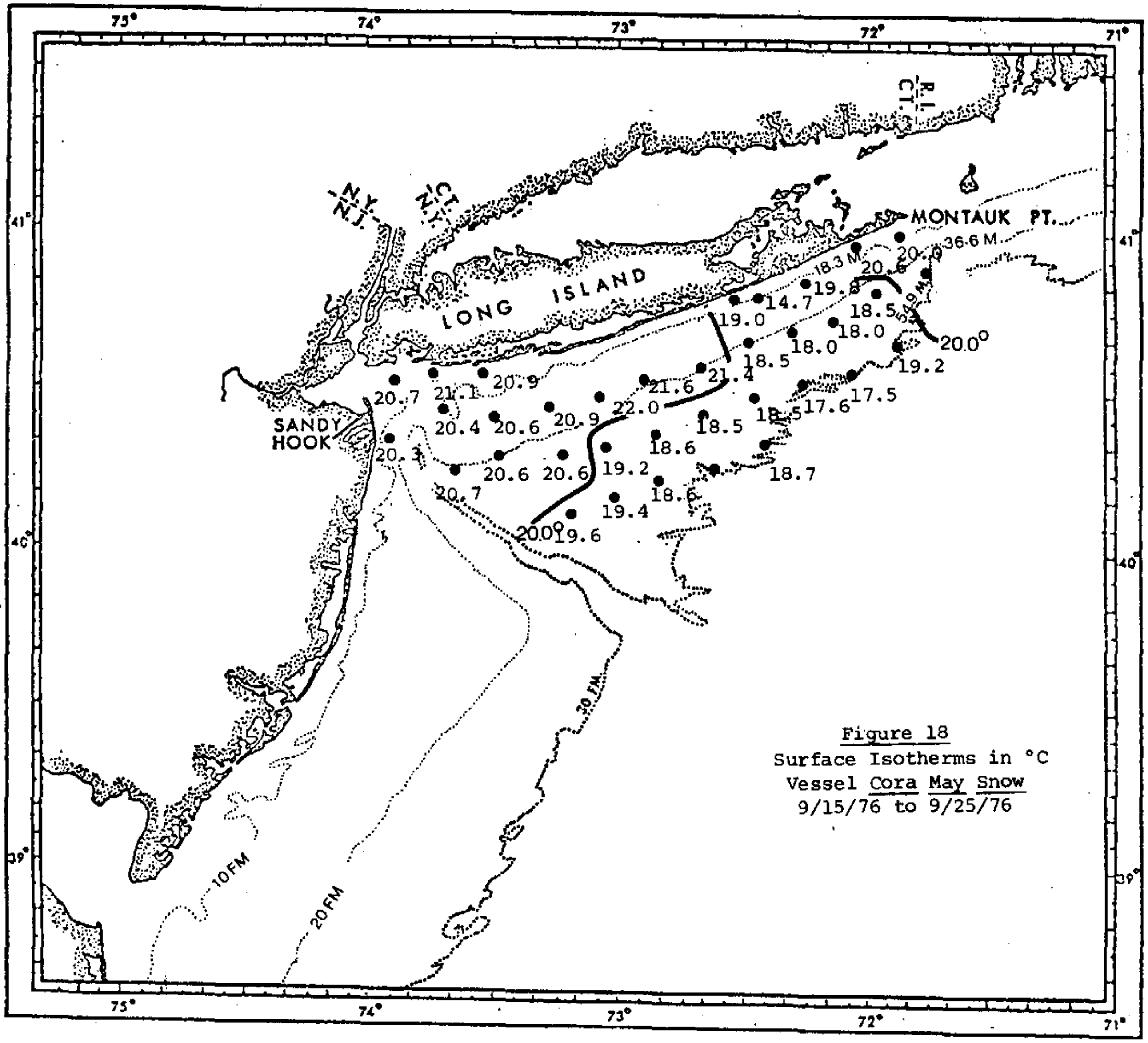

Figure 18
Surface Isotherms in °C
Vessel Cora May Snow
9/15/76 to 9/25/76

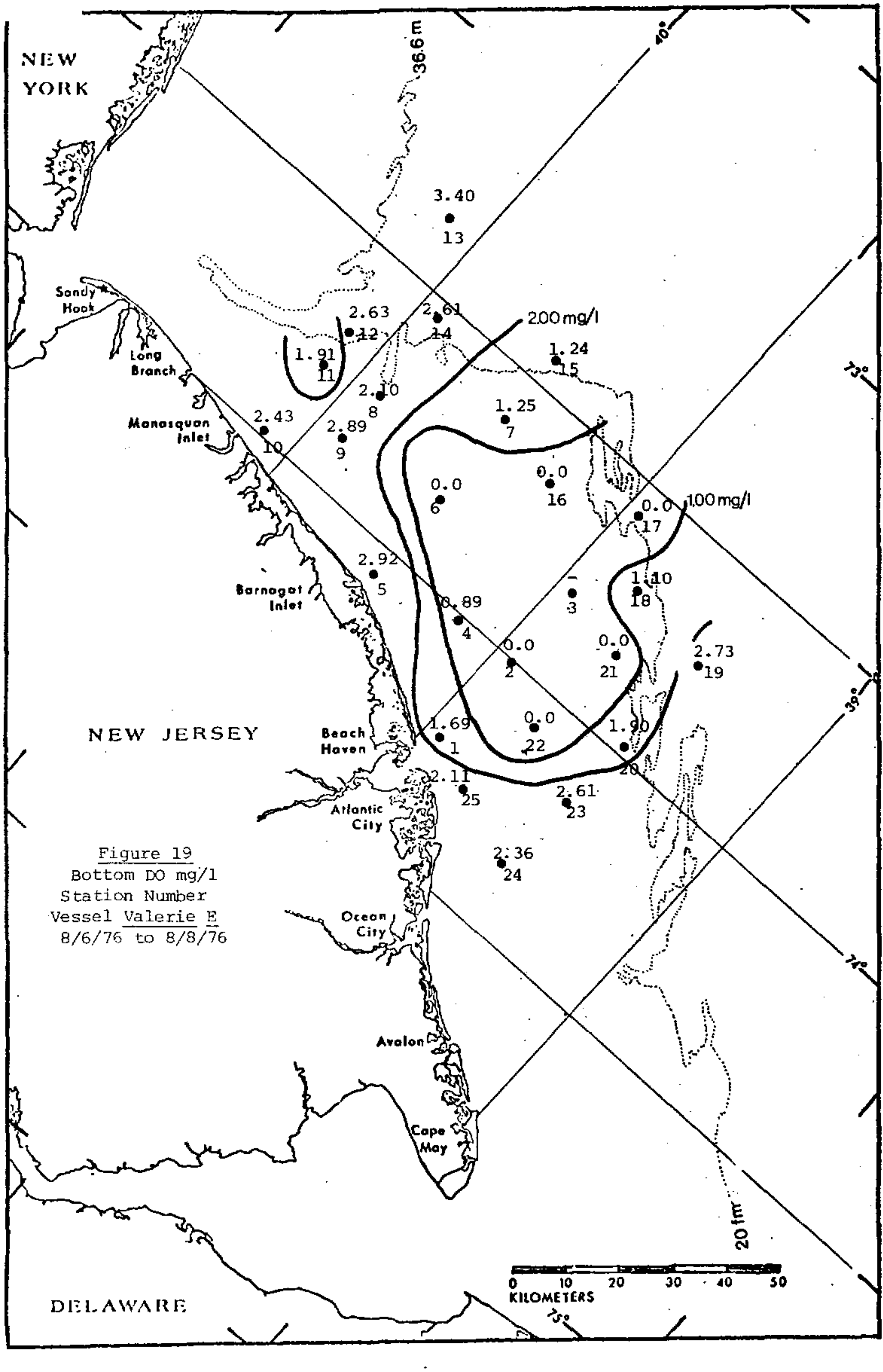

Figure 19
Bottom DO mg/l
Station Number
Vessel Valerie E
8/6/76 to 8/8/76

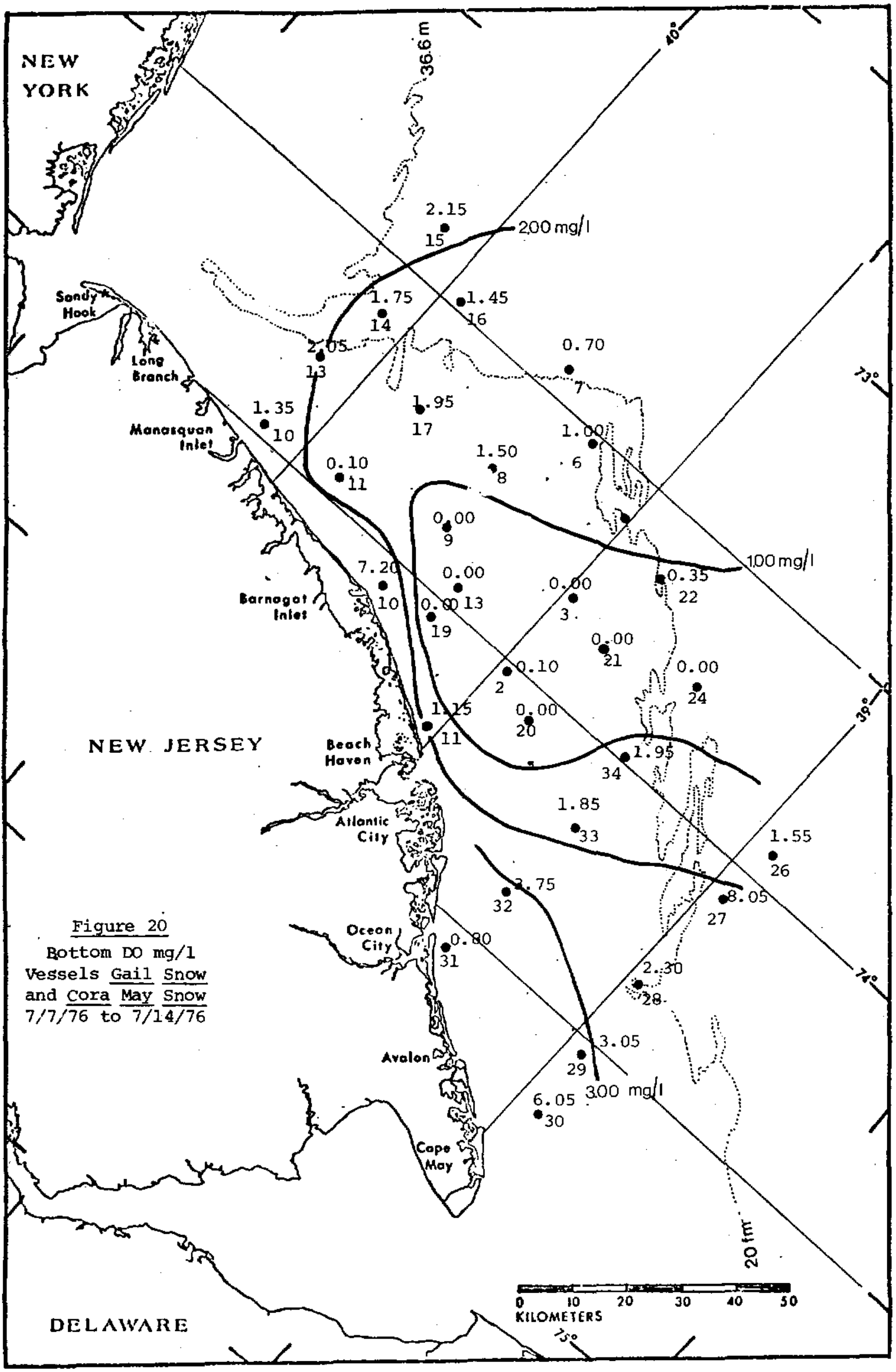

Figure 20
Bottom DO mg/l
Vessels Gail Snow
and Cora May Snow
7/7/76 to 7/14/76

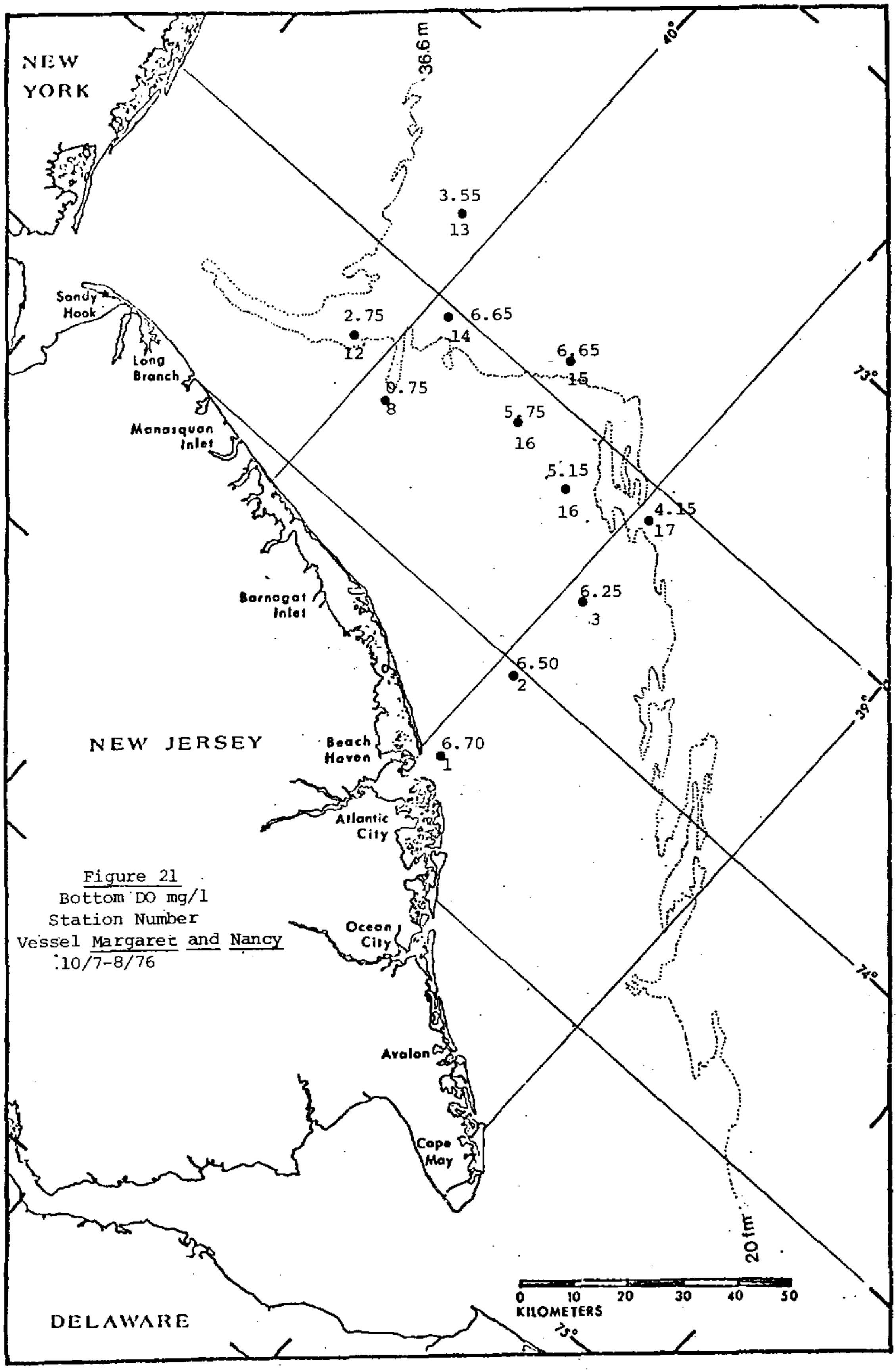

Figure 21
Bottom DO mg/l
Station Number
Vessel Margaret and Nancy
10/7-8/76

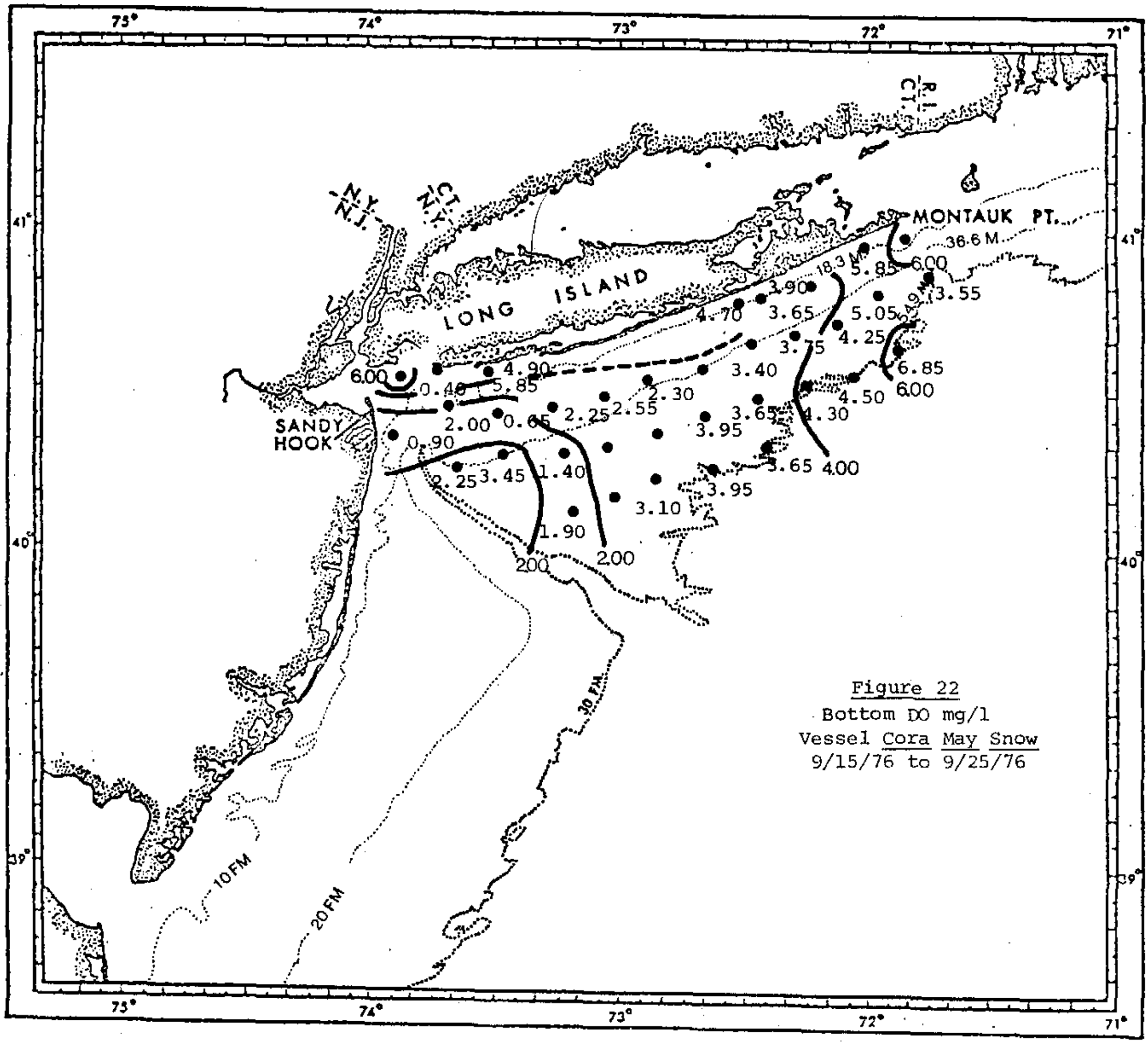

Figure 22
Bottom DO mg/l
Vessel Cora May Snow
9/15/76 to 9/25/76

APPENDIX II

EFFECT OF OXYGEN-DEFICIENT WATERS ON THE SEA SCALLOP (PLACOPECTEN MAGELLANICUS) OFF THE NEW JERSEY COAST DURING SUMMER, 1976

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National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
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Highlands, New Jersey 07732

Introduction

A portion of the sea scallop (*Placopecten magellanicus*) resource off New Jersey was killed due to deficient dissolved oxygen in the bottom water over a large area of the continental shelf during the summer of 1976. The condition persisted for several weeks and stressed or killed many marine organisms. From July through September, commercial sea scallop fishing vessels from ports in New Jersey and Massachusetts reported catches of dead and dying scallops off New Jersey to the National Marine Fisheries Service. During this and later periods, personnel of Sandy Hook Marine Laboratory also found dead scallops in their catches during resource inventory cruises for surf clams and finfish in the same area. Reports on the positions of these catches showed that scallops were stressed and dying within the shallow area off New Jersey where this species is normally found. The distribution of sea scallops was determined by a sea scallop resource assessment cruise in August, 1975 (MacKenzie and Merrill, in preparation). New Jersey scallops generally occupy depths from 35 to 75 m, and are more concentrated in deeper water.

In October and November, 1976, Sandy Hook Laboratory personnel conducted two survey cruises specifically to determine the effect of the oxygen depleted waters on the sea scallop resource off the New Jersey coast. Special emphasis was given to recording ratios of live and dead scallops to determine mortality rates and size of the dead, dying, and stressed scallop area. Survey cruises for other species, such as surf clams and finfish, from July through November, collected incidental data on sea scallops. This report describes these findings.

MATERIALS AND METHODS

Fishermen's reports of locations of dead, dying, and stressed sea scallops were recorded (Table 1, Figure 1). Similarly, positions of dead and stressed scallops were recorded during cruises on the commercial surf clam vessels, Gail Snow and Cora May Snow, from Point Pleasant, New Jersey, under charter from September 9-14, 1976 (Table 1, Figures 1, 2). The vessels towed a hydraulic clam dredge with a 1.5-m (60-in) knife for 4 min at each station with the pump operated at 80-90 p.s.i.

Positions of live, dead, and stressed sea scallops were also recorded during five finfish stock assessment cruises in 1976. The vessels employed during the different cruises were as follows: the commercial vessel Grand Larson, July 15; the R/V Rorqual, July 20-22, the R/V Atlantic Twin, August 6-17; the R/V Albatross IV, September 28 to October 18, and the R/V Delaware II, December 6-23. The vessels towed nets ranging in width from 10 to 33 m, at a standard speed of 3.5 knots. Towing time ranged from 15 to 30 min (Table 1, Figure 1).

TABLE 1. Locations of dead, dying, and stressed sea scallops reported by commerical fishermen (I), and collected during surf clam (II), and finfish survey cruises (III).

Serial No.	Position Latitude	Longitude	Depth(m)	Scallop Condition
	I. Locations from fishermen			
1	39°30'	73°10'	40	dead and dying
2	39°32'	73°12'	40	dead and dying
3	39°41 - 39°51'	73°20' - 73°29'	41	dead and dying
4	39°46' - 39°51'	73°30'	41	dead and dying
5	39°37' - 39°46'	73°15'	39	dead and dying
6	39°41' - 39°51'	73°20'	40	dead and dying
	II. Locations from surf clam cruises			
1	39°16'	73°43'	43	dead
2	40°25'	73°27'	24	stressed
	III. Locations from finfish cruises			
1	39°52'	73°45'	30	dead
2	40°01'	73°51'	24	dead
3	39°50'	73°26'	37	dead
4	39°31'	73°29'	35	dead
5	40°11'	73°14'	40	stressed
6	38°44'	73°41'	57	6 dead, 47 live scallops

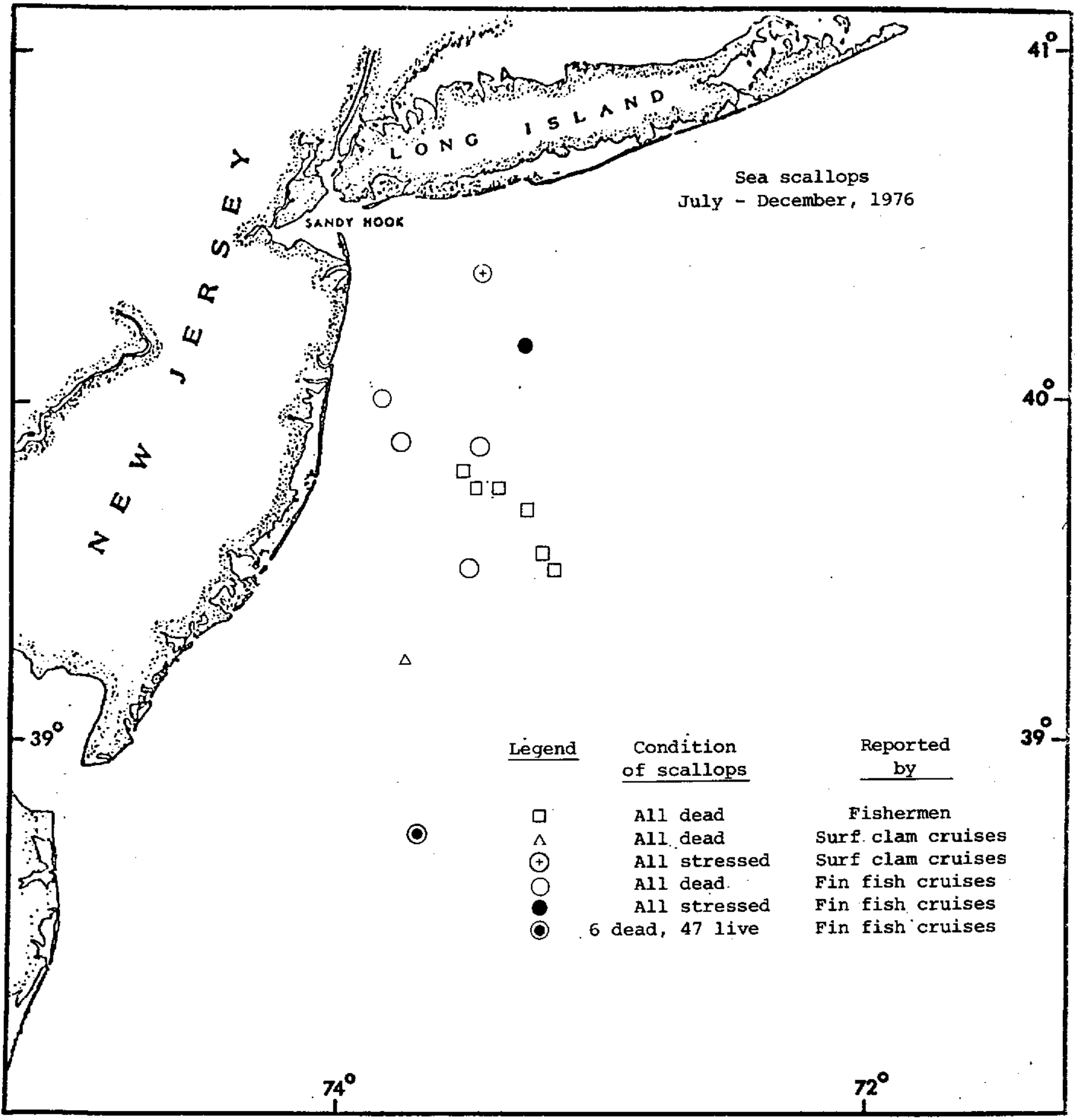

Figure 1. Positions of dead and stressed scallops reported by fishermen, surf clam cruises, and finfish cruises.

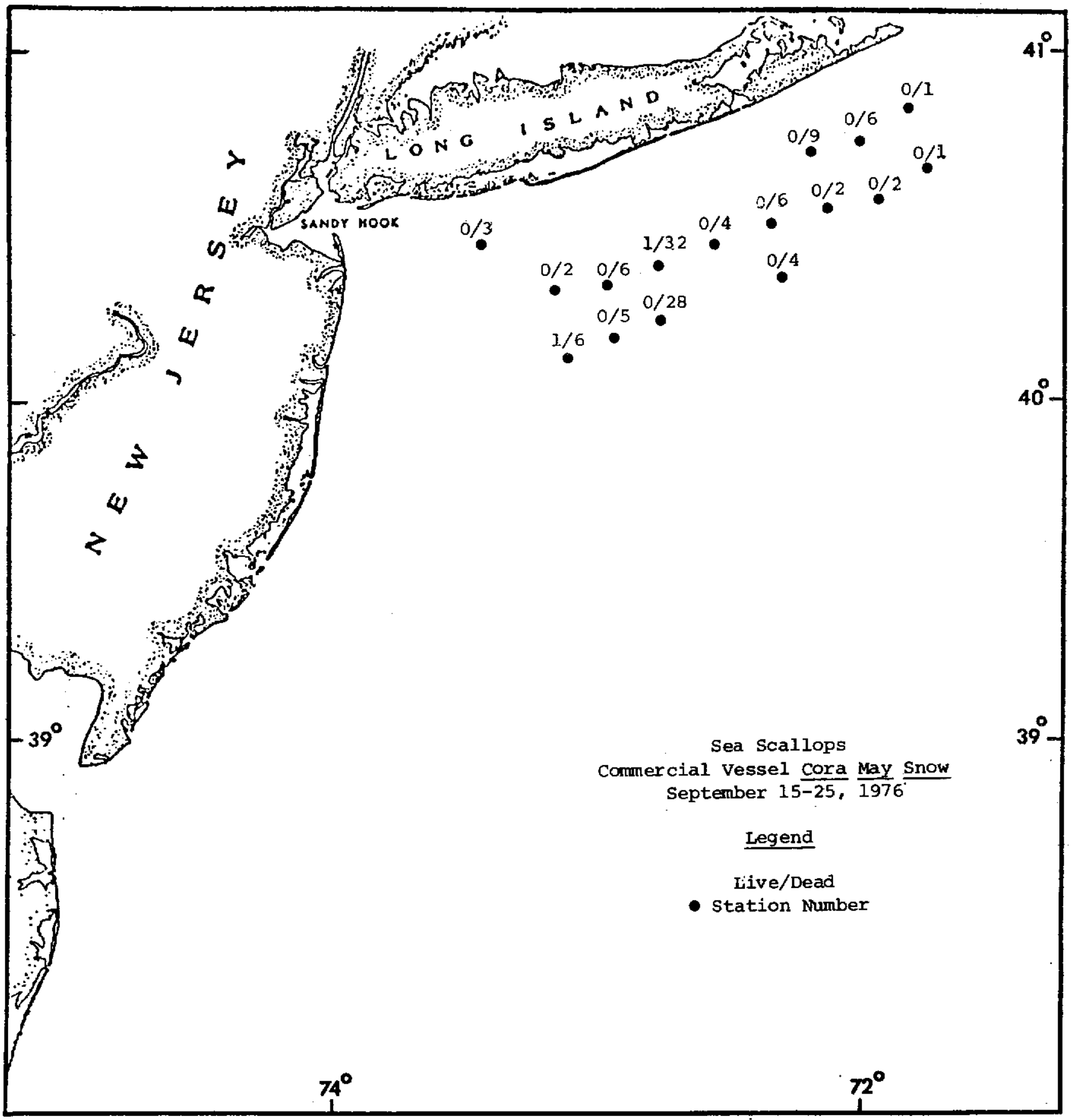

Figure 2. Number of sea scallops, live/dead, at stations on Middle Atlantic Shelf, September 15-25, 1976. Commercial vessel *Cora May Snow*.

Between October 6-15, 1976, the first sea scallop assessment cruise was made on the R/V Atlantic Twin which towed a standard 3.01-m (10-ft) sea scallop dredge with a bag having 5.0-cm (2-in) rings to collect scallops. At each station, the dredge was towed for 15 minutes at a speed of 3.5 knots. Numbers and lengths of live and dead (recent clappers) scallops, along with live and dead associated invertebrates were recorded. Bottom water was collected with a Niskin bottle and titrated on board the vessel to determine oxygen levels. Temperatures from surface to bottom were recorded using XBT's. A total of 17 stations were sampled in areas off the inner half of the continental shelf off New Jersey (Table 2, Figures 3, 4), but the full extent of the scallop resource was not surveyed due to inclement weather.

Between November 8 and 17, 1976, a second cruise was made on the R/V George B. Kelez which towed a 0.8-m (30-in) Digby sea scallop dredge with a bag having 5.0-cm (2-in) rings. Dredge tows were 15 min at 1.0 knots. Catches and hydrographic data were processed similarly to those on the R/V Atlantic Twin cruise. In addition, oxygen levels were measured at surface and mid-depth. A total of 45 stations was sampled, spaced along seven transects across the entire scallop resource on the continental shelf of the New Jersey coast (Table 3, Figures 5, 6a,b,c).

In August 1975, a survey cruise on the R/V Albatross IV was conducted to define the distribution and abundance at selected stations of sea scallops on the Middle Atlantic Shelf from eastern Long Island,

TABLE 2. Summary of live and dead sea scallops and bottom oxygen data for stations on R/V *Atlantic Twin* cruise 76-2, October 10-15, 1976.

Sta.	Lat.	Long.	Depth (m)	Sea Scallops Live	 Dead	Dissolved Oxygen (mg/l)
A	40°22'	73°41'	25	-	-	5.57
1	40°18'	73°33'	23	0	0	7.25
2	40°10'	73°21'	40	6	0	3.50
3	39°58'	73°07'	45	15	0	3.82
4	40°31'	73°09'	49	36	4	3.55
5	40°22'	73°01'	38	6	0	6.80
6	40°13'	72°49'	22	0	0	6.75
7	40°47'	72°11'	42	5	0	7.05
8	40°35'	72°08'	52	14	0	5.45
9	41°02'	71°32'	48	4	0	4.50
10	40°46'	71°23'	59	0	0	4.60
11	40°34'	71°13'	59	1	0	5.60
16	39°54'	73°40'	32	0	0	5.82
17	39°47'	73°31'	31	0	0	3.30
18	39°39'	73°18'	40	0	1	2.80
19	39°28'	73°17'	36	0	0	2.95
20	39°23'	73°29'	41	0	0	3.00
21	39°32'	73°45'	31	0	0	3.85
22	39°36'	73°52'	27	0	0	7.35
23	39°20'	74°15'	22	0	0	7.20
24	39°13'	73°51'	36	0	3	2.80
25	39°07'	73°39'	45	0	19	1.75
26	38°57'	73°39'	45	0	0	2.20
27	38°54'	73°53'	41	0	2	1.55
28	39°05'	74°20'	27	0	0	3.35
29	39°00'	74°07'	36	-	-	1.65
29a	39°00'	74°07'	36	1	0	2.85
H	38°55'	74°19'	36	-	-	1.10

Note: Dissolved oxygen levels were determined at station 29 twice; the first was on 10/13/76 at 0600 hrs, the second on 10/15/76 at 0443 hrs.

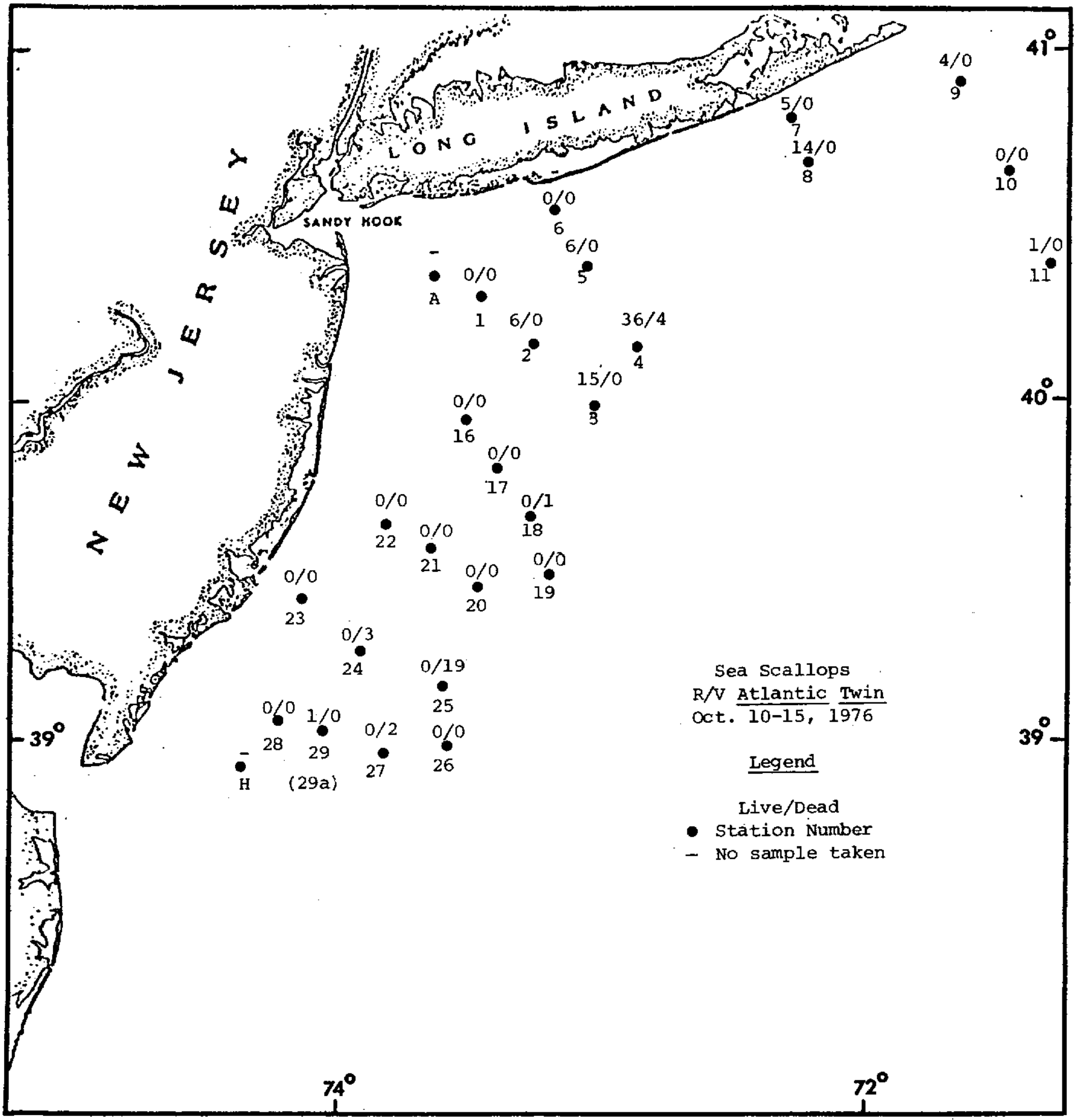

Figure 3. Number of sea scallops, live/dead, at stations on Middle Atlantic Shelf, October 6-15, 1976. R/V *Atlantic Twin* cruise 76-2.

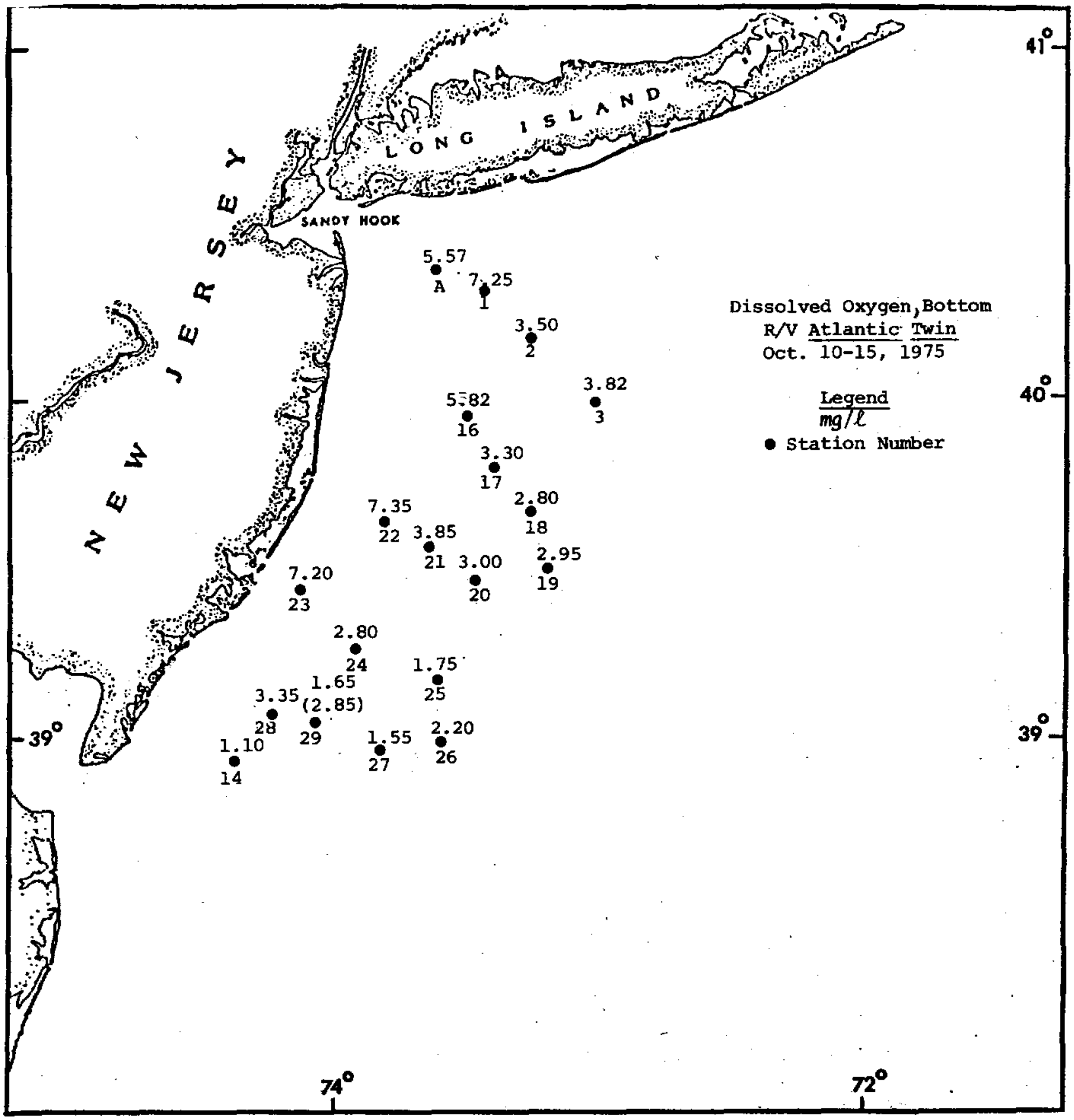

Figure 4. Distribution of bottom dissolved oxygen on Middle Atlantic Shelf, October 10-15, 1976. R/V Atlantic Twin cruise 76-2.

TABLE 3. Summary table for live and dead scallops and oxygen data for stations on R/V George B. Kelez cruise 76-2, November 8-17, 1976.

			Depth	Sea Scallops		Dissolved Oxygen (mg/l)					
Sta.	Lat.	Long.	(m)	Live	Dead	Bottom		Mid		Surface	
1	40°19'	73°32'	32	-	-	7.00	7.10	9.00	8.45	9.05	8.55
7	38°54'	74°34'	13	-	-	8.60	8.40	-	-	-	-
8	39°06'	74°18'	24	-	-	8.00	8.30	-	-	-	-
9	38°59'	74°04'	36	-	-	-	-	-	-	-	-
10	38°52'	73°53'	39	0	6	7.50	-	7.70	-	7.40	-
11	38°46'	73°43'	51	2	10	4.92	4.90	7.70	7.65	8.15	7.70
12	38°38'	73°29'	70	1	0	4.90	4.90	7.30	7.30	8.30	-
13	38°32'	73°22'	114	-	-	4.45	-	4.70	4.80	7.65	7.30
14	38°46'	73°08'	92	-	-	4.60	4.40	6.50	6.40	8.11	7.88
15	38°52'	73°18'	78	5	0	5.60	5.85	7.90	7.50	8.00	8.10
16	39°00'	73°30'	53	0	10	4.30	4.50	7.90	7.95	7.95	8.10
17	39°06'	73°39'	61	-	-	8.45	6.20	8.12	-	8.10	8.10
18	39°12'	73°51'	37	-	-	8.25	-	8.11	-	8.50	8.10
19	39°19'	74°04'	24	-	-	8.20	8.15	-	-	-	-
20	39°38'	73°55'	28	-	-	8.55	8.58	8.70	8.50	8.50	-
21	39°30'	73°42'	35	-	-	8.32	8.12	8.42	8.92	8.31	8.42
22	39°21'	73°29'	46	-	-	5.12	-	7.95	7.80	8.11	8.00
23	39°38'	73°18'	38	-	-	7.96	7.92	7.88	7.80	-	-
24	39°47'	73°30'	35	-	-	8.10	8.11	8.25	-	8.11	8.12
25	39°56'	73°42'	33	-	-	7.95	7.81	8.12	-	8.11	8.12
26	40°08'	73°20'	41	-	-	4.85	4.86	8.80	8.90	9.12	9.06
27	39°59'	73°09'	67	12	6	5.10	5.20	8.01	8.02	8.52	8.25
28	39°50'	72°57'	68	-	-	4.21	4.26	8.48	8.82	9.42	9.22
29	39°39'	72°45'	68	-	-	4.89	4.87	8.09	8.28	9.37	9.35
30	39°28'	72°33'	105	-	-	4.10	4.35	7.25	8.08	8.29	8.35
31	39°30'	73°06'	59	14	0	4.95	4.10	7.21	7.64	8.01	8.20
32	39°22'	72°55'	72	31	0	5.01	4.90	7.08	6.90	8.01	8.00
33	39°13'	72°43'	117	-	-	5.05	4.82	7.15	7.11	7.61	7.52
34	38°58'	72°52'	115	-	-	4.57	4.51	7.27	7.20	7.91	7.82
35	39°07'	73°04'	74	3	0	4.60	4.60	7.98	7.80	8.40	8.17
36	39°15'	73°18'	56	22	0	4.69	4.69	8.10	7.93	8.06	8.10
37	38°25'	73°36'	112	-	-	4.50	4.40	5.82	5.90	8.46	8.45
38	38°31'	73°48'	61	10	0	4.86	4.96	8.45	7.89	8.05	8.19
39	38°35'	73°58'	49	23	0	4.79	4.72	7.91	7.98	8.10	8.05
40	38°13'	73°54'	73	-	-	-	-	-	-	-	-
41	38°20'	74°22'	40	7	0	4.96	4.91	8.11	8.21	8.02	8.20
42	38°26'	74°20'	41	9	0	5.06	5.61	8.00	8.00	8.11	8.00
43	38°32'	74°31'	36	-	-	7.89	7.88	8.05	8.09	8.49	8.28
44	38°42'	74°10'	38	-	-	6.00	5.98	8.18	8.19	8.21	8.19
45	38°47'	74°22'	34	-	-	8.30	8.23	8.23	8.42	8.31	8.21

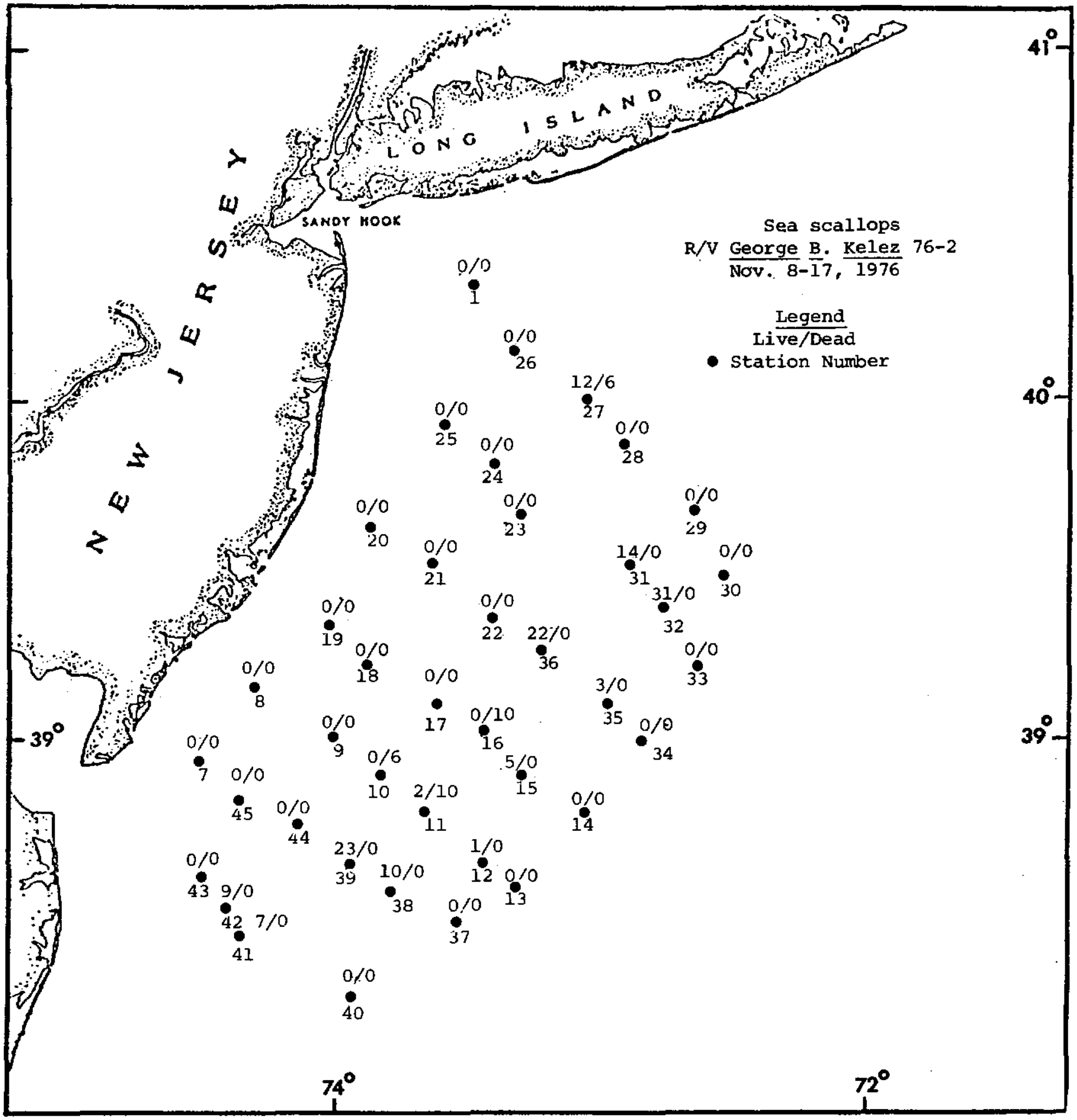

Figure 5. Numbers of sea scallops, live/dead. at stations on Middle Atlantic Shelf, November 8-17, 1976. R/V George B. Kelez cruise 76-2.

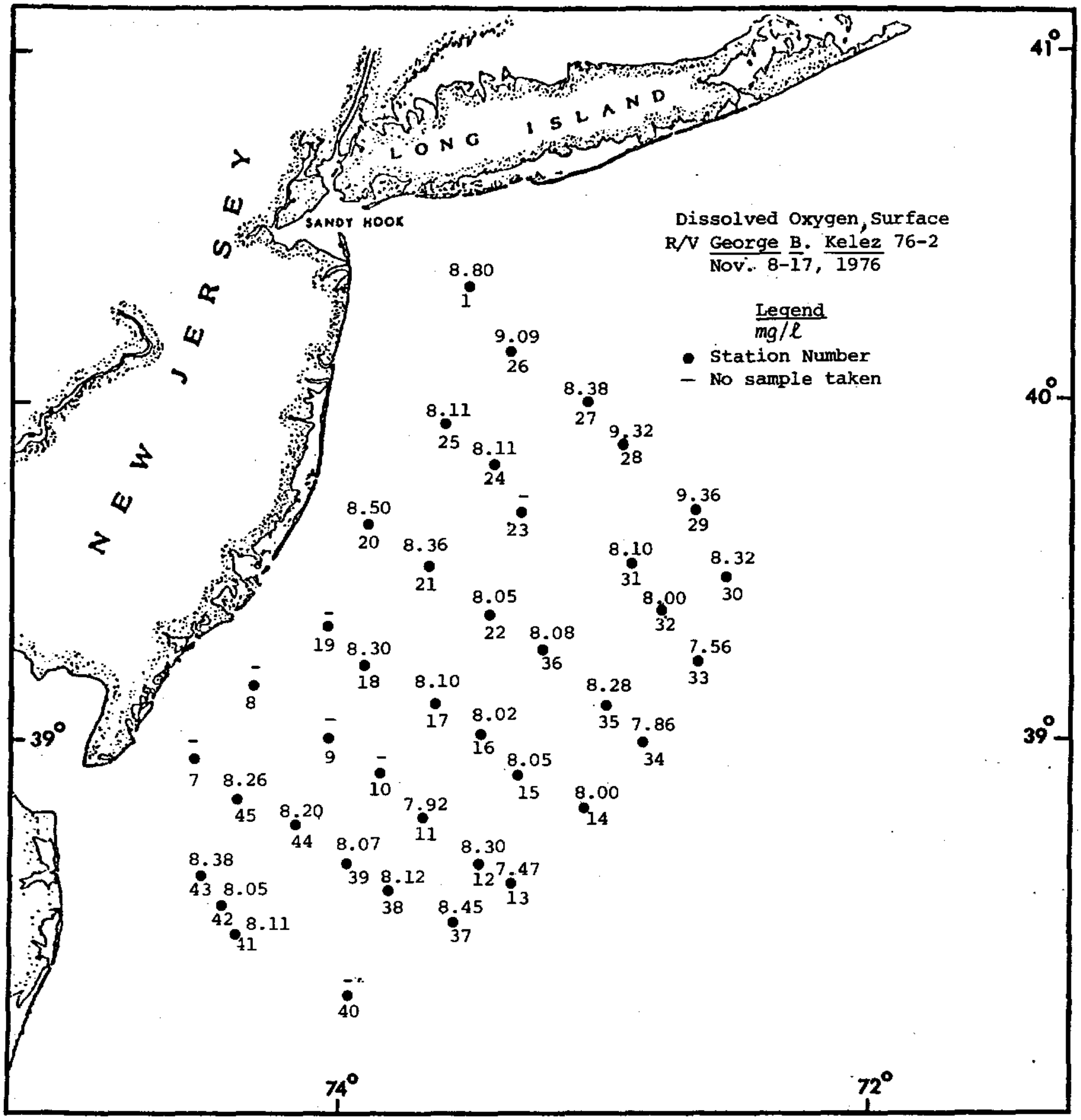

Figure 6a. Distribution of surface dissolved oxygen levels on Middle Atlantic Shelf, November 8-17, 1976. R/V George B. Kelez cruise 76-2.

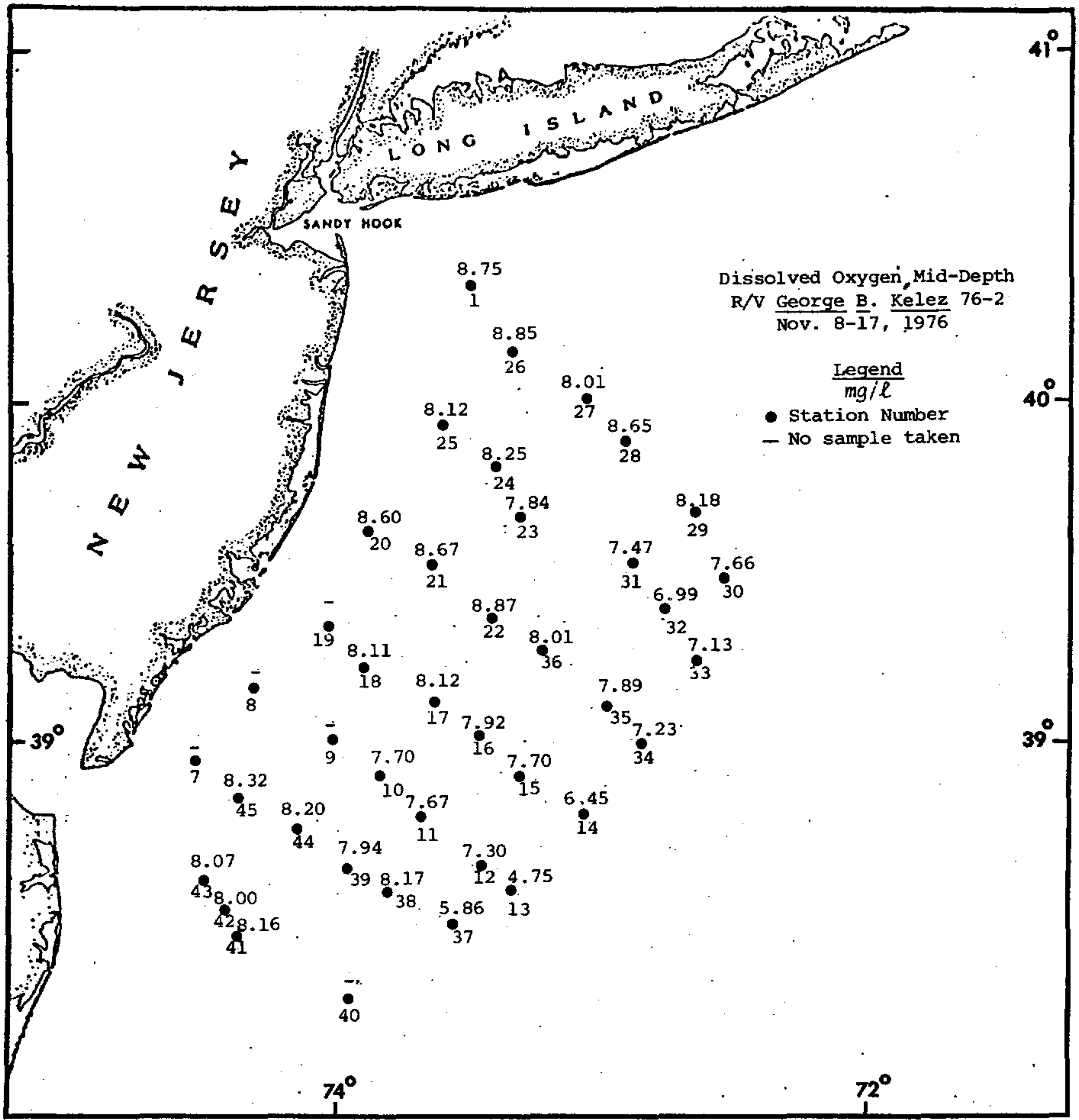

Figure 6b. Distribution of mid-depth dissolved oxygen on Middle Atlantic Shelf, November 8-17, 1976. R/V George B. Kelez cruise 76-2.

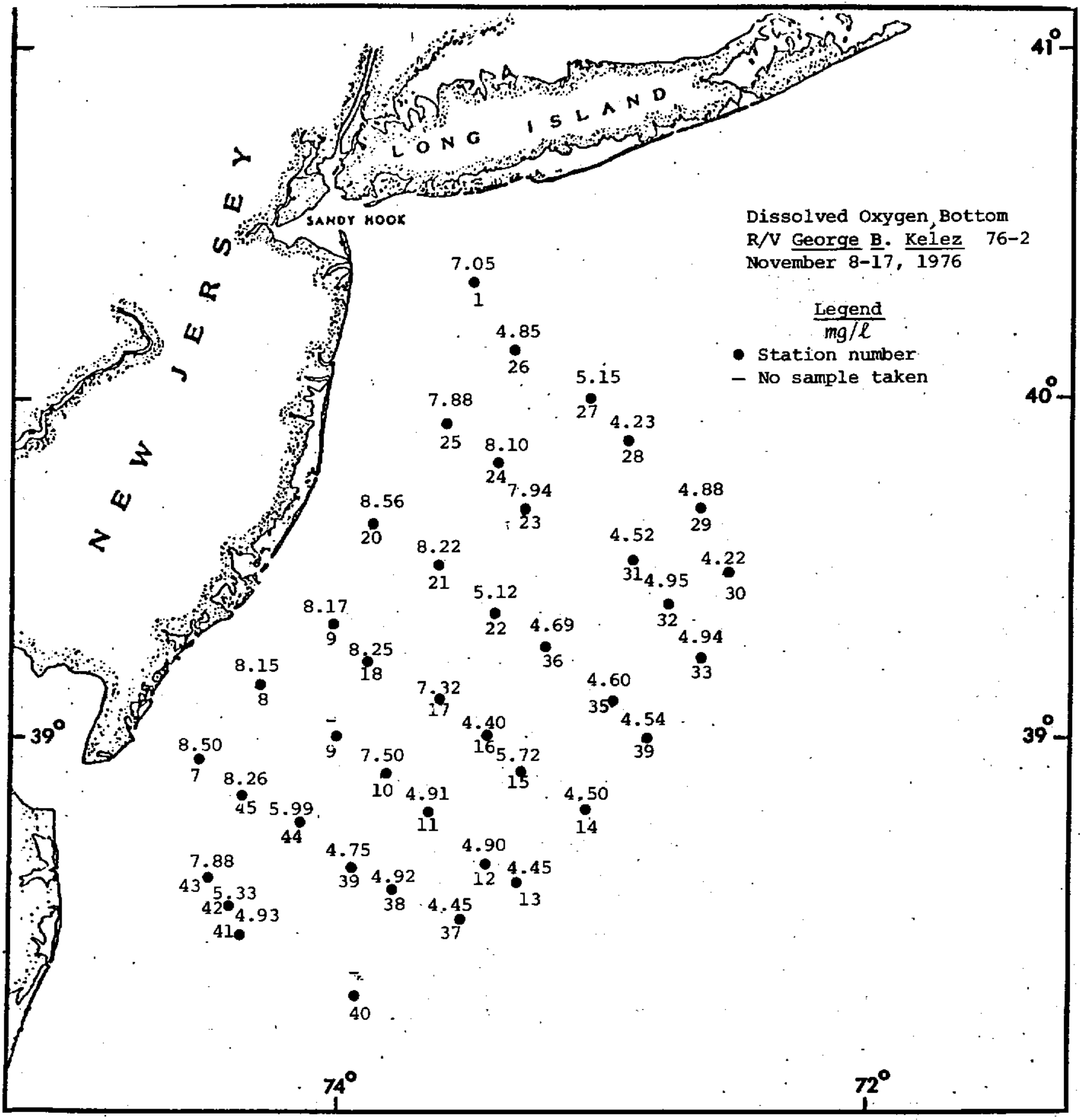

Figure 6c. Distribution of bottom dissolved oxygen on Middle Atlantic Shelf, November 8-17, 1976. R/V *George B. Kelez* cruise 76-2.

New York, to Cape Hatteras, North Carolina. The vessel towed a standard 3.01-m dredge with bag having 5.0-cm rings to collect scallops. At each station, the dredge was towed for 15 min at a speed of 3.5 knots. Numbers and lengths of live and dead scallops along with associated invertebrates were recorded. Twenty-nine stations were sampled off New Jersey. No noticeable mortality was observed among the scallops or other invertebrates. The data from the cruise can be used in this report to (1) help define the area occupied by sea scallops on the continental shelf off New Jersey, and (2) calculate the total number of scallops in both the unaffected and affected areas in 1976.

The percentage of the sea scallop resource killed was calculated by: 1) measuring the sizes of the two areas occupied by the live and dead or stressed scallops, as indicated by fishermen's reports and various survey cruises; 2) determining the area swept at each station with the 3.01 m dredge during the 1975 Albatross IV cruise, and the 0.78 m dredge during the 1976 George B. Kelez cruise; 3) computing the mean catch per tow for both cruises (assuming 100% retention by the dredge); 4) calculating the number of possible sampling units for each cruise by dividing the total area by the area swept by the gear in one tow; 5) estimating the total number of scallops in the area for each cruise by multiplying the mean catch per tow by the number of possible sampling units; and 6) comparing the total scallop number within each area for both cruises (Table 4).

TABLE 4. Data on unit areas sampled at each station, area sizes, number of scallops per unit, and percentage of scallops killed in the unaffected and affected areas off the New Jersey coast.

	Unaffected Area		Affected Area	
	Albatross IV	*Kelez*	*Albatross IV*	*Kelez*
Dredge width (m)	3.01	0.78	3.01	0.78
Length of tow (km)	6.37	1.82	6.37	1.82
Area swept per tow (unit) sampled, m^2	19,174	1,420	19,174	1,420
Total size of area sampled, km^2	7,225	7,225	4,300	4,300
No. of units in area	377,000	5,088,000	224,000	3,028,000
Scallops collected/unit (avg.)	100.75	10.8	16.3[1]	2.7[2]
Total scallops in area, if 100% were collected by dredge	$3.8x10^7$	$5.49x10^7$	$3.66x10^6$	$8.18x10^6$

Percentage of scallop resource killed, indicated by

Albatross IV Cruise	8.8%
George B. Kelez Cruise	12.9%

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1. Scallops were alive in 1975.

2. Scallops were dead in 1976.

RESULTS

A. Condition of Sea Scallops and Associated Invertebrates

1. Reports of dead or stressed scallops from fishermen, a surf clam cruise, and five finfish cruises.

Locations of dead scallops off New Jersey reported by commercial fishermen are listed in Table 1 and shown in Figure 1. Dead scallops were found at two locations during the surf clam survey cruises (Ropes, 1976a, b) at positions: lat. 39°31' and long. 73°31', at a depth of 20 m, and lat. 30°16' and long. 73°43', at a depth of 43 m. In addition, one gaping stressed scallop was collected at lat. 40°25' and long. 73°27' at a depth of 24 m (Table 1, Figure 1). Off Long Island, only 2 of 122 scallops collected during the Cora May Snow cruise, September 15-25, were dead. The results from five finfish assessment cruises (Azarovitz, Byrne, and Silverman, 1976, unpublished data) were as follows:

a) Commercial vessel Grand Larson cruise, July 15, 1976 - evidence of sea scallop mortality was observed at one position: lat. 39°52' and long. 73°45', at a depth of 30 m (1 clapper).

b) R/V Rorqual cruise, July 20-22, 1976 - evidence of sea scallop mortality was observed at one position: lat. 40°01' and long. 73°41', at a depth of 24 m (1 clapper).

c) R/V Atlantic Twin cruise, August 6-17, 1976 - evidence of sea scallop mortality was observed at two positions: lat. 39°50' and long. 73°26', at a depth of 37 m (1 scallop meat); and lat. 39°31' and long. 73°29', at a depth of 35 m (2 dead scallops with meats, 3 clappers).

d) R/V Albatross IV cruise, September 28 to October 18, 1976 -

evidence of weak sea scallops but no mortality was observed at one position: lat. 40°11' and long. 73°14', at a depth of 40 m.

e) R/V Delaware II cruise, December 6-23, 1976 - evidence of sea scallop mortality was observed at one position: lat. 38°44' and long. 73°41, at a depth of 57 m (6 clappers among 49 live scallops) (Table 1, Figure 1).

2. Results from Two Sea Scallop Assessment Cruises, R/V Atlantic Twin and R/V George B. Kelez.

a) R/V Atlantic Twin cruise, October 6-15, 1976 - recently-killed scallops were collected at five stations. All scallops were dead at the following four positions: 1) lat. 39°39' and long. 73°18', at a depth of 40 m; 2) lat. 39°13' and long. 73°51', at a depth 36 m; 3) lat. 39°07' and long. 73°39', at a depth of 45 m; and 4) lat. 38°54' and long. 73°53', at a depth of 41 m. Live scallops were collected at 3 stations off New Jersey and 6 stations under Long Island (Figure 3).

Recently-killed surf clams and mahogany quahogs were collected in areas where they had been surveyed during clam assessment surveys in 1976 (see various survey reports for 1976 by J. W. Ropes).

b) R/V George B. Kelez cruise, November 8-17, 1976 - recently-killed scallops were collected at four stations. All scallops were dead at the following two positions: lat. 38°52' and long. 73°53', at a depth of 39 m; and lat. 39°00' and long. 73°30, at a depth of 53 m. At the following two positions, 83% and 33%, respectively, of scallops were dead: lat. 38°46' and long. 73°43', at a depth of 51m; and lat. 39°59' and long. 73°09', at a depth of 67 m (Figure 5). Live sea scallops were collected at 10 stations in areas offshore and south of where dead and stressed scallops were taken.

Recently-killed surf clams and mahogany quahogs were collected in areas where they had been found on earlier cruises. Mahogany quahog clappers were found as far as 80 km from shore. An area of dead invertebrates which included sea scallop clappers, mahogany quahogs, razor clams, and tests of dead sand dollars was located 70 to 80 km off Atlantic City and Cape May, New Jersey, at a depth of about 53 m. Numbers of live rock crabs and starfish were collected in portions of this area.

The R/V George B. Kelez cruise was well-timed because dissolved oxygen levels over the entire continental shelf had returned to normal (see next section). Therefore, it is believed there were no further sea scallop mortalities due to the oxygen-deficient water.

The two areas of the continental shelf off the New Jersey coast occupied by the live and dead or stressed sea scallops are shown in Figure 7. Areal extent was determined from the 1975

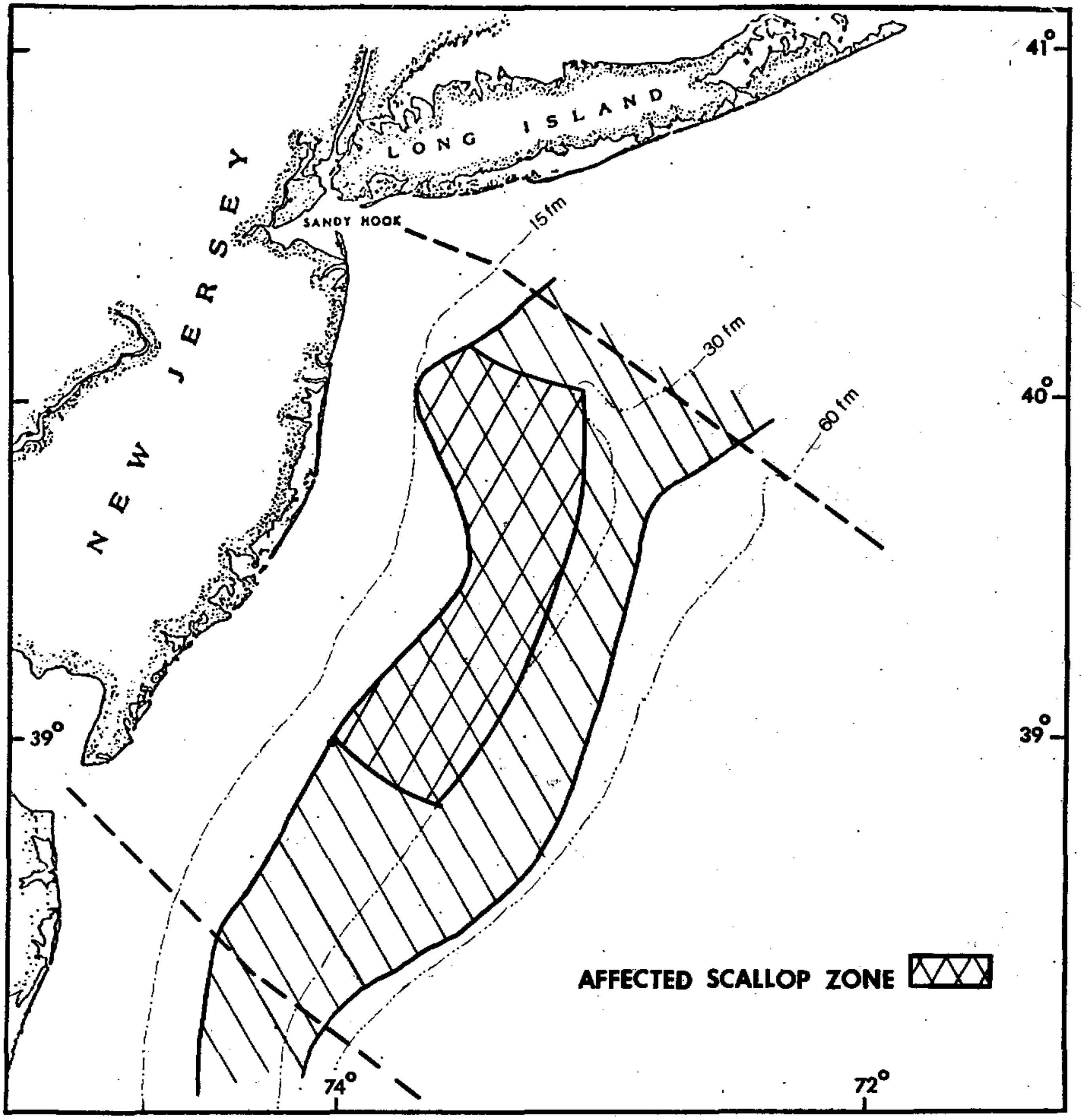

Figure 7. Areas occupied by unaffected and affected sea scallops off the New Jersey coast, November 8-17, 1976.

R/V Albatross IV cruise, the 1976 reports from fishermen, and data from various Sandy Hook Laboratory resource assessment survey cruises for sea scallops, clams, and finfish. The area occupied by unaffected sea scallops covers about 11,525 km^2; of this, the area of unaffected scallops covers about 7,225 km^2, 63%, and area of affected scallops about 4,300 km^2, 37%. The area occupied by affected scallops lies on the shallow, inner side of the scallop area, and along about 60% of its north to south length. In the main part of the area, virtually all scallops were apparently dead; around its periphery, individual scallops were either dead, stressed, or live. The average numbers of scallops/station,as determined by the 1975 R/V Albatross IV and the 1976 George B. Kelez cruises,were 6.2 and 4.0 times greater respectively in the unaffected, than in the affected areas, showing that scallop concentrations were much denser in the former area. The indicated kill of the total New Jersey sea scallop resource by the oxygen-deficient waters during the summer of 1976 was 8.8 and 12.9% for the two cruises respectively (Table 4).

B. Hydrographic Data from Sea Scallop Assessment Cruises

a) R/V Atlantic Twin cruise, October 6-15, 1976.

Dissolved oxygen. Bottom dissolved oxygen levels were significantly higher than they had been in the August and September survey cruises (Figure 3, Table 2). At most stations, D. O.'s ranged between 2.20 and 7.35 mg/l, but they ranged between 1.10 and 1.75 mg/l at the following four positions: (1) lat. 39°07' and long. 73°39'; (2) lat.

38°54' and long. 73°53'; (3) lat. 39°00' and long. 74°07'; and (4) lat. 38°55' and long. 74°19'

Temperature. At most stations, there was evidence of a recent overturn of the water because temperatures were nearly identical (17°C) from top to bottom. However, at some, there was evidence of a weak thermocline near the bottom. Temperatures below the thermocline ranged between 10° and 14°C.

b) R/V *George B. Kelez* cruise, November 8-17, 1976

Dissolved oxygen. Oxygen levels were determined at the surface, mid-depth, and bottom at the sea scallop stations (Table 3). The few points where determinations were not made were a result of inclement weather or Niskin bottle loss. At the surface and mid-depth, oxygen levels were mostly between 6.99 and 9.36 mg/l (Figures 6a, b). At the bottom, oxygen levels ranged between 4.22 and 8.56 mg/l (Figure 6c). Generally, the lowest levels were at the farthest offshore and deepest stations, while the highest ones were at the close-to-shore and shallow stations. In the area which had oxygen-depleted water during July through October, bottom oxygen concentrations ranged from 4.91 to 8.56 mg/l. Thus, oxygen levels had returned to normal for the fall of the year.

Temperature. At all stations, temperatures were virtually similar from the surface to the bottom. There was no evidence of a thermocline. Most temperatures ranged between 11.3° and 14.7°C.

SUMMARY

During the summer of 1976, water depleted in oxygen covered a large area of the continental shelf off New Jersey. In July and thereafter for a few months, commercial fishermen and personnel on cruises conducted by the National Marine Fisheries Service found dead, dying, and stressed sea scallops extending over an area on the shallow inner side of the area occupied by scallops. It was determined that between 8.8 and 12.9% of scallops were killed off New Jersey.

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APPENDIX III

A PRELIMINARY REPORT

RECENT AND HISTORIC CATCHES OF FINFISH TAKEN BY OTTER TRAWL IN THE VICINITY OF THE 1976 NEW JERSEY HYPOXIC WATER MASS

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INTRODUCTION

In late June 1976, the National Marine Fisheries Service Laboratory at Sandy Hook received reports from fishermen and divers of dead and dying fish off northern coastal areas of New Jersey (Steimle, 1976). Immediate attempts were made to confirm these reports by taking hydrographic and biological samples from the reported areas. Unfortunately, the laboratory's largest research vessel, R/V Delaware II, was undergoing extensive shipyard overhaul at the time. Two of the laboratory's small vessels, the R/V Rorqual and R/V Xiphias, were used, but size, speed and accommodations limited these vessels to day trips and prevented adequate sampling especially for biological specimens. However, we were able to make several exploratory surveys using a small trawl in early July on the northern edge of the hypoxic water. We continued to receive reports from scuba divers indicating that the mortalities were occurring on wrecks off South Jersey that were previously unaffected. The first reports, in early July, were off Monmouth Beach, then in a southerly progression off of Manasquan Inlet, Barnegat Inlet and finally, by the third week in July, Atlantic City (Figure 1). In mid-July, we chartered a commercial trawler, the Grand Larson, out of Barnegat Light, New Jersey, and for the first time, we trawled in waters reportedly totally anoxic. In response to the above reports, the R/V Rorqual was sent down along the New Jersey coast to operate on a daily basis out of southern New Jersey ports. Although some stations were made south of Manasquan Inlet, the speed of the Rorqual and some mechanical difficulties necessitated returning the vessel to Sandy Hook. The R/V Xiphias was then sent south and made several stations in the hypoxic area but it was also limited and returned to Sandy Hook in three days. During July, arrangements were being made to charter the R/V Atlantic Twin as soon as it became available. The vessel, used by the laboratory on previous occasions, was capable of conducting a 24 hour trawl operation for at least a one week period. In August, we arranged for charter and were finally able to extensively survey the hypoxic area and collected not only trawl data, but made fairly complete hydrographic and associated biological data.

The NMFS Resource Assessment Investigations conducted two routine finfish stock assessment cruises over the entire mid-Atlantic shelf (Cape Cod-Cape Hatteras), one from the end of September through mid-October, the other in December, using the R/V Albatross.

The finfish catch results of otter trawl tows from the above series of eight cruises are presented in this report.

Assessment surveys of mid-Atlantic finfish stocks have been calculated by the National Marine Fisheries Service since 1968. During several summer and fall cruises from this time series, stations were occupied off the New Jersey coast in the same area as the 1976 hypoxic water mass. A preliminary tabulation of available data (1971-75) are included in this report. A detailed statistical analyses comparing data from this historic time series with the 1976 catch results is presently underway at Sandy Hook

It should be kept in mind that otter trawls, tow durations and vessels used varied considerably on the cruises, therefore, any comparisons should be made in a strict qualitative sense and direct quantitative conclusions should be based on future papers and reports containing statistically sound comparisons.

MATERIALS AND METHODS

Stations were selected according to the requirements of the cruise. Resource Assessment cruises are designed to show seasonal distribution and relative abundance of finfish over a large portion of the continental shelf and stations are selected on a random basis. Cruises intended to study the hypoxic area were designed to investigate the extent of a phenomenon in a relatively small area and stations were laid out in simple transects or grids.

A station consisted of one or more of the following components: 1) XBT, thermistor or mechanical BT cast; 2) hydro-cast (using Niskin water sampling bottles) to selected depths to collect samples for salinity, dissolved oxygen, hydrogen sulfide or for subsequent phytoplankton analysis; 3) and a trawl haul.

The otter trawl employed depended upon the purpose of the cruise. A roller rigged No. 36 Yankee (60/80 net) is the standard trawl for the fall resource assessment surveys. This net opens approximately 10 m wide and 3 m high. The scope (ratio of wire out to depth) varied with depth and the net was towed at 6.5 km/hr (3.5 knots). The rollers are 0.4 m (16 in.) in diameter, and 544 kg (1200 lb.) BMV oval doors were used.

The No. 36 Yankee rigged with a chain sweep was used for special surveys when a sufficient vessel (i.e. Delaware II, Albatross IV) was available. This net is similar to the roller rigged net except for the sweep. As a result it opens somewhat wider but not as high.

The 3/4 size No. 36 Yankee is used when the vessel (R/V Atlantic Twin, R/V Dolphin) is not large enough to handle a full size #36 Yankee. This smaller trawl has a relatively light chain sweep and requires 227 kg (500 lb) rectangular "New England" trawl doors. The "3/4 trawl" opens approximately 9.3 m wide and 1.3 m high. It is towed at 6.5 km/hr (3.5 knots) and the scope varies with depth.

Specifications for the bay trawl and the 50/70 trawl are not available as they have not been subjected to the vigorous and detailed acoustical measuring (French, 1968) that the other trawls have undergone. However, both of these nets had chain sweeps and were fished with rectangular doors. The 50/70 trawl was used only once aboard the charter vessel Grand Larson while the bay trawl is normally used aboard the two small vessels (R/V Xiphias and R/V Rorqual) belonging to this laboratory.

Of the two types of sweep mentioned here, the chain sweep more closely tends the bottom. As a result the chain sweep-rigged nets more effectively sample the fish species that are very closely associated with the bottom (such as the flounders) and the benthic invertebrates.

When either of the No. 36 Yankee trawls are used, the tow duration is normally 30 minutes. The tow duration time for the 3/4 No. 36 Yankee, 50/70 trawl and bay trawl was normally 15 minutes (with the exception of the July-August 1973 Albatross IV survey). Once the trawl was recovered, the catch was sorted to species, weighed and a length-frequency for each species was recorded on the trawl log. The data on the trawl logs were subsequently entered into the Northeast Fisheries Center Automatic Data Processing system. In addition to this basic information, special biological samples, as well as whole frozen fish, were retained for laboratory examination as set forth in a pre-determined sampling plan.

Salinities were measured at the laboratory using an induction salinometer, dissolved oxygens were measured using the Azide modification of the Winkler Method (Standard Methods for the Examination of Water and Wastewater, 1975), hydrogen sulfide levels were determined using the colorimetric technique as set forth in Strickland and Parsons (1968). The water samples for subsequent phytoplankton analysis were either preserved with Lugol's Iodine or put on ice and turned over to the Primary Productivity section of Ecosystems Analysis (Sandy Hook Laboratory) for examination. Except as specifically indicated in the Results and Discussion sections, the results from these collections will be presented in other sections of this report.

RESULTS

Finfish catch listings in this report have been grouped into demersal or nondemersal categories. This grouping is based on our knowledge of the close association or degree of dependence of certain fishes with the sea floor. This is not to say that the demersal types cannot, on occasion, be found in the upper waters or the nondemersals or pelagics close to or on the bottom. But, if nondemersals are the only fish taken in areas where the waters below the thermocline are unsuitable for their existence, their presence is explainable by assuming they have been caught in the upper waters while the trawl was being lowered or raised. Another factor is the usual presence of at least several of the demersal species in the vast majority of trawl catches made during our surveys in the Middle Atlantic shelf waters. The number of fish species and individuals taken varies considerably, but only on the rarest of occasions are they totally absent. If several tows are made in any area of the New York Bight and none of the demersal types listed in this report is caught, the existence of a stressed or unsuitable environment is suggested.

Another indication of a stressed environment is the presence in trawl catches of certain benthic invertebrates. These animals such as surf clams, mud shrimp and marine worms, usually are not available to, or avoid capture by the trawl by living in deeper sediments or burrowing as it approaches. Such invertebrates caught during our surveys of 1976 are discussed in sections of this report dealing with benthic megafauna and shellfish resources. However, the presence of these invertebrates in combination with the absence or presence of finfish, helped us to evaluate the overall biological condition of hypoxic areas. Included in the report are results from all trawl hauls from selected cruises (Table 1) made within the area outlined in Figure 2. Much of the area included was never hypoxic but these stations are included for comparative purposes.

July 8, 1976 was the first opportunity we had to trawl in or near the areas of the reported fish kills. The 19.8 m R/V Rorqual was sent on a one day trip with the intent to verify these preliminary reports. Four trawl stations were occupied approximately 18.5 km (10 naut. mi.) offshore between Sandy Hook and Shark River, New Jersey (Fig. 3). The results are summarized in Table 2. The lowest bottom dissolved oxygen (1.10 *mg/l*) was found at the first station. The catch at this station, however, was not unusual and all fish appeared healthy. The second station was 18.9 km (10.2 naut. mi.) east of Monmouth Beach, New Jersey at the northern edge of the Christiaensen Basin. This was the general area of the initial reports of dead fish from commercial fishermen. The dissolved oxygen at this station was quite high (6.40 *mg/l*) and the live fish in the trawl were representative of what we expected to catch and appeared healthy. However, a few dead ocean pout were found in the trawl catch along with several dead invertebrates (see invertebrate section). Although D.O.'s were at a satisfactory level at this station, it is apparent that the fishermen's reports were accurate and anoxic conditions did exist previously in this area. D.O.'s at Stations 3 and 4 were acceptable and the catch appeared representative and healthy.

The following day the Xiphias, a 11.6 m research vessel used primarily in bays and estuaries, was sent south with the 9.1 m bay trawl. Two trawl stations were occupied 10.6 and 16.9 km east of Shark River (5.7 and 9.1 naut. mi. respectively) (Fig. 3). Trawl catches at these stations (Table 2) appeared normal in all respects. Reports indicated that lower oxygen waters existed further offshore in this area but the operational limitations of the vessel prevented us from sampling there. Realizing the need for offshore and more southern sampling, we chartered the 14.6 m fishing trawler Grand Larson out of Barnegat Light, New Jersey. This vessel was equipped with a 50/70 net rigged for summer flounder fishing. Although this type of net does not open very high, it samples bottom fishes and invertebrates quite well.

On July 13 the Grand Larson made four trawls (Fig. 3, Sta. 1-4) 18.5 km (10 naut. mi.) off the beach between Beach Haven Inlet and Lavallette, New Jersey. The results of these tows (Table 2) were the first direct evidence we had that a serious anoxic condition existed; one which dramatically affected finfish distribution. Tow #1 off of Beach Haven Inlet produced a representative catch with all animals alive and apparently healthy. The bottom dissolved oxygen at this station was 1.4 *mg/l*. At Stations 2 and 3, oxygen levels were below the detection limits of the method employed, while at Station 4, there was 0.4 *mg/l*. No finfish of any kind were caught at these stations except for a dead cusk-eel at Station 2. Invertebrates were either dead or just barely alive (see invertebrate section). We continued our sampling on July 15, 1976 but this time sampled a line extending 61.1 km (33 naut. mi.) northeast from Barnegat Inlet (Fig. 3). We trawled on three stations at 28.7, 48.2, and 55.6 km offshore. Oxygen values were near 0 at Station 5 and approximately 1.5 *mg/l* at 6 and 7 (Table 2). At Station 5 a dead little skate was the only fish caught. Most invertebrates were dead or dying. Trawls 6 and 7 did not yield many species of fish or numbers but all that were caught were alive and appeared healthy; this was also true for the invertebrates.

Unable to secure a larger vessel, we again sent the Rorqual south July 20-22, 1976. Two trawl hauls were made (Fig. 3) east of Manasquan and Barnegat Inlets. The station east of Barnegat (#6) had an undetectable bottom dissolved oxygen level and as expected, no fish alive or dead were caught. This station produced many dead or nearly dead invertebrates as summarized in the invertebrate section of this report. The station east of Manasquan Inlet (#2) had a bottom D.O. of 1.25 *mg/l* and a few live fish were caught here (Table 2). However, many of the invertebrates were dead or dying.

On July 28 through 30, 1976, the Xiphias was sent south to continue monitoring the hydrographic and biological conditions. Four trawl stations were occupied (Fig. 3) two east of Manasquan Inlet and two east and slightly north of Barnegat Inlet. Trawl stations 8 and 6 (8.5 and 18.7 km off the beach, respectively) had depressed dissolved oxygen values of 2.83 and 2.55 *mg/l*. Fish were caught all alive and well at these two stations (Table 2). The only indication of anything wrong were two dead scallops at Station 6. Dissolved oxygens on Stations 12 and 15 were significantly lower 1.85 and 1.60 *mg/l*, respectively and the only fish caught was a clearnose skate at Station 12. Many dead and "unusual" invertebrates were caught on these stations.

On August 6 we chartered the 27.4 m (90 ft) R/V Atlantic Twin, a catamaran stern trawler. This vessel would for the first time provide the capability to synoptically assess the hypoxic area and its effects on finfish distribution. A grid sampling scheme was established in order to accurately determine hydrographic and biological boundaries. Transects were laid out east to west at intervals of 10 minutes latitude. Stations on the transects were spaced 9.3 km (5 naut. mi.) apart with the most inshore stations about 1.9 km (1 naut. mi.) from the beach. By picking and choosing stations on the grid in obviously hypoxic or healthy areas we hoped to sample the entire area twice. This would let us establish rates of change or movement of the condition, which were constant questions we had from the previously fragmented data. Two significant events occurred which disrupted our sampling plans considerably. The first was hurricane "Belle" which, although not strong enough to turn over or disrupt the offshore waters ($>$33 m), did change the inshore hydrographic structure considerably. Inshore finfish distributions were likewise seriously affected. Valuable time was also lost during the storm's passage. The other was that during the cruise we received several reports of mortalities off the Delaware-Maryland coast; which we felt obliged to investigate. Nonetheless, a total of 97 stations were occupied with trawls made on 63 as indicated in Figure 3. In addition to the fish and standard hydrographic data collections, plankton samples, fluorometer readings and H_2S measurements were taken. Details concerning the cruise are available upon request from the Sandy Hook Laboratory. Catch results are summarized in Table 2. Figure 4 shows an area where no demersal finfish were caught during this cruise.

The laboratory's regularly scheduled mid-Atlantic fall survey was conducted September 28-October 17, 1976 aboard the 57 m (187 ft) R/V Albatross IV. Because of the New Jersey fish kill, bottom dissolved oxygen determinations were made at all stations. The location of stations in or near the "fish kill area" and the catch results are shown in Fig. 3 and Table 2, respectively. As a result of cooling temperatures and strong easterly winds in late September-early October, the hydrographic conditions that permitted the establishment of the anoxic water mass changed considerably. The areas that had no fish and zero dissolved oxygen during the August Atlantic Twin cruise showed significant recovery. Dissolved oxygen values were near saturation levels. A band of low oxygen water still remained but it was further offshore. One station (#99) had a bottom D.O. of less than 1 *mg/l* and no fish were caught. This indicated a possible southerly movement of the condition since August.

A mid-Atlantic finfish assessment survey was conducted between December 5 and 21, 1976 aboard the 47.9 m (157 ft) R/V Delaware II. The 45 trawl stations made off the New Jersey coast are depicted in Figure 3. The previous anoxic conditions were not apparent in the finfish catch composition (Table 2). The number of surf clam and ocean quahog clappers (see invertebrate report) did indicate the previous presence of the anoxic conditions. Bottom dissolved oxygens had recovered (See Table 2) to the point that the lowest recorded was 5.5 *mg/l*, a value that is considered normal.

Trawl catch summaries from available cruises conducted in and near the 1976 hypoxic area during previous years are in Table 2. In all 257 stations from 8 cruises between 1971 and 1975 are listed. Station locations are plotted in Figure 3. Dissolved oxygen measurements were not made on any of these cruises.

Table 3 is a listing of all finfish species taken on the recent and historic trawl surveys. Asterisks (*) indicate those species considered to be nondemersal.

DISCUSSION AND CONCLUSIONS

"The fish kill" is a phrase used most often when describing the hypoxic water mass that occurred off the New Jersey coast this past summer. This phrase, though accurate in that some fish were indeed killed, is misleading because a massive mortality of finfish populations did not occur. The first indications of a fish kill were based on reports of dead fish being caught in trawls of commercial fishermen (Steimle, 1976). Diver observations on offshore wrecks (Figure 1) further substantiated these finfish death reports. Our first surveys in early July did find a few dead fish in areas reported to have extensive mortalities. But further intensive trawling throughout the summer and fall did not produce significant numbers of dead fish. In fact, of the 196 trawl hauls made (52 in waters of <2.00 mg/l oxygen) only 16 dead fish were found (Table 4). Of the 16 dead fish, 12 of them (ocean pout) were caught on one station. Therefore, based on our observations, we must conclude that although there were some continued scattered finfish mortalities during the summer (Steimle, 1976; Freeman, this report) a significant and sustained kill of adult fish did not take place. Table 5 is a compilation from Steimle (1976) of all reported finfish mortalities.

What our data do show is that instead of dying, finfish were, in most cases, able to avoid the hypoxic area. This phenomenon of avoidance and subsequent repopulation is well demonstrated by the results of three stations that were each sampled three times (Table 6) during the August Atlantic Twin cruise. These three stations were first occupied the day before hurricane Belle passed over the area. The next samples were taken the day after hurricane Belle passed. And the last sampling occurred approximately one week later.

The first time these stations were sampled, the bottom oxygen levels were so low that they were below the detection limits of the method employed. Of the species captured, only the American sand lance is usually found closel associated with the bottom; the other species are able to thrive in and probably were captured well up in the water column above the anoxic waters. Also, it is probable that the sand lance was taken in these upper layers since the combination of anoxia and hydrogen sulfide poisoning would preclude life in the lower level.

Immediately after the passage of hurricane Belle, several demersal finfish species had repopulated the previously vacated (anoxic) area. This was a direct result of the extensive mixing which had brought the oxygen levels to over 4 *mg/l* at all three of these stations. However, offshore waters of depths greater than 33 m were unaffected by the storm and bottom dissolved oxygen levels remained low. Station 32 (not included in Table 6), which was 9.3 km (5 n miles) further offshore than Station 31, had a dissolved oxygen level of 0.37 *mg/l*. No finfish were taken at this station. Bottom dissolved oxygen levels to the east of this station were not detectable.

Approximately one week later, these stations were revisited and due to west winds which dominated the week, the hypoxic water mass was again shifting toward the coastline. At two of the stations there were less than 0.50 *mg/l* of dissolved oxygen and no finfish were taken. At Station 92 the dissolved oxygen was approximately 0.9 *mg/l* and 7 species of demersal finfish were taken. This was either in a lens or part of a tongue of higher oxygen water. In either case, it is obvious that these fish actively sought out, or stayed in the waters with the higher oxygen concentrations. This is further supported by the fact that no dead finfish were collected in any of the trawls in this general area.

Although the fish were avoiding the hypoxic water mass, on several occasions an undetermined number of fish were trapped in the hypoxic mass near beaches. These events occurred in late July between Manasquan and Beach Haven, N. J. when persistant westerly winds blew the oxygenated surface waters offshore causing an inshore movement or upwelling of the hypoxic bottom water. The fish, so trapped, were observed to be gaping for air at the surface and behaving lethargically. Species involved reportedly were striped bass, bluefish, weakfish, windowpane, summer flounder and northern searobin (Freeman, unpublished data). It was virtually impossible to obtain an accurate estimate of mortalities since the gulls were very active, but some dead fish were observed on the beach.

Although the above events were not devastating from a total resource point of view, other biological and economic effects were extremely deleterious. Spawning behavior or success, and established migration habits may have changed resulting in reduced commercial and recreational catches. The effect on benthic invertebrate communities and surf clams in particular was catastrophic. Other impacts equally devastating are discussed in other sections of this report.

Based on diver observations, commercial fishermen reports, beach observations and our trawl data, the area outlined in Figure 5 shows where during the summer and fall of 1976, finfish were affected by hypoxic conditions. The area involved totals approximately 11,339 sq. km (3,306 sq. miles) of some of the most utilized waters for commercial and recreational purposes in the world.

The catches on Stations 36, 37 and 38 (Figure 3) of the 1973 Albatross IV cruise during July-August should be discussed. Unfortunately, no dissolved oxygens were taken, but the lack of demersal finfish on these stations and the hypoxic occurrences in the same area (Steimle, 1976) in recent years indicates that perhaps a small and short-lived hypoxic condition existed during the summer of 1973.

The data discussed in this report and from additional sources are presently being incorporated into the Northeast Fisheries Center ADP system. The catch differences will then be analyzed in detail permitting a statistical assessment of the effects on finfish of the 1976 New Jersey hypoxic water mass.

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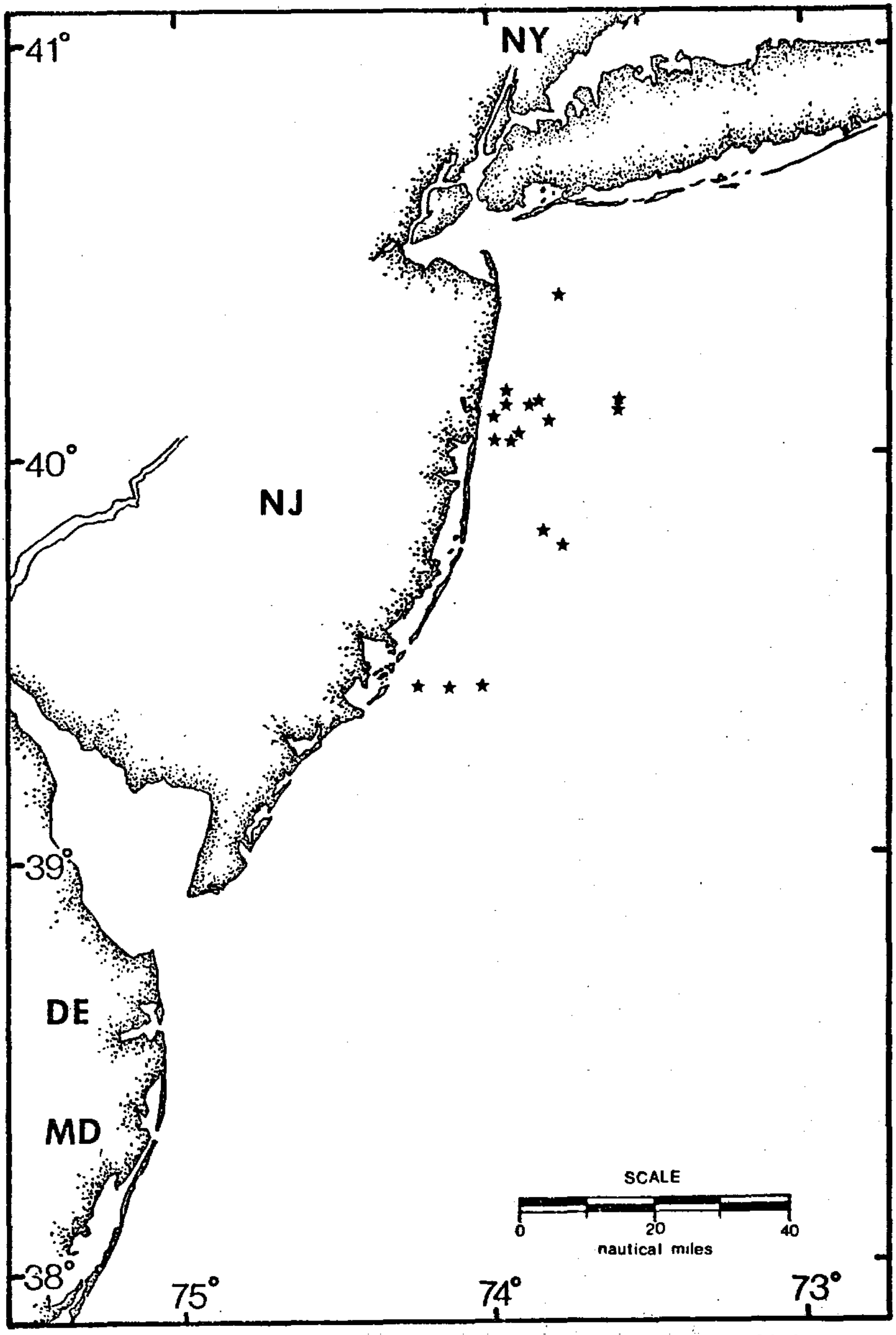


Figure 1. Wreck locations where divers reported finfish mortalities (July 3-18, 1976).

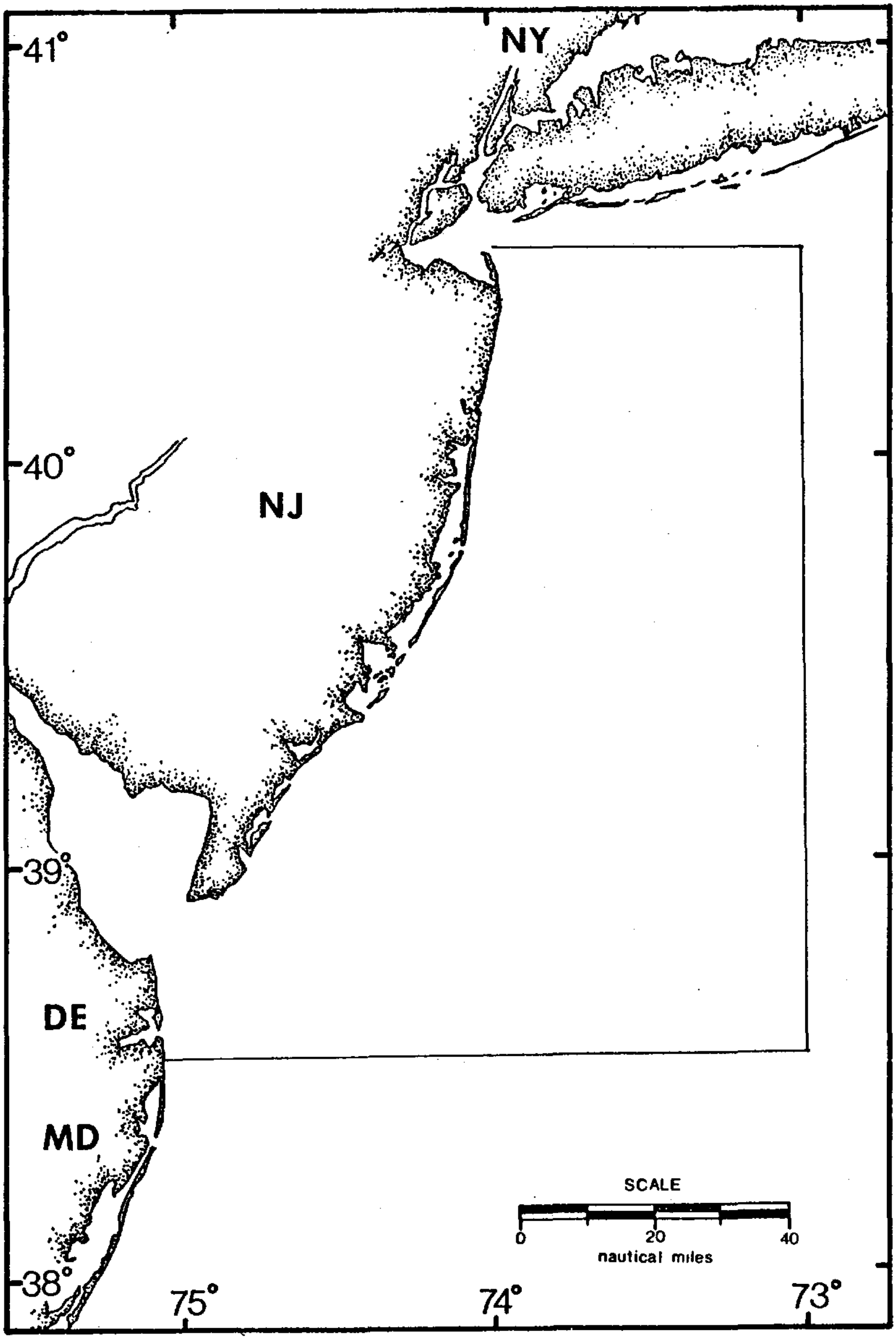
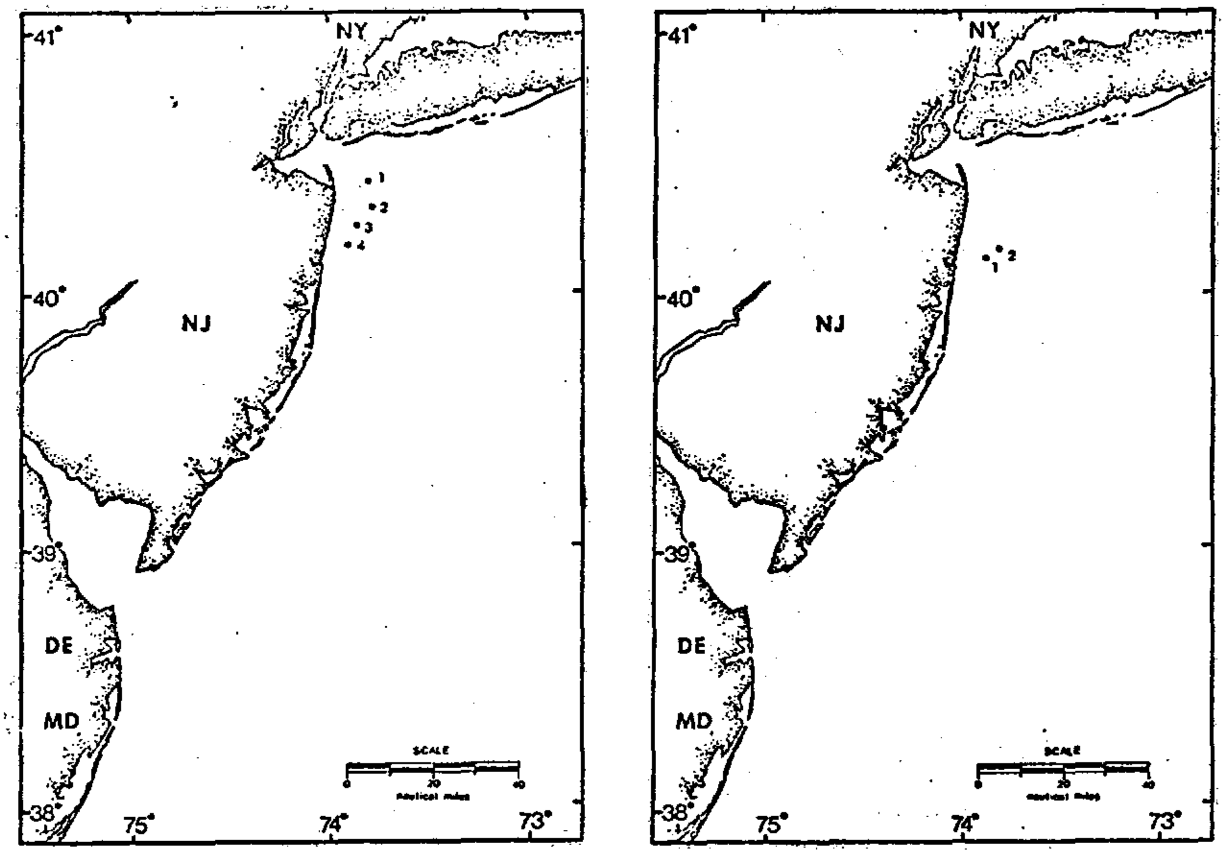
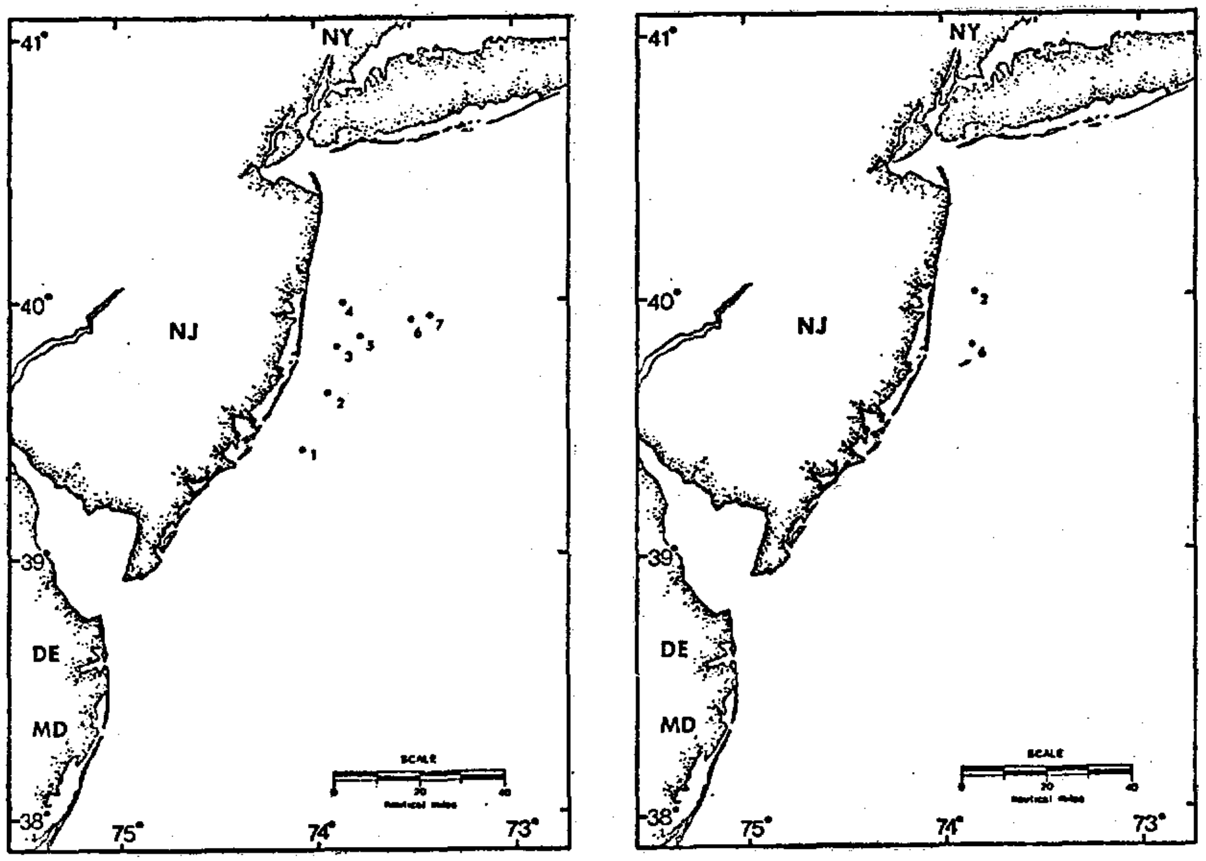


Figure 2. Area considered in this report for comparison of recent (post July 1, 1976) and historic trawl catch data.

Figure 3. Stations plots for sixteen surveys. Eight surveys from July to December 1976 and eight historic surveys from 1971 to 1975.

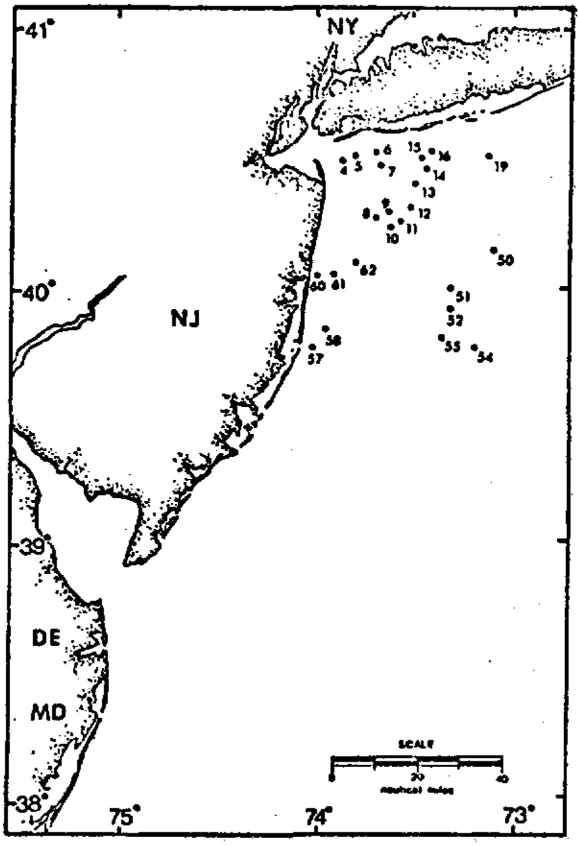


R/V Rorqual July 8, 1976 R/V Xiphias July 9, 1976

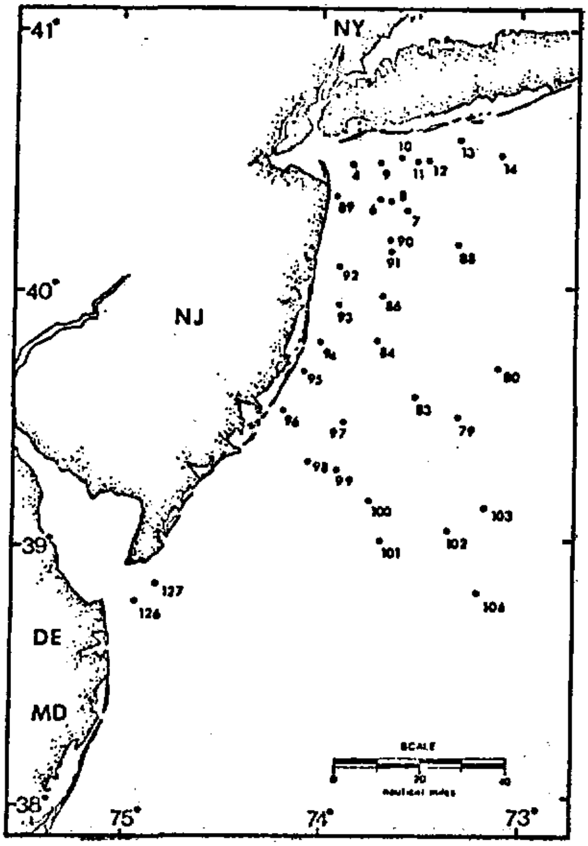


Grand Larson July 13 and 15, 1976 R/V Rorqual July 20-22, 1976

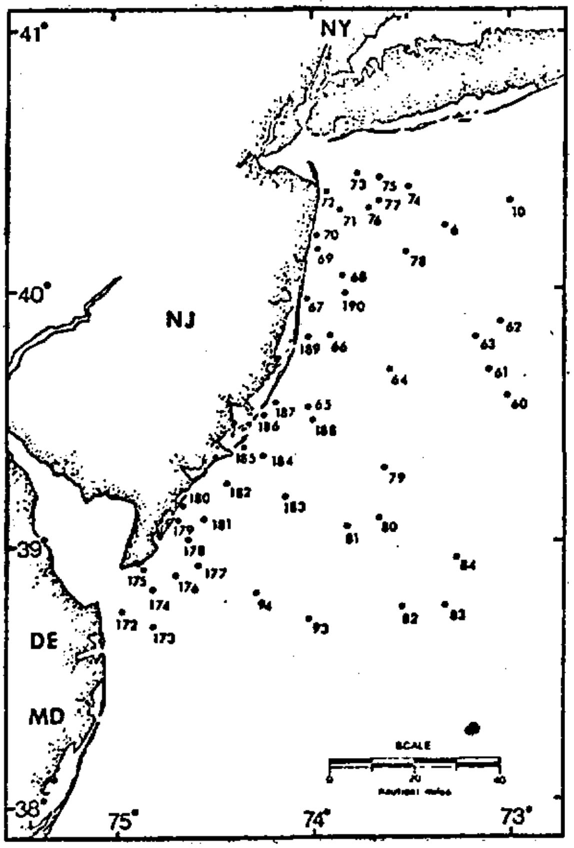
Figure 3. (continued)



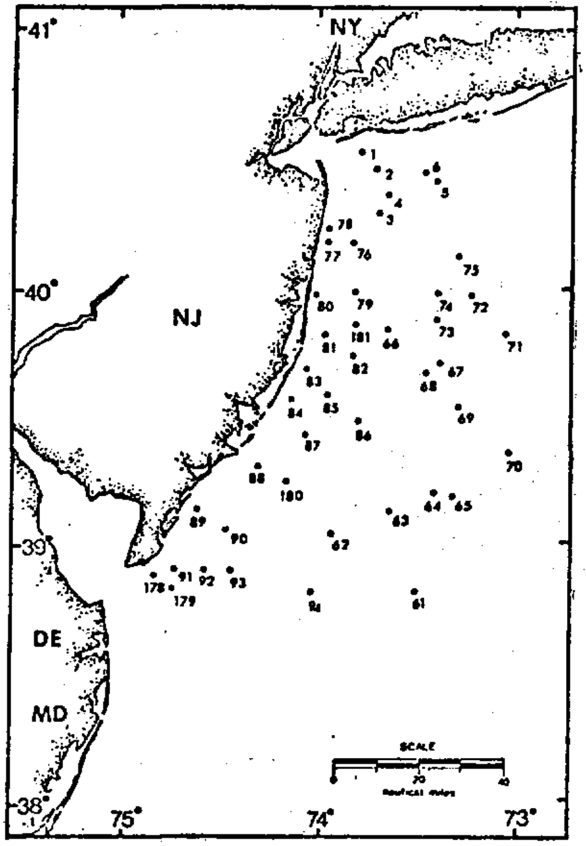
R/V Delaware II September 23-29, 1974



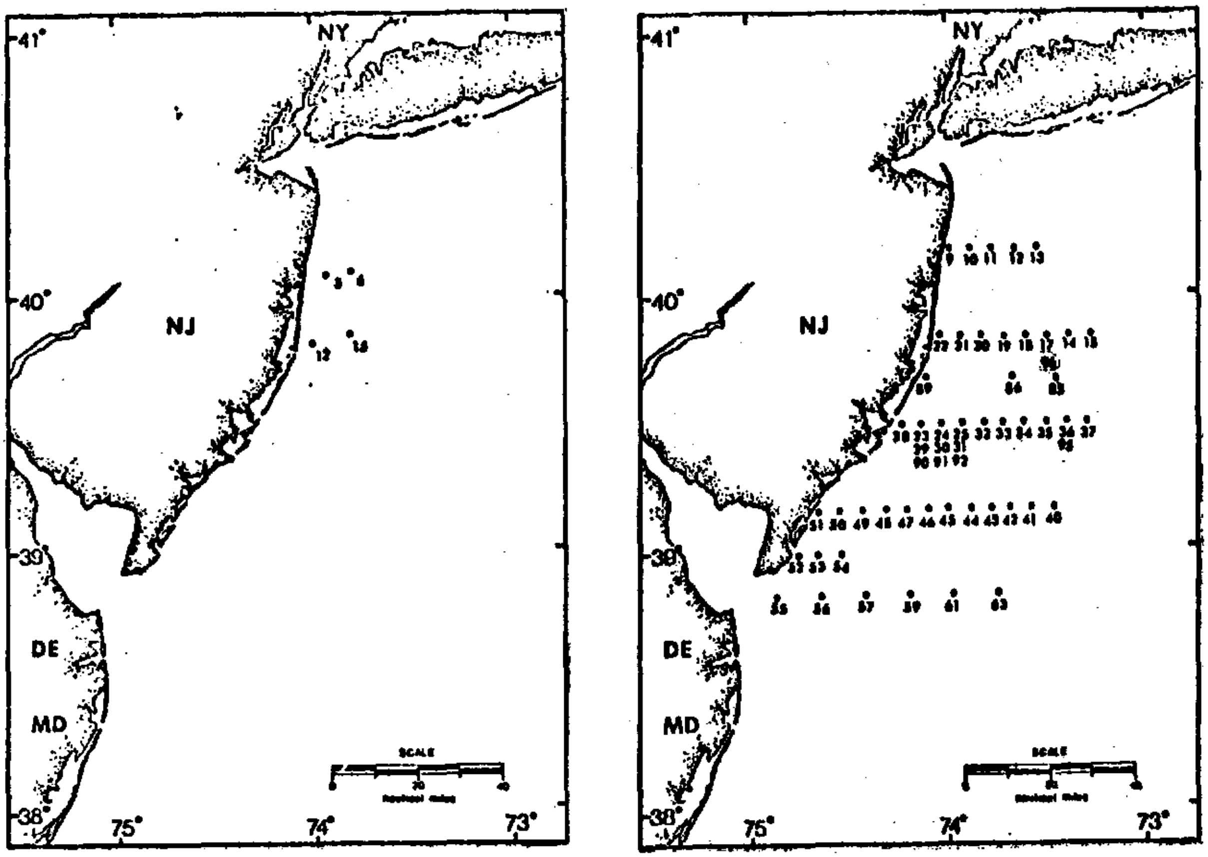
R/V Delaware II September 8-18, 1975



R/V Delaware II October 15-November 7, 1975

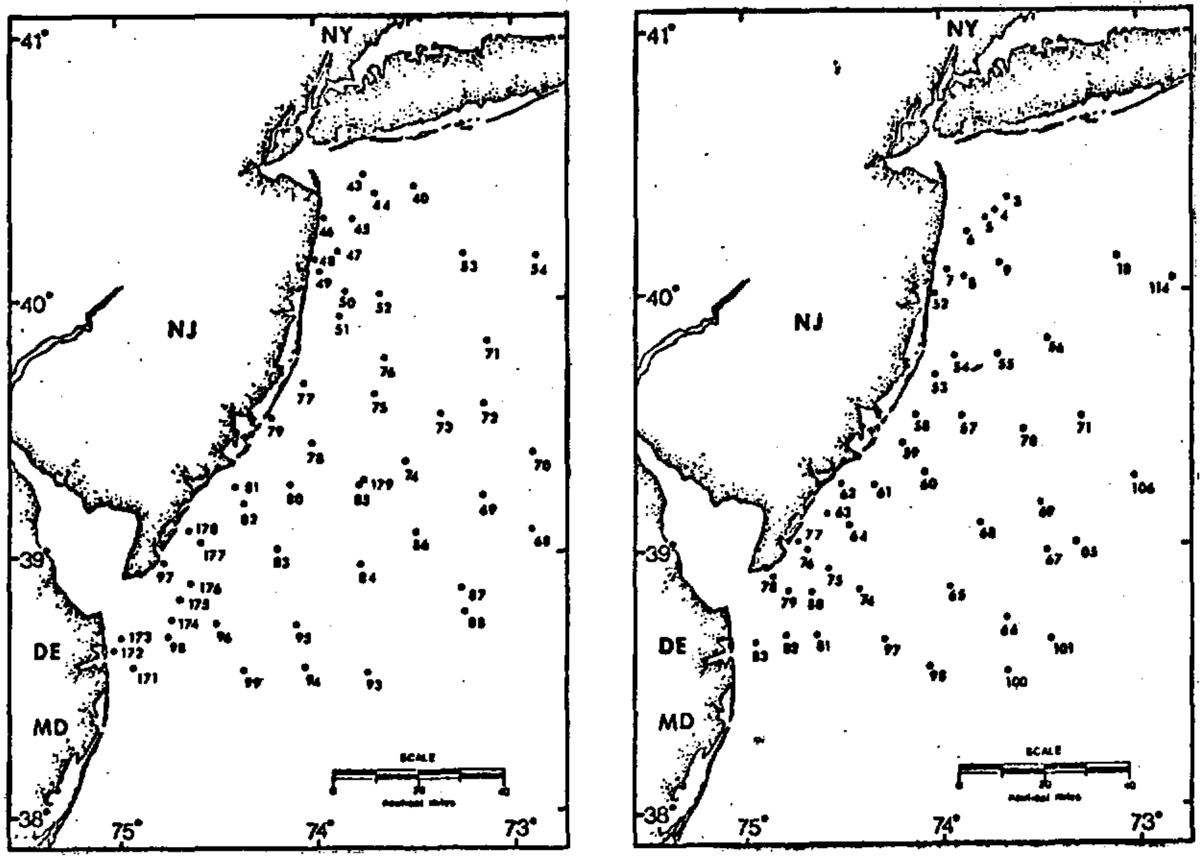


R/V Delaware II December 1-18, 1975



R/V Xiphias July 28-30, 1976

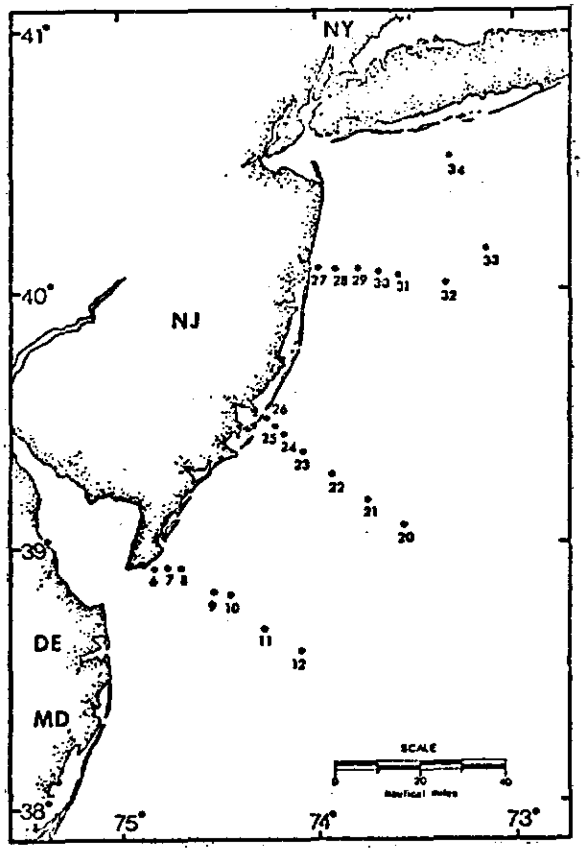
R/V Atlantic Twin August 6-17, 1976



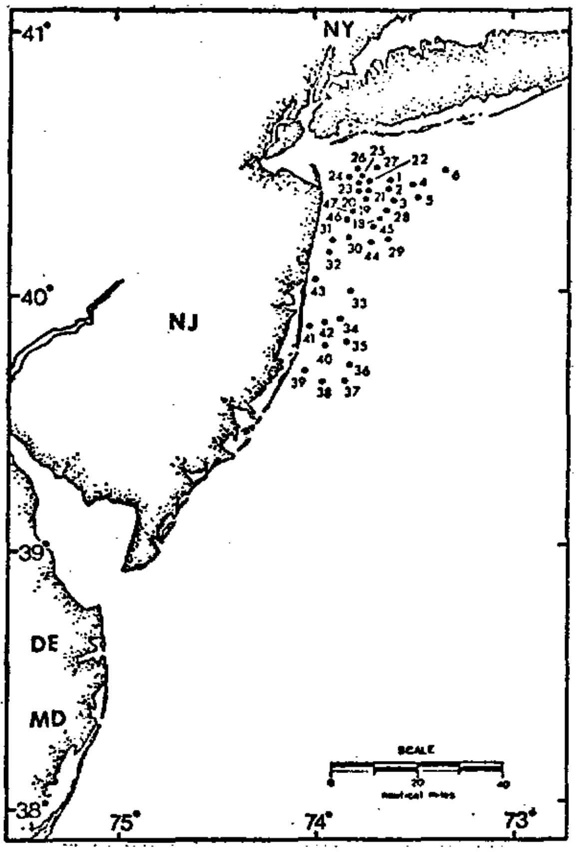
R/V Albatross IV September 28-October 17, 1976

R/V Delaware II December 5-21, 1976

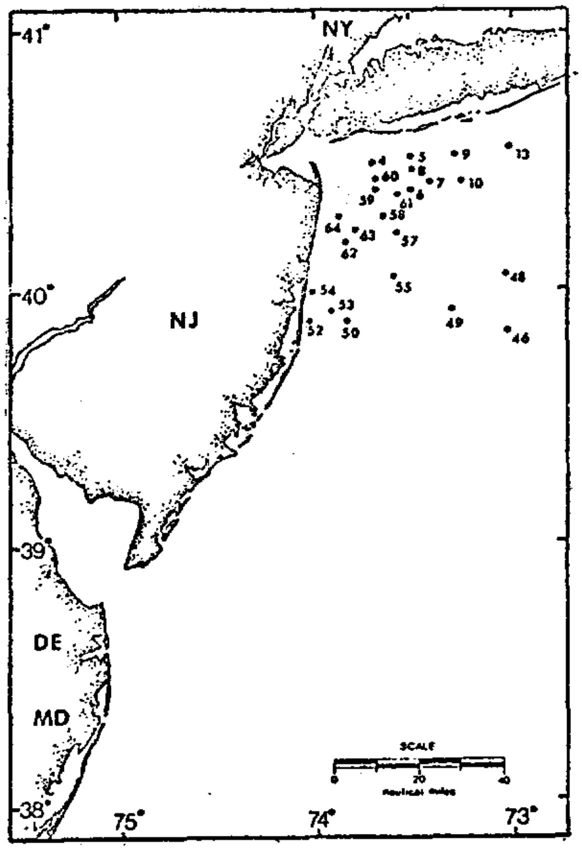
Figure 3. (continued)



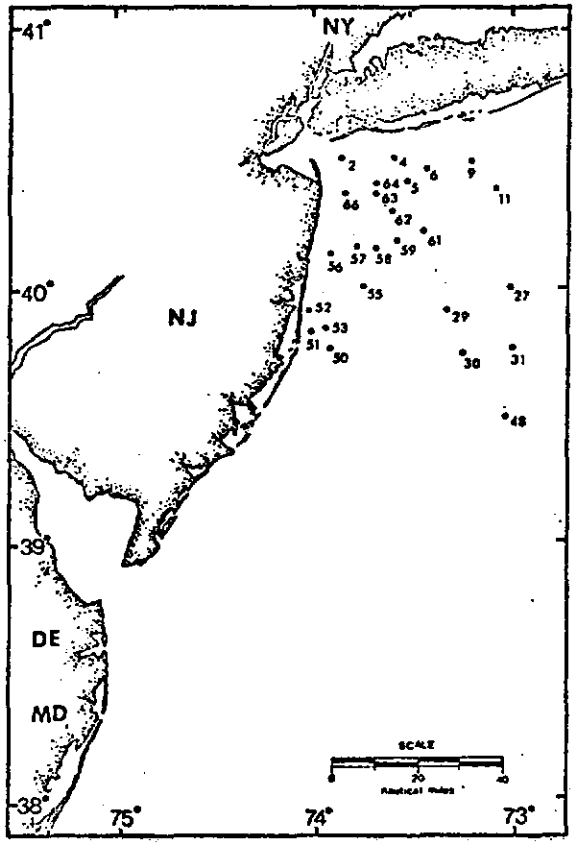
R/V Dolphin August 23-27, 1971



R/V Albatross IV July 29-August 2, 1973



R/V Delaware II July 24-29, 1974



R/V Delaware II August 16-21, 1974

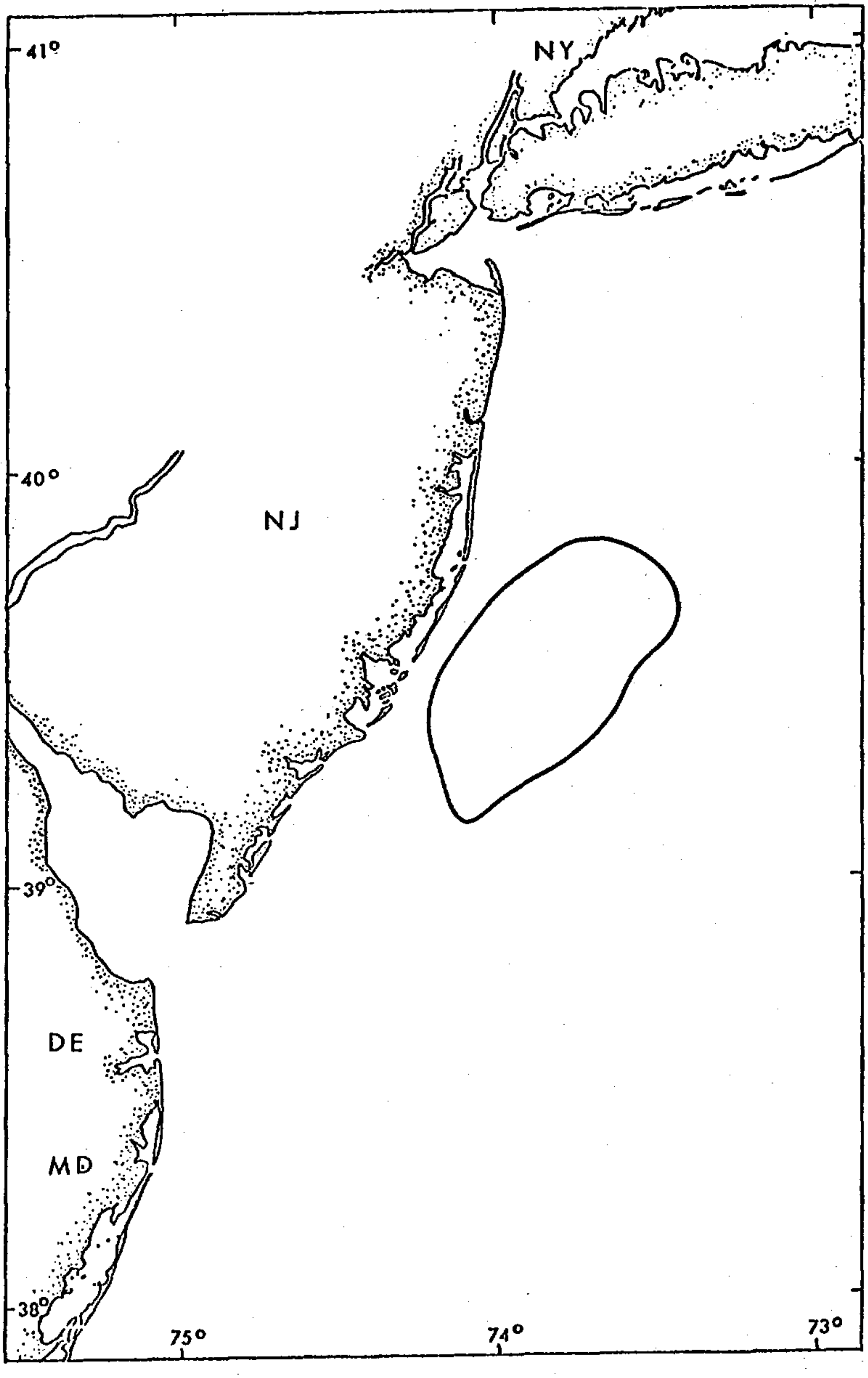


Figure 4. Area where no demersal fish were caught.

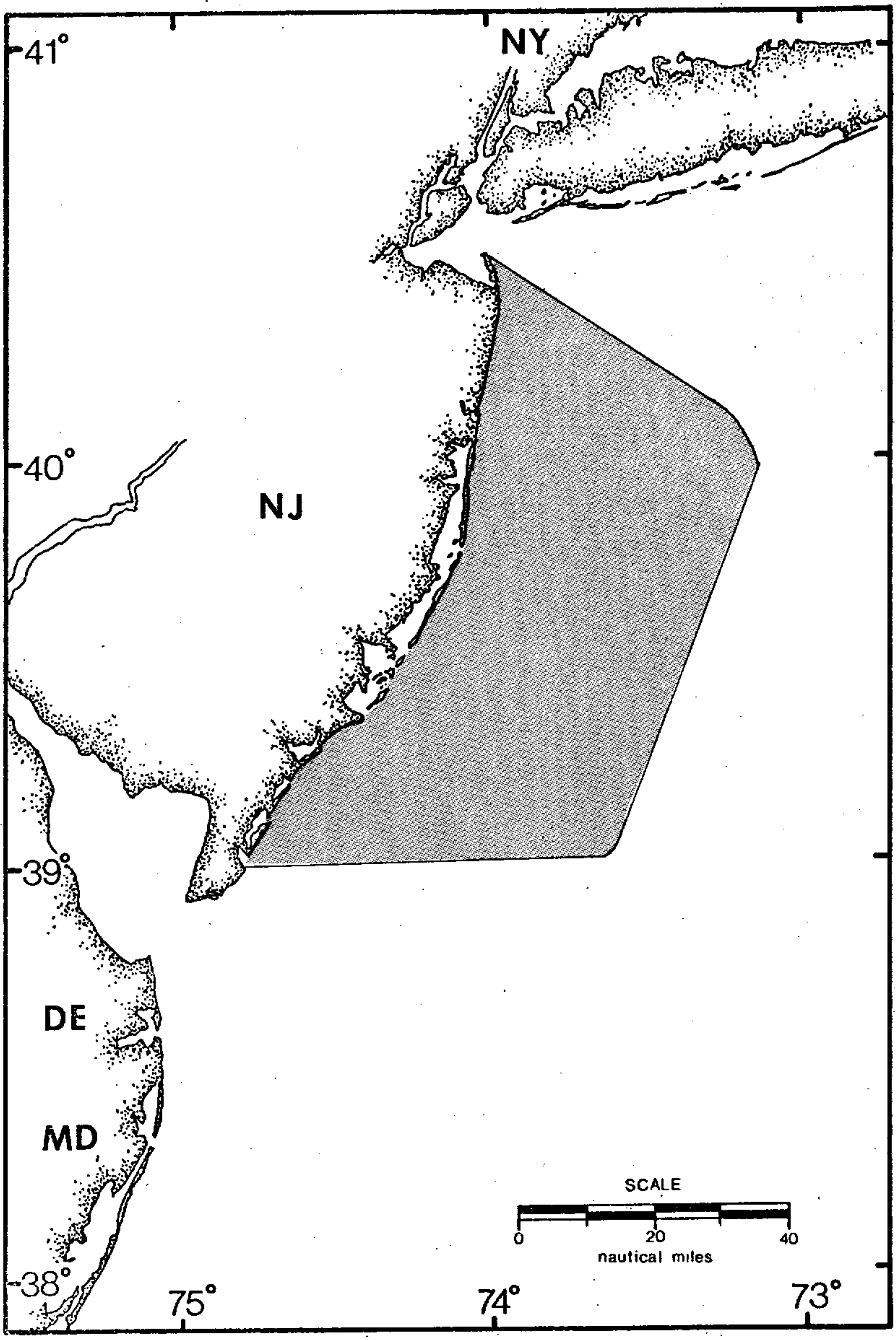


Figure 5. Area where NMFS survey data and confirmed reports show finfish were affected by hypoxic conditions between the end of June 1976 and October 1976.

Table 1. List of recent (post-July 1, 1976) and selected historic (pre-July 1, 1976) resource assessment cruises, conducted by NEFC, in the area from Sandy Hook, New Jersey to Cape Henlopen, Delaware, and from the coastline to approximately 73° West longitude. Included are dates, vessel, trawl description, tow duration and the number of stations occupied on each cruise.

Date	Vessel	Trawl	Tow Duration	Number of Trawl Stations
July 8, 1976	*Rorqual*	bay trawl, 9.1m chain sweep, no liner	15 min	4
July 9, 1976	*Xiphias*	bay trawl, 9.1m chain sweep, no liner	15 min	2
July 13 and 15, 1976	*Grand Larson*	50/70 trawl, 21.3m chain sweep, no liner	15 min	7
July 20-22, 1976	*Rorqual*	bay trawl, 9.1m chain sweep, 1.27 cm liner	15 min	2
July 28-30, 1976	*Xiphias*	bay trawl, 9.1m chain sweep, 1.27 cm liner	15 min	4
August 6-17, 1976	*Atlantic Twin*	3/4 #36 Yankee, 16.5m chain sweep, 1.27 cm liner	15 min	55
September 28-October 17, 1976	*Albatross IV*	#36 Yankee, 24.4m roller sweep, 1.27 cm liner	30 min	50
December 5-21, 1976	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	45
August 23-27, 1971	*Dolphin*	3/4 #36 Yankee, 16.5m chain sweep, no liner	15 min	22
July 29-August 2, 1973	*Albatross IV*	3/4 #36 Yankee, 16.5 m chain sweep, 1.27 cm liner	30 min	36

Table 1. (continued)

Date	Vessel	Trawl	Tow Duration	Number of Trawl Stations
July 24-29, 1974	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	24
August 16-21, 1974	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	25
September 23-29, 1974	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	24
September 8-18, 1975	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	34
October 15-November 7, 1975	*Delaware II*	#36 Yankee, 24.4m roller sweep, 1.27 cm liner	30 min	48
December 1-18, 1975	*Delaware II*	#36 Yankee, 24.4m chain sweep, 1.27 cm liner	30 min	44

TABLE 2

Summary of trawl catches from recent (post-July 1, 1976) and selected historic (1971-1975) cruises by station. Catches are broken down into demersal and nondemersal components. Included are weights (kilograms), numbers of individuals, numbers of species, depth (meters), bottom temperature (degrees centigrade), and bottom dissolved oxygen (milligrams of dissolved oxygen per liter of sample).

Station locations for each cruise are depicted in Figures through

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Rorqual</u> - July 8, 1976									
1	2.1	36	3	0	0	0	27	10.5	1.10
2	7.7	59	6	0	0	0	31	9.5	6.40
3*	0.1	1	1	0	0	0	22	10.5	3.30
4	12.4	102	8	0	0	0	18	20.4	7.20

* = tow not typical due to snagging the trawl on the bottom.

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Xiphias</u> - July 9, 1976									
1	6.7	56	8	0	0	0	21	11.1	4.40
2	2.5	72	4	0	0	0	30	9.0	2.80
<u>Grand Larson</u> - July 13+15, 1976									
1	8.5	56	6	0.3	26	1	20	12.0	1.40
2	0	0	0	0	0	0	24	10.8	0.00
3	0	0	0	0	0	0	24	10.5	0.00
4	0	0	0	0	0	0	26	10.1	0.30
5	0	0	0	0	0	0	30	10.5	0.05
6	+	1	1	0	0	0	39	8.5	1.55
7*	1.1	16	3	0	0	0	47	9.3	1.65

* = 7 minute tow.

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Rorqual</u> - July 20-22, 1976									
2	1.4	10	3	0	0	0	23	7.6	1.25
6	0	0	0	0	0	0	24	9.0	0.00

TABLE 2. (continued)

Station	Demersal Species			Nondemersal Species			Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
	Weight (kg)	Number of Individuals	Number of Species	Weight (kg)	Number of Individuals	Number of Species			
Xiphias - July 28-30, 1976									
3	1.9	35	4	0	0	0	22	12.1	2.83
6	1.0	13	6	0	0	0	29	11.3	2.55
12	0	0	0	0	0	0	22	12.4	1.85
15	0	0	0	0	0	0	26	11.9	1.60
Atlantic Twin - August 6-17, 1976									
9	2.6	19	3	+	15	1	17	10.4	4.01
10	+	2	2	+	7	1	21	10.3	4.80
11	8.6	37	2	0	0	0	30	8.4	1.80
12	13.2	47	4	+	2	1	57	6.8	2.55
13	3.6	20	4	0	0	0	37	7.4	3.00
14	0.7	8	4	0	0	0	37	7.5	1.50
15	1.5	13	2	0	0	0	44	7.6	1.70
17	0.2	2	2	+	2	1	34	7.7	1.60
18	+	1	1	+	1	1	33	8.3	1.50
19	0	0	0	+	8	1	28	8.1	1.50
20	0.3	2	2	1.6	104	1	27	9.5	2.30
21	0.1	1	1	1.3	93	1	23	10.4	2.70
22	0.3	2	1	0	0	0	12	12.8	2.30
23	0	0	0	+	4	2	17	11.1	0.00
24	+	1	1	+	1	1	28	10.8	0.00
25	0	0	0	0	0	0	25	11.1	0.00
28	5.9	39	7	0	0	0	14	18.3	4.91
29	7.0	12	4	0	0	0	18	17.4	4.80
30	1.1	5	2	+	7	1	23	15.0	4.16
31	0.1	2	1	+	13	1	26	13.0	0.87
32	0	0	0	0	0	0	34	11.8	0.39
33	0	0	0	0	0	0	33	10.6	0.00
34	0	0	0	0	0	0	34	10.3	0.00
35	15.6	199	8	0	0	0	35	10.2	1.01
36	1.6	9	6	0	0	0	37	9.7	1.17
37	5.5	33	7	0.5	11	2	40	8.9	1.80

TABLE 2. (continued)

Station	Demersal Species			Nondemersal Species			Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
	Weight (kg)	Number of Individuals	Number of Species	Weight (kg)	Number of Individuals	Number of Species			
Atlantic Twin - August 6-17, 1976 (continued)									
40	2.5	15	4	+	1	1	50	7.9	1.26
41	2.0	16	2	0	0	0	43	8.2	0.80
42	4.4	31	7	0	0	0	34	9.4	0.85
43	151.7	119	9	41.0	1353	1	36	11.8	1.90
44	67.0	68	7	0.2	13	1	43	11.0	1.40
45	0.7	2	2	0	0	0	38	11.9	1.03
46	0	0	0	0	0	0	29	13.2	0.51
47	0.4	2	1	+	2	1	27	15.6	1.11
48	7.3	18	4	0	0	0	23	17.2	2.10
49	10.5	16	11	0	0	0	20	18.1	2.58
50	3.6	11	6	+	24	2	17	18.4	4.22
51	36.7	96	9	1.4	27	4	10	18.6	3.20
52	39.7	174	13	9.0	3005	3	14	20.2	5.61
53	84.3	84	11	0.6	358	6	15	20.3	6.04
54	13.8	19	5	0.3	137	2	16	18.5	6.34
55	26.4	267	6	2.0	109	1	16	18.9	6.09
56	9.2	14	4	1.5	177	2	16	17.6	6.51
57	34.5	137	11	0	0	0	20	17.7	5.72
59	15.7	114	12	+	1	1	43	10.8	5.01
61	8.4	75	10	0	0	0	44	9.9	4.65
63	5.6	34	6	0	0	0	47	8.6	2.10
85	0	0	0	0	0	0	35	10.2	0.00
86	0	0	0	0	0	0	32	9.2	0.00
89	15.7	41	6	4.3	1728	3	15	17.3	2.91
90	0	0	0	0	0	0	20	16.3	0.40
91	0	0	0	0	0	0	25	13.4	0.01
92	5.2	47	7	+	1	1	26	11.6	0.87
95	6.0	51	5	0	0	0	37	9.1	0.65
96	+	1	1	+	1	1	34	8.5	1.23

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Albatross IV - September 28-October 17, 1976									
40	10.3	50	8	6.4	306	3	22	15.8	7.00
43	0.4	41	2	6.5	493	2	26	13.1	6.69
44	2.9	503	3	5.3	1159	2	20	14.2	6.49
45	19.8	3109	7	3.1	27	2	39	11.7	1.43
46	36.6	245	12	18.4	5850	3	15	17.9	6.79
47	27.0	324	10	0.4	279	2	18	17.9	7.15
48	19.6	206	11	1.5	325	3	15	17.3	6.95
49	28.7	407	16	2.6	597	3	19	17.6	6.75
50	27.7	150	7	7.3	397	2	22	17.7	6.75
51	17.6	115	8	1.5	2476	4	21	17.0	6.16
52*	11.4	6	3	3.8	94	2	35	12.0	1.53
53	9.8	6	4	0.1	72	1	40	11.4	1.69
54	3.7	13	6	9.4	94	1	48	10.7	4.19
68	1.6	5	3	6.5	119	1	86	10.0	
69	1.2	8	3	1.5	33	1	62	9.0	3.01
70	5.0	37	3	0.0	0	0	62	9.0	4.62
71	26.0	755	9	0.1	1	1	53	10.8	2.78
72	5.0	226	7	4.8	1	1	42	10.9	1.84
73	1.6	145	7	+	2	1	33	11.0	2.36
74	4.4	265	7	+	9	1	46	11.4	2.53
75	30.9	48	6	11.8	1081	2	27	17.5	6.41
76	12.3	4	3	4.9	108	3	31	17.1	5.79
77	13.4	19	6	140.8	9983	6	13	17.2	6.94
78	15.1	12	3	0.4	98	2	22	17.7	6.92
79	32.4	212	6	26.9	4306	7	10	16.6	6.86
80	11.2	10	3	3.2	563	5	26	18.0	6.81
81	24.1	189	14	0.8	156	3	13	16.6	6.89
82	22.5	144	15	0.6	140	4	15	17.3	6.63
83	66.8	32	5	3.2	8	2	29	17.0	7.00
84	0.4	129	5	0.0	0	0	40	12.6	1.18
85	33.8	118	8	7.0	43	2	35	17.0	5.49
86	+	1	1	+	2	1	51	11.0	1.50
87	0.3	2	2	0.2	3	1	73	9.0	5.28
88	6.1	33	4	8.0	204	1	79	9.3	5.45

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Albatross IV - September 28-October 17, 1976 (continued)									
93	10.0	180	8	0.1	4	1	60	8.4	2.84
94	1.2	98	7	0.0	0	0	51	9.7	2.92
95	0.1	28	3	0.0	0	0	46	11.3	1.51
96	14.0	12	4	7.4	5	3	27	18.8	6.91
97	19.7	45	8	352.7	136114	9	11	17.0	6.31
98	634.5	226	3	4.5	13	2	12	18.1	6.91
99	0.0	0	0	0.0	0	0	42	14.0	0.89
171	37.4	66	9	61.7	9200	5	15	17.3	7.21
172	153.2	274	9	44.7	5571	4	9	16.5	7.95
173	10.4	19	3	19.5	12920	4	13	16.6	7.58
174	5.8	3	2	10.2	1048	2	15	17.6	7.60
175	966.3	337	5	6.1	68	3	15	17.6	7.65
176	185.1	92	8	3.0	44	3	13	17.6	7.54
177	196.2	552	18	1.2	444	2	15	16.5	7.62
178	71.7	636	15	0.7	354	2	15	16.1	7.90
179	13.8	1368	7	0.4	3	1	22	14.1	1.89

* = 46 minute tow.

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Delaware II - December 5-21, 1976									
3	98.0	863	10	0	0	0	21	9.3	8.63
4	341.6	1112	14	0	0	0	24	8.6	
5	30.2	117	10	0	0	0	25	8.0	6.20
6	42.9	104	13	+	4	3	20	6.0	
7	4.4	14	7	+	2	1	20	6.7	
8	75.8	41	6	1.3	23	1	22	7.3	9.31
9	331.7	842	11	2.1	51	1	38	12.5	5.51
18	273.0	134	10	3.9	29	1	44	9.5	8.79
52	9.2	28	5	1.2	58	4	16	5.1	
53	6.6	28	6	0.4	51	2	15	5.0	9.98

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Delaware II</u> - December 5-21, 1976 (continued)									
54	132.0	179	9	0	0	0	22	7.2	
55	282.3	514	9	0	0	0	28	7.5	9.39
56	77.9	63	9	0	0	0	37	7.8	
57	158.6	96	7	0.3	1	1	24	6.6	9.38
58	8.9	49	6	5.2	25	3	15	5.6	
59	10.0	73	6	3.7	156	5	13	5.7	
60	125.0	66	5	0.4	19	1	24	7.4	9.42
61	188.3	1834	6	3.7	14	3	18	7.6	
62	15.7	329	8	3.7	46	7	11	5.5	
63	34.4	744	10	0.2	8	4	14	5.6	9.86
64	110.5	235	14	0.5	3	1	20	6.5	
65	268.6	281	14	1.2	8	1	42	10.8	8.25
66	226.2	286	12	0	0	0	57	11.2	
67	162.6	163	11	0.2	1	1	53	10.1	
68	124.8	135	7	0.7	4	1	34	10.0	9.06
69	197.5	127	7	0.4	2	1	45	9.0	
70	330.6	108	6	0.5	3	2	37	8.6	8.71
71	200.9	97	6	0	0	0	35	9.2	
74	157.8	111	11	0	0	0	28	8.8	8.91
75	85.0	261	14	+	1	1	13	7.4	
76	41.7	171	9	+	4	4	14	5.6	
77	13.0	174	8	+	22	2	8	5.0	
78	8.7	452	11	1.0	184	4	10	5.2	
79	18.4	255	9	1.6	93	7	14	6.2	10.02
80	71.9	146	7	+	1	1	20	7.2	
81	83.1	72	7	0.5	1	1	26	8.6	8.80
82	207.4	4308	8	0	0	0	19	7.1	
83	98.0	2019	13	0.4	40	4	16	7.1	9.35
97	136.4	78	8	2.7	18	1	39	9.5	
98	192.6	323	13	5.6	48	1	57	11.6	7.70
100	104.9	263	13	0	0	0	72	11.9	
101	222.5	160	9	0	0	0	78	12.1	5.79
105	505.5	498	9	0	0	0	68	12.0	6.09
106	96.4	185	9	1.2	8	1	73	12.0	6.00
114	300.2	369	14	0	0	0	52	9.7	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Dolphin - August 23-27, 1971									
6	60.3	253	14	2.3	44	1	11	20.7	
7	10.0	91	5	+	1	1	11	21.6	
8	211.4	1999	8	+	1	1	14	20.1	
9	5.0	18	4	+	35	1	24	11.8	
10	4.1	33	7	0	0	0	24	9.2	
11	7.7	87	9	0	0	0	42	6.5	
12	4.1	45	10	0	0	0	53	5.6	
20	11.6	104	6	0	0	0	47	5.2	
21	13.6	143	10	0	0	0	34	7.3	
22	9.4	78	8	0	0	0	31	7.6	
23	6.9	99	6	0	0	0	20	9.8	
24	20.1	69	7	0	0	0	17	11.3	
25	13.3	253	5	0	0	0	13	14.4	
26	46.6	264	8	0	0	0	9	19.2	
27	15.6	101	6	0.1	50	1	13	12.0	
28	16.2	27	7	0.1	16	2	22	8.6	
29	4.0	16	4	0.5	56	2	28	8.1	
30	4.4	19	7	0	0	0	33	7.2	
31	6.3	65	8	0	0	0	38	5.7	
32	20.0	73	8	0	0	0	47	5.5	
33	18.7	117	9	0	0	0	45	5.5	
34	32.8	57	5	0.2	72	1	21	13.0	
Albatross IV - July 29-August 2, 1973									
1	10.9	32	4	+	6	1	20	13.1	
2	3.2	9	3	4.1	31	2	24	13.0	
3	7.7	25	3	0	0	0	26		
4	15.9	68	7	0	0	0	26	12.8	
5	14.5	66	8	0	0	0	24	11.6	
6	16.8	78	10	+	2	1	20	12.4	
18	10.0	48	7	0	0	0	24	10.6	
19	5.0	10	6	+	97	1	29	9.0	
20	33.6	88	8	+	1	1	33	11.0	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Number of Individuals	Number of Species	Nondemersal Species Weight (kg)	Number of Individuals	Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Albatross IV - July 29-August 2, 1973 (continued)									
21	6.4	18	4	+	1	1	22	11.5	
22	2.7	6	4	1.8	72	2	27	10.2	
23	10.4	29	6	2.7	93	3	27	9.9	
24	9.5	9	3	+	4	2	18	10.6	
25	37.2	32	5	+	1	1	24	10.9	
26	10.0	26	4	+	7	2	22	13.0	
27	10.4	26	6	+	2	1	24	10.4	
28	8.6	25	4	+	11	1	24	11.4	
29	15.4	96	9	+	1	1	33	9.8	
30	68.9	230	14	+	1	1	22	10.0	
31	36.7	114	9	0	0	0	16	10.7	
32	12.2	54	7	0.5	15	1	15	11.0	
33	6.4	38	9	+	6	1	22	10.2	
34	24.0	50	7	1.4	29	1	22	11.7	
35	11.8	29	6	0.5	32	1	24		
36	1.8	5	2	0.5	38	1	27	11.2	
37	+	1	1	+	82	1	27	11.2	
38	0	0	0	+	6	1	18	11.7	
39	23.1	122	8	+	42	2	14	14.3	
40	5.4	15	4	+	14	1	18	12.5	
42	14.1	25	6	0.9	75	3	18	12.5	
44	26.8	80	10	+	1	1	55	8.0	
45	22.7	137	10	0	0	0	51	11.5	
46	47.1	179	8	0	0	0	27	10.2	
47	39.9	205	9	0	0	0	26	12.7	
Delaware II - July 24-29, 1974									
4	72.6	171	9	3.6	238	1	18	13.5	
5	24.9	180	8	1.8	182	1	15	9.8	
6	43.1	121	8	9.5	434	1	22	13.8	
7	42.2	87	7	3.6	38	2	24	13.5	
8	97.1	218	11	+	7	2	16	15.1	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Delaware</u> <u>II</u> - July 24-29, 1974 (continued)									
9	70.3	171	14	0	0	0	18	15.9	
10	125.2	513	9	+	1	1	27	14.1	
13	4.5	5	3	1.4	106	1	20	15.1	
46	135.2	1044	15	0	0	0	60	7.3	
48	15.9	113	12	0	0	0	46	8.3	
49	120.7	510	11	1.4	35	1	51	9.0	
50	5.4	17	2	0.9	54	1	27	12.9	
52	3.2	14	4	1.8	783	2	15	16.2	
53	24.9	1027	3	2.3	184	1	22	13.5	
54	36.3	154	10	3.2	1028	2	15	15.7	
55	59.4	328	11	26.8	1123	1	42	10.7	
57	6.8	41	7	0.5	7	2	33	14.1	
58	9.5	40	7	+	1	1	27	14.1	
59	169.6	979	13	0	0	0	26	14.8	
60	156.9	920	9	0	0	0	27	14.5	
61	60.3	308	11	+	3	2	22	14.9	
62	13.2	30	6	6.4	981	2	24	14.5	
63	13.2	60	6	5.4	106	1	33	13.9	
64	26.3	103	9	7.3	1041	4	20	16.5	
<u>Delaware</u> <u>II</u> - August 16-21, 1974									
2	61.7	80	7	24.5	393	3	11	22.0	
4	21.8	49	8	14.1	1820	4	20	19.1	
5	31.8	147	10	0	0	0	27	17.1	
6	37.2	239	12	+	5	2	24	17.1	
9	35.4	187	12	0	0	0	24	17.2	
11	21.3	74	8	+	4	1	40	10.9	
27	7.7	22	7	+	4	1	49	8.5	
29	69.4	277	13	2.7	25	1	49	8.5	
30	27.7	587	11	2.7	68	1	45	10.7	
31	33.1	126	11	5.4	111	2	67	8.4	

TABLE 2. (continued)

	Demersal Species			Nondemersal Species					
Station	Weight (kg)	Number of Individuals	Number of Species	Weight (kg)	Number of Individuals	Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Delaware II - August 16-21, 1974 (continued)									
48	39.0	380	14	0.9	10	1	66	8.1	
50	6.8	65	10	+	6	2	25	14.0	
51	1.8	10	1	5.0	254	2	17	16.2	
52	0.5	3	2	0.5	22	1	18	17.0	
53	0.9	4	4	+	79	2	21	14.4	
55	6.4	22	6	0.5	31	2	33	13.3	
56	+	1	1	1.4	106	2	17	16.3	
57	11.3	53	6	63.5	2600	1	33	13.1	
58	63.5	599	9	47.2	1398	1	49	9.2	
59	7.7	31	5	60.8	1554	2	42	10.8	
61	17.7	115	8	2.7	80	1	38	12.5	
62	9.1	104	9	1.4	279	1	26	15.4	
63	11.8	222	10	+	56	1	27	15.9	
64	8.6	99	6	+	13	1	28	15.3	
66	5.4	34	4	+	3	1	25	15.3	
Delaware II - September 23-29, 1974									
4	124.7	222	9	6.4	699	4	12	16.5	
5	70.8	171	14	22.7	3280	5	11	16.4	
6	52.2	278	13	20.4	446	4	12	16.7	
7	147.9	226	15	+	2	1	18	12.9	
8	49.0	110	11	+	2	1	26	14.6	
9	66.2	190	15	+	6	2	25		
10	145.6	65	11	+	7	2	26	19.4	
11	57.6	129	14	+	6	2	25	16.9	
12	298.0	158	13	+	7	2	25	18.9	
13	57.2	308	14	+	5	2	25	18.4	
14	112.5	84	10	+	4	3	20	19.5	
15	22.7	147	11	35.8	14234	4	16	17.1	
16	65.8	222	15	27.7	2572	5	16	17.5	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Delaware II - July 24-29, 1974 (continued)									
50	61.7	225	13	+	2	1	46	14.5	
51	203.2	2175	15	25.4	1094	2	66	11.0	
52	46.3	183	9	+	3	2	49	10.4	
54	20.4	69	8	+	5	1	38	10.3	
55	558.8	19935	9	0	0	0	39	10.3	
57	142.9	114	13	14.1	313	4	13	19.1	
58	93.9	162	10	+	9	2	19		
60	98.0	386	13	+	18	1	18		
61	93.9	162	10	+	9	2	19		
62	112.9	273	15	+	2	1	33		
Delaware II - September 8-18, 1975									
4	78.5	185	10	266.3	51880	4	17	16.9	
6	155.6	247	13	0.9	264	1	26	17.1	
7	172.4	190	12	+	20	1	26	16.1	
8	151.1	158	10	+	28	2	25	17.1	
9	47.2	109	10	0.9	197	2	21	16.2	
10	43.1	170	15	1.8	714	6	18	18.3	
11	114.3	210	15	0.9	455	4	20	18.0	
12	81.6	88	11	3.2	1164	3	19	18.5	
13	44.5	2062	10	62.1	8806	5	17	19.6	
14	14.5	34	5	7.7	1043	5	27	19.8	
79	3.6	18	6	0	0	0	33	9.8	
80	8.2	49	11	0.5	48	1	43	9.7	
83	28.2	265	9	+	3	1	35		
84	23.1	208	8	6.4	107	2	28	11.4	
86	47.6	221	13	+	2	1	30	18.3	
88	28.6	286	11	0	0	0	37	10.9	
89	62.1	96	12	45.4	3051	3	21	16.0	
90	169.6	131	8	16.3	1584	1	31	15.0	
91	290.3	904	12	4.5	346	1	61	8.7	
92	23.6	91	14	+	39	1	20	16.3	
93	21.8	64	6	+	32	3	20	18.9	
94	106.0	266	18	10.0	30	5	19	17.3	
95	171.0	349	15	0.9	9	5	13	18.1	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Delaware II - September 8-18, 1975 (continued)									
96	124.7	297	17	+	472	4	17	18.6	
97	22.2	39	6	+	14	1	27	13.3	
98	7.7	17	3	+	37	1	22	12.9	
99	37.2	132	8	+	7	1	31	11.1	
100	5.9	32	7	+	2	2	37	9.0	
101	1.4	17	4	+	1	1	41	8.5	
102	1.4	24	5	+	1	1	60	8.2	
103	5.0	99	7	+	1	1	65	7.6	
106	28.6	997	8	+	69	1	81	7.7	
126	165.6	377	14	4.1	65	3	20	19.4	
127	32.7	32	4	0.5	29	1	15	19.0	
Delaware II - October 15-November 7, 1975									
6	37.6	1186	13	+	1	1	37	16.5	
10	62.1	194	5	+	14	1	38	13.0	
60	137.4	680	13	+	1	1	59	10.7	
61	85.3	478	13	0	0	0	46	11.7	
62	271.3	437	11	+	2	1	69	10.2	
63	209.6	284	13	1.8	6	2	46	12.0	
64	47.6	64	6	15.0	3	1	33	16.0	
65	337.0	190	9	4.5	7	4	19	16.5	
66	207.3	113	6	1.8	137	2	24	16.3	
67	20.4	54	7	17.7	1018	4	17	16.2	
68	516.7	348	7	10.9	171	4	22	16.7	
69	1.4	5	3	0.5	337	2	15	16.4	
70	24.9	61	9	5.9	830	4	13	16.3	
71	32.2	46	9	63.1	3582	3	23	16.2	
72	7.3	38	6	2.3	169	3	14	16.0	
73	119.8	152	13	+	4	1	27	15.6	
74	153.3	551	9	6.8	44	4	24	16.1	
75	101.2	137	9	+	14	2	24	16.2	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
Delaware II - October 15-November 7, 1975 (continued)									
76	62.1	104	9	0.9	8	3	26	16.2	
77	130.2	261	8	+	3	1	24	16.1	
78	147.9	184	10	1.4	3	2	35	15.0	
79	9.5	17	4	0	0	0	42	15.4	
80	29.5	153	8	3.6	1	1	42	14.6	
81	18.1	178	10	0	0	0	36	15.9	
82	24.9	179	9	+	2	1	63	10.6	
83	3.6	75	7	+	1	1	72	11.6	
84	17.2	117	10	0.5	7	1	76	10.8	
93	59.9	509	14	0	0	0	48	13.4	
94	81.2	304	10	2.7	3	3	37	16.2	
172	62.6	140	11	23.1	9739	6	21	15.9	
173	10.4	5	1	56.2	68	4	17	16.0	
174	6.4	6	3	5.9	7	3	12	16.2	
175	11.3	8	6	27.2	6964	5	11	16.0	
176	20.0	140	13	4.5	19	5	14	16.0	
177	63.5	332	12	9.1	6	2	15	16.0	
178	8.2	89	11	0.5	166	2	16	15.7	
179	24.5	117	13	9.5	4145	3	13	15.5	
180	31.8	132	7	3.6	5154	3	11	15.2	
181	87.7	246	18	12.7	278	3	17	15.5	
182	477.2	335	6	+	10	2	17	15.4	
183	192.8	286	12	2.3	1	1	22	15.5	
184	558.4	192	4	15.0	137	5	18	15.6	
185	12.7	24	6	20.9	2495	5	12	15.3	
186	5.4	24	7	18.1	2065	5	9	15.3	
187	24.9	11	3	48.5	1476	5	12	15.1	
188	426.4	169	2	+	5	1	22	15.4	
189	756.6	277	8	8.2	257	3	16	15.1	
190	567.5	263	7	6.4	119	2	25	14.6	

TABLE 2. (continued)

Station	Demersal Species Weight (kg)	Demersal Species Number of Individuals	Demersal Species Number of Species	Nondemersal Species Weight (kg)	Nondemersal Species Number of Individuals	Nondemersal Species Number of Species	Depth (m)	Bottom Temp.(°C)	Bottom DO(mg/ℓ)
Delaware II - December 1-18, 1975									
1	63.5	2394	12	20.4	281	6	12	11.3	
2	107.0	2335	12	0.9	12	2	25	12.6	
3	502.1	1681	13	0	0	0	26	11.6	
4	175.1	1613	18	+	9	2	22	13.5	
5	120.7	5143	18	+	1	1	25	11.6	
6	59.4	1896	18	1.4	339	3	19	11.6	
61	108.9	532	14	+	5	1	57	13.0	
62	385.1	803	18	+	7	1	35	12.0	
63	141.1	572	14	0	0	0	38	11.9	
64	114.3	352	14	0.9	11	1	50	13.5	
65	109.3	306	15	0.9	7	1	55	13.4	
66	243.1	108	8	2.7	135	1	31	13.4	
67	137.0	640	7	1.4	56	2	32	11.4	
68	119.3	183	15	0	0	0	33	11.4	
69	121.6	354	12	3.2	1	1	35	11.4	
70	128.4	232	14	+	3	1	62	13.9	
71	226.8	682	13	6.3	7	2	59	14.1	
72	260.8	547	15	0.5	3	1	55	12.7	
73	138.8	237	13	0.9	9	1	41	12.5	
74	200.5	213	11	+	4	1	50	12.2	
75	544.8	340	13	15.4	149	2	39	12.2	
76	51.7	44	7	5.4	200	1	22	11.0	
77	38.1	229	9	3.6	156	1	16	10.0	
78	96.6	440	9	5.0	209	2	17	10.4	
79	342.5	113	9	10.4	438	1	25	10.5	
80	74.8	1100	14	+	17	4	17	9.8	
81	156.9	853	10	+	19	2	21	9.9	
82	95.7	787	10	0	0	0	24	10.7	
83	95.7	1046	16	+	66	7	17	10.0	
84	83.0	2310	12	2.7	3797	1	15	9.9	
85	180.1	737	16	+	29	3	24	10.2	
86	106.1	194	17	+	1	1	30	11.2	
87	167.4	583	15	+	1	1	20	10.2	
88	119.3	434	15	0.9	288	1	15	9.8	
89	73.9	508	14	0.9	536	2	14	9.1	
90	3097.2	1048	8	23.6	19	2	18	10.4	

TABLE 2. (continued)

	Demersal Species			Nondemersal Species					
Station	Weight (kg)	Number of Individuals	Number of Species	Weight (kg)	Number of Individuals	Number of Species	Depth (m)	Bottom Temp. (°C)	Bottom DO (mg/ℓ)
<u>Delaware II</u> - December 1-18, 1975 (continued)									
91	83.5	87	8	+	14	2	15	8.9	
92	199.6	118	13	0.5	2	1	21	9.5	
93	153.8	111	10	1.4	23	1	27	11.0	
94	184.2	408	10	5.4	198	1	46	11.7	
178	34.5	787	17	+	206	3	11	8.7	
179	196.4	253	14	0	0	0	21	9.8	
180	328.0	677	13	0	0	0	23	9.6	
181	301.2	370	12	0	0	0	24	10.0	

TABLE 3. A phylogenetic listing of finfish species captured during recent (post-July 1, 1976) and selected historic (pre-July 1, 1976) resource assessment cruises, conducted by NEFC, in the area from Sandy Hook, New Jersey to Cape Henlopen, Delaware and from the coastline to approximately 73° West Longitude. Asterisks (*) indicate those species considered to be nondemersal.

SPECIES COMMON NAME	SCIENTIFIC NAME	Rorqual July 8, 1976	Xiphias July 9, 1976	Grand Larson July 13+15, 1976	Rorqual July 20-22, 1976	Xiphias July 28-30, 1976	Atlantic Twin Aug. 6-17, 1976	Albatross IV Sept. 28-Oct. 17 1976	Delaware II Dec. 5-21, 1976	Dolphin Aug. 23-27, 1971	Albatross IV July 29-Aug. 2, 1973	Delaware II July 24-29, 1974	Delaware II Aug. 16-21, 1974	Delaware II Sept. 23-29, 1974	Delaware II Sept. 8-18, 1975	Delaware II Oct. 15-Nov. 7, 1975	Delaware II Dec. 1-18, 1975
*White shark	*Caracharodon carcharias*												X				
Sandbar shark	*Carcharhinus milberti*										X				X		
Smooth dogfish	*Mustelus canis*			X			X	X		X	X	X	X	X	X	X	
Spiny dogfish	*Squalus acanthias*								X	X						X	X
Atlantic angel shark	*Squatina californica*							X									
shark											X						
Clearnose skate	*Raja eglanteria*					X	X	X		X		X	X	X	X	X	
Little skate	*Raja erinacea*		X		X		X	X	X	X	X	X	X	X	X	X	X
Rosette skate	*Raja garmani*														X		
Winter skate	*Raja ocellata*								X					X		X	X
Roughtail stingray	*Dasyatis centroura*						X			X	X		X				
Bluntnose stingray	*Dasyatis sayi*						X			X					X		
Spiny butterfly ray	*Gymnura altavela*							X							X		
Bullnose ray	*Myliobatis freminvillei*									X					X		
stingray	Dasyatidae sp.										X						
American eel	*Anguilla rostrata*																X
conger eel	Congridae sp.							X	X		X			X	X		X
snake eel	Callechelys sp.												X	X	X		
eel												X					
*Blueback herring	*Alosa aestivalis*							X	X		X					X	X
*Alewife	*Alosa pseudoharengus*								X								X
*Hickory shad	*Alosa mediocris*										X						
*American shad	*Alosa sapidissima*								X								X
*Atlantic menhaden	*Brevoortia tyrannus*							X	X							X	X
*Atlantic herring	*Clupea harengus harengus*								X								
Round herring	*Etrumeus teres*							X		X	X	X	X	X	X	X	
Striped anchovy	*Anchoa hepsetus*							X			X					X	X
Bay anchovy	*Anchoa mitchilli*						X	X	X					X	X	X	X
Silver anchovy	*Engraulis eurystole*							X									
anchovy	Engraulidae sp.												X	X			X
Inshore lizardfish	*Synodus foetens*							X						X		X	
Snakefish	*Trachinocephalus myops*													X			X
Oyster toadfish	*Opsanus tau*																X
clingfish	Gobiesocidae sp.									X							
Goosefish	*Lophius americanus*							X	X	X	X	X	X	X	X	X	X
Atlantic batfish	*Dibranchus atlanticus*																X
Fourbeard rockling	*Enchelyopus cimbrius*										X		X	X	X		
Atlantic cod	*Gadus morhua*								X							X	X
Haddock	*Melanogrammus aeglefinus*										X				X		
Offshore hake	*Merluccius albidus*												X				
Silver hake	*Merluccius bilinearis*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Red hake	*Urophycis chuss*	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Spotted hake	*Urophycis regius*	X	X			X	X	X	X	X	X	X	X	X	X	X	X
White hake	*Urophycis tenuis*												X		X		X
Fawn cusk-eel	*Lepophidium cervinum*								X				X			X	
Blotched cusk-eel	*Ophidion grayi*														X	X	X
Striped cusk-eel	*Rissola marginata*						X	X	X				X	X	X		X
cusk-eel	Ophidiidae sp.										X	X					X
Ocean pout	*Macrozoarces americanus*	X									X		X	X	X		
*Atlantic silverside	*Menidia menidia*								X								X
*Bluespotted cornetfish	*Fistularia tabacaria*												X			X	
Lined seahorse	*Hippocampus erectus*						X							X			X
Northern pipefish	*Syngnathus fuscus*												X		X		X
pipefish	Syngnathidae sp.													X			
Striped bass	*Morone saxatilis*															X	X
Black sea bass	*Centropristis striata*	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
*Bigeye	*Priacanthus arenatus*														X	X	
*Short bigeye	*Pristigenys alta*														X		
*Bluefish	*Pomatomus saltatrix*						X	X			X		X	X	X	X	X
*Mackerel scad	*Decapterus macarellus*													X			
*Round scad	*Decapterus punctatus*						X						X	X	X	X	
*Blue runner	*Caranx crysos*							X				X					
*Bigeye scad	*Selar crumenophthalmus*											X					
*Banded rudderfish	*Seriola zonata*												X				
*Rough scad	*Trachurus lathami*							X						X			

TABLE 3. (continued)

SPECIES		Rorqual July 8, 1976	Xiphias July 9, 1976	Grand Larson July 13+15, 1976	Rorqual July 20-22, 1976	Xiphias July 28-30, 1976	Atlantic Twin Aug. 6-17, 1976	Albatross IV Sept. 28-Oct. 17, 1976	Delaware II Dec. 5-21, 1976	Dolphin Aug. 23-27, 1971	Albatross IV July 29-Aug. 2, 1973	Delaware II July 24-29, 1974	Delaware II Aug. 16-21, 1974	Delaware II Sept. 23-29, 1974	Delaware II Sept. 8-18, 1975	Delaware II Oct. 15-Nov. 7, 1975	Delaware II Dec. 1-18, 1975
COMMON NAME	SCIENTIFIC NAME																
*Lookdown	*Selene vomer*													X	X		
*Atlantic moonfish	*Vomer setapinnis*							X						X		X	
*jack	Carangidae sp.												X				
snapper	Lutjanidae sp.													X			
porgy	Sparidae sp.												X				
Scup	*Stenotomus chrysops*			X			X		X		X	X	X	X	X	X	X
Silver perch	*Bairdiella chrysura*																X
Weakfish	*Cynoscion regalis*						X	X	X			X		X	X	X	X
Spot	*Leiostomus xanthurus*						X	X	X					X	X		
Northern kingfish	*Menticirrhus saxatilis*							X						X	X	X	X
Atlantic croaker	*Micropogon undulatus*							X	X					X	X	X	X
Red goatfish	*Mullus auratus*											X	X				
butterflyfish	Chaetodontidae sp.														X		
Tautog	*Tautoga onitis*			X				X	X		X				X	X	X
Cunner	*Tautogolabrus adspersus*	X	X			X					X	X	X		X		X
*Guaguanche	*Sphyraena guachancho*						X										
*barracuda	Sphyraenidae sp.													X	X		
Southern stargazer	*Astroscopus y-graecum*															X	
Rock gunnel	*Pholis gunnellus*											X	X				
Wrymouth	*Cryptacanthodes maculatus*														X		
American sand lance	*Ammodytes americanus*						X	X	X		X	X	X	X	X	X	X
*Atlantic cutlassfish	*Trichiurus lepturus*															X	
*Atlantic mackerel	*Scomber scombrus*								X		X				X		
*Butterfish	*Peprilus triacanthus*			X			X	X	X	X	X	X	X	X	X	X	X
Black bellied rosefish	*Helicolenus dactylopterus*																X
Northern searobin	*Prionotus carolinus*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Striped searobin	*Prionotus evolans*	X					X	X	X	X	X	X	X	X	X	X	X
Sea raven	*Hemitripterus americanus*								X	X	X		X				
Longhorn sculpin	*Myoxocephalus octodecemspinosus*								X	X	X		X				X
Striped seasnail	*Liparis liparis*															X	X
Gulf Stream flounder	*Citharichthys arctifrons*						X	X	X	X			X		X	X	X
Smallmouth flounder	*Etropus microstomus*	X	X						X		X	X	X	X	X	X	X
Summer flounder	*Paralichthys dentatus*						X	X	X	X	X	X	X	X	X	X	X
Fourspot flounder	*Paralichthys oblongus*	X					X	X	X	X	X	X	X	X	X	X	X
Windowpane	*Scophthalmus aquosus*	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Witch flounder	*Glyptocephalus cynoglossus*								X		X			X			X
Yellowtail flounder	*Limanda ferruginea*							X	X	X	X		X		X		X
Winter flounder	*Pseudopleuronectes americanus*	X	X				X	X	X	X	X		X	X	X	X	X
Hogchoker	*Trinectes maculatus*									X						X	X
tonguefish	Cynoglossidae sp.								X								
*Scrawled filefish	*Aluterus scriptus*														X		
*Orange filefish	*Aluterus schoepfi*															X	
*Planehead filefish	*Monacanthus hispidus*											X	X	X	X	X	X
Northern puffer	*Sphoeroides maculatus*							X				X	X	X	X	X	X
puffer	Tetraodontidae sp.							X									
Striped burrfish	*Chilomycterus schoepfi*							X									

Table 4. Summary of all dead finfish observed on recent resource assessment cruises.

Vessel	Date	Station Number	Species	Number	Wt. (kg.)
Rorqual	7/ 8/76	2	Ocean pout (*Macrozoarces americanus*)	12	4.6
Grand Larson	7/13/76	2	Fawn cusk-eel (*Lepophidium cervinum*)	1	< 0.1
	7/15/76	5	Little skate (*Raja erinacea*)	1	0.2
Rorqual	7/20/76	2	Lined seahorse (*Hippocampus erectus*)	1	< 0.1
Atlantic Twin	8/ 8/76	21	Silver hake (*Merluccius bilinearis*)	1	0.1

Table 5. Species reported in mortality observations (from Steimle, 1976).

Species		Reports			
		NEFC Survey	Sport Dives	Commercial Fishermen	Beach
Smooth dogfish	*Mustelus canis*				X
Little skate	*Raja erinacea*	X			
Silver hake	*Merluccius bilinearis*	X	X	X	
Red hake	*Urophycis chuss*	X	X	X	
Fawn cusk-eel	*Lepophidium cervinum*	X			
Striped cusk-eel	*Rissola marginata*				X
Ocean pout	*Macrozoarces americanus*	X	X	X	
Lined seahorse	*Hippocampus erectus*	X			
Black sea bass	*Centropristis striata*			X	
Bluefish	*Pomatomus saltatrix*			X	
Spot	*Leiostomus xanthurus*				X
Tautog	*Tautoga onitis*			X	X
Cunner	*Tautogolabrus adspersus*		X	X	
Northern stargazer	*Astroscopus guttatus*				X
Searobin	*Prionotus* sp.				X
Summer flounder	*Paralichthys dentatus*			X	X

Table 5. (continued)

Species		Reports			
		NEFC Survey	Sport Dives	Commercial Fishermen	Beach
Windowpane	*Scophthalmus aquosus*				X
Winter flounder	*Pseudopleuronectes americanus*	X		X	

Table 6. Avoidance of the anoxic water mass and subsequent repopulation of an area as demonstrated by trawl catches from the *Atlantic Twin* cruise (August 6-17, 1976) taken at three stations; before the passage of hurricane "Belle" (August 9, 1976), just after passage, and approximately one week later. Included are location, species taken, date, depth, bottom temperature (°C), and bottom dissolved oxygen (mg/l). A value of 0.00 mg/l indicates a level below the detection limits of the method employed.

Location		39°30'N 74°08'W			39°30'N 74°01'W			39°30'N 73°55'W		
Station Number		23	29	90	24	30	91	25	31	92
Depth (m)		17	18	20	28	23	25	25	26	26
Bottom Temp. (°C)		11.1	17.4	16.3	10.8	15.0	13.4	11.1	17.4	11.6
Bottom D.O. (mg/l)		0.00	4.80	0.40	0.00	4.16	0.01	0.00	4.80	0.87
		August			August			August		
Date		9	10	16	9	11	16	9	11	16
Smooth dogfish	*Mustelus canis*		X							
Striped anchovy	*Anchoa hepsetus*	X								
Silver hake	*Merluccius bilinearis*									X
Spotted hake	*Urophycis chuss*								X	X
Lined seahorse	*Hippocampus erectus*				X					
Black sea bass	*Centropristis striata*									X
Scup	*Stenotomus chrysops*									X
Weakfish	*Cynoscion regalis*		X							
American sand lance	*Ammodytes americanus*				X					
Butterfish	*Peprilus triacanthus*	X				X			X	X
Northern searobin	*Prionotus carolinus*		X			X				X
Summer flounder	*Paralichthys dentatus*		X							
Windowpane	*Scophthalmus aquosus*					X				X
Gulf stream flounder	*Citharichthys arctifrons*									X
Loligo sp.		X							X	

APPENDIX IV

THE EFFECTS OF ANOXIC WATER CONDITIONS ON THE LOBSTER FISHERY OF NEW JERSEY

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Introduction

In early July 1976, the Division of Fish, Game and Shell Fisheries began getting reports of dead fish and lobsters off our northern coast from fishermen, lobstermen and scuba divers. As our investigations into this matter intensified, we found very low dissolved oxygen levels near the bottom along with high occurrence levels of the dinoflagellate *Ceratium tripos* in the area of reported kills. During several interviews with charter dive boat captains, we were told that the yellow-brown layer (caused by the presence of large numbers of *Ceratium tripos*) that existed at and below the thermocline had been observed occasionally as much as a month earlier (early to mid-June). The spread and severity of the anoxic condition mentioned above is well documented in other sections of this report. The intent of this section is to show any correlation of the anoxic condition with the decrease in the lobster landings this year.

During the four year period from 1971 through 1974, the lobster industry in New Jersey remained fairly stable with commercial landings of 1.28, 1.30, 1.37 and 1.19 million pounds respectively. In 1975 the landings dropped to 850 thousand pounds. During the first four months of 1976, there were signs of a comeback as the landings were 22% greater than over the same time period in 1975. In May, the 1976 landings were down about 3% from May 1975 landings. The months of June, July, August and September, normally the most productive months of the year, showed decreases in the commercial landings of 27.5%, 40.8%, 29.7% and 16.3% respectively as compared to the 1975 landings for the same time period. At the end of September the 1976 commercial catch was down 17.8% from the first nine months of 1975 (See Table 1).

The inshore pot fishery, from zero to twelve miles offshore, was hit the hardest. The inshore landings for Ocean County decreased from over 115 thousand pounds in the first nine months of 1975 to less than 26 thousand pounds for the same time period in 1976. That represents a decrease of better than 75% for a nine month period, when the 1976 catch was actually up 23% after the first six months. The majority of the Ocean County landings are from the ports of Belmar, Point Pleasant and Barnegat Light. The catch per effort data in Table 2 was collected aboard the vessels of several inshore pot fishermen from the Belmar - Point Pleasant area over the past two years. These data show that the catch per unit of effort had decreased at about the same rate as the landings during the months of July, August and September, 1976.

Much of the inshore pot fishing grounds for the Monmouth County ports of Belford and Atlantic Highlands are to the west and north of the area hardest hit by the anoxic conditions and the nine month catch showed an increase of about 42% over the same time period in 1975. Personal communication with lobster fishermen from this area, however, indicated that the consensus of opinion was that the bad water condition had adversely affected the lobster fishing in that area. It was the contention of the local lobstermen that there were fewer offshore immigrants after the anoxic water conditions had been established. Offshore lobsters make up a fair proportion of the inshore catch and can often be distinguished by the lobstermen by the lighter and redder color and generally larger size of the offshore visitors. A closer look at the catch data on Tables 6 and 7 supports this contention to a great extent. The 1976 landings through June showed an increase of about 124 percent over the 1975 landings for the same time period. However, the 1976 landings from July through September showed a decrease of 15 percent as compared to the 1975 landings for the same period. A drop in landings from over double the year before for the first six months of the year to only 85 percent for the next three months is very significant, especially since it coincides so well with the appearance of the anoxic conditions off our coast.

Lobster landings by otter trawl were also off in the Ocean County area, but cannot be attributed solely to the oxygen depleted waters. For one, the otter trawl catch was down prior to the reported fish kills and secondly, most lobster trawlers are capable of fishing far enough offshore to avoid the bad water areas.

The offshore pot catch landed in Ocean County was up for the months of August and September. This is due primarily to an increase in effort in the offshore area caused by inshore fishermen moving offshore if they had the vessels and equipment that would enable them to do so.

The lobster landings in the southern end of the State (Cape May County) did not seem to be affected, and were up slightly this year over last. Since the southernmost end of the State did not come under the effects of the anoxic water conditions that existed farther north, this area acted as a sort of control for the rest of the State. With this in mind, it seems evident that the decreased landings to the north can be attributed to the change in water conditions rather than natural fluctuation.

TABLE 1

STATE-WIDE LOBSTER CATCH BY MONTH

	1974		1975		1976	
	Month	Cumulative	Month	Cumulative	Month	Cumulative
January	44,947	44,947	27,216	27,216	14,093	14,093
February	26,395	71,342	6,337	33,553	5,613	19,706
March	22,106	93,448	4,762	38,315	8,336	28,042
April	27,677	121,125	38,896	77,211	65,898	93,940
May	106,226	227,351	105,067	182,278	101,456	195,396
June	162,753	390,104	107,993	290,271	78,300	273,696
July	236,230	626,334	108,266	398,537	64,065	337,761
August	192,795	819,129	99,162	497,699	69,673	407,434
September	124,226	943,355	121,722	619,421	101,866	509,300

TABLE 2

CATCH PER EFFORT FOR INSHORE POT FISHERY

from Shark River & Point Pleasant area

1975	of Pots	# of Lobsters	Length of sets in days	% Legal	Pot Days	Lobsters/ Pot	Lobsters/ Pot set over day	Legal Lobsters/ Pot	Legal Lobsters/Pot set over day
April	150	264	2.00	46.0	300	1.76	0.88	0.81	0.40
May	411	897	3.00	30.5	1,233	2.18	0.73	0.66	0.22
June	855	1,118	3.07	46.0	2,627	1.31	0.43	0.60	0.20
July	638	809	3.43	41.0	2,186	1.27	0.37	0.52	0.15
Aug	596	1,493	3.52	39.9	2,095	2.50	0.71	1.00	0.28
Sept	255	657	5.31	42.2	1,353	2.58	0.49	1.09	0.21
Oct	735	1,209	4.00	36.6	2,942	1.64	0.41	0.60	0.15
Nov	313	128	4.00	60.2	1,252	0.41	0.10	0.25	0.06
1976									
April	148	189	7.00	44.0	1,029	1.28	0.18	0.56	0.08
May	186	316	3.00	30.7	558	1.70	0.57	0.52	0.18
June	567	1,009	4.00	34.8	2,268	1.78	0.44	0.62	0.15
July	89	24	10.00	50.0	890	0.27	0.03	0.12	0.015
Aug	126	90	9.00	43.3	1,134	0.71	0.08	0.31	0.03
Sept	229	192	8.02	47.4	1,837	0.84	0.10	0.40	0.05

TABLE 3 1972 Lobster Catch By Gear, Month and County

	Monmouth			Ocean			Atlantic			Cape May			
Month	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Total
Jan				30,360			1,069			59			31,488
Feb				26,626			1,223			387			28,236
Mar				25,264			6,137			1,735			33,136
Apr		3,208		21,373	770		14,484		499	422			40,756
May		16,736		28,749	1,026	2,808	6,796		1,699	4,915	2,130		64,859
June		15,351		60,307	3,592	6,840	11,049		10,394	7,001	1,327	4,920	120,781
July		66,975		40,221	21,595	8,626	9,201	1,580	29,183	25,370	596	53,056	256,403
Aug		100,172		32,018	37,602	21,888	1,762	701	34,435	1,071	820	21,810	252,279
Sept		75,628		26,668	7,557	42,179	695		19,669	72	538	14,544	187,550
Oct			53,903	24,580		55,465	1,509		18,472		375	13,000	167,304
Nov			14,400	15,850		21,637			23,611	150	976	6,010	82,634
Dec				24,644		1,465	4,236		9,717	812	14	1,821	42,709
Totals		278,070	68,303	356,660	72,142	160,908	58,161	2,281	147,679	41,994	6,776	115,161	1,308,135

TABLE 4 1973 Lobster Catch by Gear, Month and County

Month	Monmouth			Ocean			Atlantic			Cape May			Total
	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	
Jan				489		25,615	167		5,730	599			32,600
Feb				17,747			650		10,415	128			28,940
Mar				17,425			1,040		6,700	102			25,267
Apr		5,229		21,492	723		256		9,264	470		667	38,101
May		21,955		45,230	5,483		4,387	100	5,450	3,452	1,111	2,511	89,679
June		16,360		84,082	5,472	6,962	598	344	12,291	6,317	746	11,358	144,530
July		67,856		38,098	32,978	8,886			25,925	3,392	2,191	17,349	196,675
Aug		116,899		35,417	43,822	21,958			29,383		1,295	17,670	266,444
Sept		45,812		20,233	39,099	20,573			54,228	32	902	16,223	197,102
Oct		33,667		40,397	38,090	14,844		350	30,869	35	4,368	8,151	170,771
Nov		9,728		44,682	25,156	12,043		412	19,051	628	349	1,545	113,594
Dec		1,777	807	40,537	6,546	7,621		185	3,900	393			61,766
Totals		319,283	807	405,829	197,369	118,502	7,098	1,391	213,206	15,548	10,962	75,474	1,365,469

TABLE 5

1974 Lobster Catch By Gear, Month and County

Month	Monmouth Otter Trawl	Monmouth Inshore Pots	Monmouth Offshore Pots	Ocean Otter Trawl	Ocean Inshore Pots	Ocean Offshore Pots	Atlantic Otter Trawl	Atlantic Inshore Pots	Atlantic Offshore Pots	Cape May Otter Trawl	Cape May Inshore Pots	Cape May Offshore Pots	Total
Jan		167			457	3,819			4,900	35,604			44,947
Feb	69	304		23,677	68				2,250	27			26,395
Mar		607		20,521	903		75						22,106
Apr	393	3,495		19,884	2,220								25,992
May	320	5,883		72,022	5,300		10,116		4,400	155	87	7,943	106,226
June		28,825		75,705	13,681		9,414	1,287	6,900		730	26,211	162,753
July		62,193		43,655	48,000	5,502	13,744	188	25,497		1,587	35,864	236,230
Aug		45,503		35,216	59,636	5,748	2,100	226	12,137		526	31,703	192,795
Sept		8,602		40,775	25,853	8,611	5,635	784	8,922	840	660	23,561	124,243
Oct		10,781		67,926	22,883	3,719	4,730	111	4,977	54	1,636	17,078	133,895
Nov		3,973		26,763	14,230	2,480	1,782	35	140	34	326	6,200	55,963
Dec				38,905	16,286	2,136				94		663	58,084
Total	782	170,333		465,049	209,517	32,015	47,596	2,631	70,123	36,808	5,552	149,223	1,189,629

TABLE 6

1975 Lobster Catch by Gear, Month and County

Month	Monmouth Otter Trawl	Monmouth Inshore Pots	Monmouth Offshore Pots	Ocean Otter Trawl	Ocean Inshore Pots	Ocean Offshore Pots	Atlantic Otter Trawl	Atlantic Inshore Pots	Atlantic Offshore Pots	Cape May Otter Trawl	Cape May Inshore Pots	Cape May Offshore Pots	Total
Jan		445		17,907	781	8,083							27,216
Feb		2,710		1,282	90	2,255							6,337
Mar		1,749		2,381	132	500							4,762
Apr		638		25,373	1,056	5,153				210		6,466	38,896
May		10,220		75,840	3,238		1,890		139	594		13,146	105,067
June		22,111		50,486	6,858		903	72	422	97	287	26,757	107,993
July		20,535		28,829	17,494	4,346		130	1,423	941	701	33,867	108,266
Aug		17,080		11,174	37,197	1,655	2,488	78	2,368	815	388	25,919	99,162
Sept		16,040		24,270	48,493	3,997		190	1,200	1,982	1,065	24,485	121,722
Oct		6,980		38,062	33,340	12,598	139		2,341	1,625	573	16,682	112,340
Nov		5,465		22,395	12,982	18,521			679	322	170	13,944	74,478
Dec				9,692		27,264				670		2,679	40,305
Totals		103,973		307,691	161,661	84,372	5,420	470	8,572	7,256	3,184	163,945	846,544

TABLE 7

1976 Lobster Catch By Gear, Month and County

	Monmouth			Ocean			Atlantic			Cape May			
Month	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Otter Trawl	Inshore Pots	Offshore Pots	Total
Jan				1,404	863	11,648						178	14,093
Feb		529		1,523		2,073				335			4,460
Mar		4,002		3,265	33					688		348	8,336
Apr		25,630		31,566	2,107		134			587		5,874	65,898
May		27,503		56,708	3,976					320		12,949	101,456
June		27,240		24,272	7,943		3,600		2,600			12,645	78,300
July		20,242		9,160	6,146		700			357		28,460	65,065
Aug		15,706		2,182	3,374	5,306			2,250	558		40,367	69,743
Sep		9,425		9,004	1,389	44,062			1,200	929		35,857	101,866
Oct													
Nov													
Dec													
Totals													

TABLE 8

Catch per Effort Data for each Full Year
Trawl (>12 mi.)

Year	Fishermen	Boats (Gear)	Catch	Per Man	Per Boat (Gear)
1976					
1975	55	18	320,367	5,825	17,798
1974	72	22	550,235	7,642	25,011
1973	73	22	428,475	5,870	19,476
1972	96	27	456,815	4,758	16,919

Inshore Pot (0 - 12 mi.)

Year	Fishermen	Boats	Gear	Catch	Per Man	Per Boat	Per Pot
1976							
1975	109	55	24,950	269,288	2,471	4,896	10.8
1974	93	48	21,950	388,033	4,172	8,084	17.7
1973	107	55	26,400	529,005	4,944	9,618	20.0
1972	80	44	19,290	359,269	4,491	8,165	18.6

Offshore Pot (>12 mi.)

Year	Fishermen	Boats	Gear (Pots)	Catch	Per Man	Per Boat	Per Pot
1976							
1975	32	14	7,900	256,889	8,028	18,349	32.5
1974	22	9	5,850	251,361	11,425	27,929	43.0
1973	52	21	11,915	407,989	7,846	19,428	34.2
1972	55	25	13,950	492,051	8,946	19,682	35.3

TABLE 9

Catch per Effort Data for First 9 Months of Each Year

Trawl (12 mi.)

Year	No. Fishermen	Gear	Catch	Per Man	Per Boat (Gear)
1976	55	18	147,292	2,678	8,183
1975	55	18	247,462	4,499	13,748
1974	72	22	409,927	5,693	18,633
1973	73	22	301,803	4,134	13,718
1972	96	27	385,034	4,011	14,261

Inshore Pot (0 - 12 mi.)

Year	No. Fishermen	Boats	Gear (Pots)	Catch	Per Man	Per Boat	Per Pot
1976	109	55	24,950	156,108	1,432	2,838	6.26
1975	109	55	24,950	209,778	1,925	3,814	8.41
1974	93	48	21,950	317,772	3,417	6,620	14.48
1973	107	55	26,400	408,374	3,817	7,425	15.47
1972	80	44	19,290	357,904	4,474	8,134	18.55

Offshore Pot (12 mi.)

Year	No. Fishermen	Boats	Gear (Pots)	Catch	Per Man	Per Boat	Per Pot
1976	32	14	7,900	205,817	6,432	14,701	26.05
1975	32	14	7,900	162,181	5,068	11,584	20.53
1974	22	9	5,850	213,968	9,726	23,774	36.58
1973	52	21	11,915	309,158	5,945	14,722	25.95
1972	55	25	13,950	272,550	4,955	10,902	19.54

APPENDIX V

THE EFFECTS OF ANOXIC WATER ON THE BLUEFISH, (POMATOMUS SALTATRIX), AN ACTIVELY SWIMMING FISH

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INTRODUCTION

A mass mortality of marine organisms by, suffocation in the ocean off New Jersey, occurred during the summer of 1976 as the dissolved oxygen in the water became depleted. Without question, the hypoxia has seriously affected the populations of several groups of marine organisms, especially sedentary ones, such as clams, mussels, and barnacles. Even highly mobile organisms were killed, such as the squirrel hake (*Urophycis chuss*), white hake (*Urophycis tenuis*), ocean pout (*Macrozoarces americanus*), and conger eel (*Conger oceanicus*).

While it is possible to measure with some precision the extent of mortalities for some of the sedentary organisms, it is difficult to measure with any precision the extent of damage to highly mobile organisms, especially the fishes. Sublethal effects can also occur. Among the observed effects of the anoxic water on fishes were behavioral changes involving vertical distribution and migratory routes which in turn may affect feeding and spawning habits.

IMPORTANCE OF BLUEFISH AND GENERAL NATURAL HISTORY

The bluefish (*Pomatomus saltatrix*) is among the most important species of fish occurring along the Atlantic coast of the United States. Commercial fishermen annually catch some four to six million pounds, and recreational fishermen catch nearly 120 million pounds (U. S. Dept. of Interior, 1967; Deuel, 1973). Indeed, along the middle Atlantic coast, the bluefish has been the single most important species (total weight) to recreational fishermen for the past decade (Clark, 1962; Deuel, 1968 and 1973).

The bluefish is a migratory species. It usually travels in schools of like-sized fish of its own kind with the schools being loosely associated in much larger aggregations which may extend over several square miles. The schools travel seasonally, in the northern hemisphere, northward in the spring and summer and southward in the fall and winter. The schools composed of the largest fish move fastest and travel farthest and they tend to congregate in the northernmost part of their range during the summer months (Freeman, Cox, and O'Hanlon, Ms.). The movements of the bluefish are correlated to a considerable degree, though imperfectly, with water temperature.

Judging from more than a thousand returned tags, bluefish weighing from one to three pounds migrate between the Middle Atlantic Bight (the area from Cape Cod, Massachusetts to Cape Hatteras, North Carolina) and southeastern Florida (Deuel, Ms.). Many of the one to three pound fish which summer in the Bight migrate southward and occur in Florida's east coast fishery during the winter. During the spring, these fish, together with much larger size bluefish that have apparently wintered offshore or perhaps south of Florida, return to north of Cape Hatteras. Tagging returns from adult bluefish indicate that they often return to the same general area year after year in the Middle Atlantic Bight but with a slight northerly shift in area as the fish grow older and larger (Lund and Maltezos, 1970; Deuel, Ms.; Freeman, unpub. data).

Field and tagging studies, fishing surveys and fishermen reports from over the last dozen years or so have provided us with information to construct, for the first time, the migratory pathways of the bluefish within the Middle Atlantic Bight (Figures 1 and 2). The pathways off New Jersey are of particular interest and will be dealt with here since the unusual occurrence of anoxic water during the summer of 1976 was situated along much of this state's coast.

Normal migration of bluefish

It is usually during late April or early May that the first large schools of bluefish occur offshore of New Jersey (Freeman et al., Ms.). They first appear in the southern part of the state from 6 to 10 or 15 miles offshore. The schools are usually swimming along rapidly in a northerly direction in the upper half of the water column and consist mostly of fish weighing 3 to 10 pounds and measuring 18 to 28 inches long. At about the same time, other schools of slightly larger fish, most weighing 6 to 15 pounds and measuring 23 to 32 inches, occur 50 to 70 miles offshore. These fish, too, are swimming in a northerly direction high up in the water column, often within 60 feet of the surface. Somewhat later, usually during the end of May or beginning of June, schools of bluefish weighing 1 to 3 pounds and measuring 13 to 18 inches arrive along New Jersey's southern coast and continue to swim progressively northward. Throughout the remainder of May, June and most of July, schools of various size fish continue to arrive in New Jersey's waters from a southerly direction. They arrive in waves, the fish in each wave spending varying amounts of time before resuming their journey northward. The arriving and departing times of the waves and the amount of overlap from one to the next determine the relative abundance of bluefish at any given time and in any given area. However, the greatest concentration of passing schools in the 3 to 10 pound range occurs during the early part of July. Bluefish occurring off New Jersey after about the middle of July seem to reside there the remainder of the summer months. Although there is local movement, it appears to be governed by the availability of suitable food, which is mostly forage fishes.

The southward migration of bluefish usually begins during late August and continues into November, or in some years, into December. The routes during the fall migration differ from those of the spring only in that those groups using the mid-shelf tend to take a course about a half dozen miles closer to the coast while those far out over the edge of the shelf seem to travel farther offshore, between the 400 and 600 foot contours (Figures 1 and 2).

Location of bluefish within the water column

While the bluefish is able to swim at any level within the water column from the surface to depths of at least 400 feet, the depth that it tends to frequent most often appears to be influenced greatly by water temperature. During their stay within the Middle Atlantic Bight adult fish occur in water of 47° to 79°F, but mostly in 54° to 68°F (Freeman, unpub. data). The preferred temperature varies with the size of fish and with the particular season. During the early spring migration the adults seem to occur mostly within 60 feet of the surface, i.e., in the warmest stratum. Early in June, however, they take more and more to the bottom until by late in the month they are often, if not always, found close to the bottom, frequently in water cooler than at the surface. It is not uncommon during July and August to find bluefish along the bottom in temperatures of 54°F when the water above the thermocline is 68°F or more (Freeman, unpub. data). This seems to hold true through the fall, though they often make forays to the surface to feed and they can easily be attracted to the surface by fishing lures or chum. The last bluefish disappearing in late fall and early winter are usually swimming along the bottom, where the water is warmest.

OCCURRENCE AND DISTRIBUTION OF BLUEFISH OFF NEW JERSEY DURING THE 1976 SEASON

On June 8, 1976, fishery biologists from Sandy Hook Laboratory and several students from Brookdale Community College traveled with

Capt. David Bramhall on his boat "Mimi V" sailing out of Brielle to the Tolten Lump, a fishing ground 18 miles southeast of Manasquan Inlet (Figure 3). There in a period of about four hours they caught and tagged 139 bluefish ranging in weight from 4 to 12 pounds and measuring $19^1/2$ to 29 inches. The bluefish recorded on the vessel's SONAR were located mostly within 20 feet of the sea floor. The water depth was 84 feet; the temperature at the surface was 64°F, and at the bottom 54°F. A week or so before this tagging, a large mass of bluefish ranging in weight from about 5 to 15 pounds, had been 6 to 12 miles offshore, first off Five Fathom Bank, then off Atlantic City Ridge, and then still later, off Barnegat Ridge (Figure 3). The sequence of anglers' catches indicates that the normal migration of bluefish northward was proceeding as would be expected.

On 25 June, about two weeks after tagging, the first of these tagged fish was recaptured off Cape Henlopen, Delaware, more than 85 miles south of where it had been released (Figure 4). On 29 June, just a few days later, a second bluefish was recaptured off Avalon, New Jersey, 60 miles south of where it had been released. During August, on the 20th and 22nd, the third and fourth bluefish were recaptured 2 miles and 45 miles south of where they had been released on the Tolten Lump. The recapture of these specimens in time and space is contrary to what might be expected of northward migrating fish.

As a continuing program of the American Littoral Society, a number of bluefish were tagged by several of its members along the New Jersey coast during the summer season of both 1975 and 1976. Two specimens, weighing about 3 pounds each were recaptured off New York City during the 1976 season (Figure 4). Both of them had been tagged off Manasquan Inlet, one on June 16, 1975, the other on August 1, 1976. These small bluefish occurring close to the ocean shore were recaptured north of the tagging site. The recapture of these specimens in time and space is what might be expected of northward migrating fish.

Catch data regarding various species of fishes occurring along the New Jersey coast during 1975 and 1976 are known for charter-boat and party-boat anglers (see Freeman, Turner and Christensen, 1976). In certain areas where bluefish had been abundant off New Jersey in previous years, they were notably absent in 1976. Those areas coincided for the great part with the anoxic water.

DISCUSSION AND CONCLUSIONS

Tagging returns, fishing reports and catch rates of recreational fishermen indicate that the great majority of bluefish weighing between 3 and 12 pounds, i.e., the middle-shelf contingent, may have been blocked from migrating northward past New Jersey during the summer of 1976. This blockage was presumably caused by the anoxic water (Figure 5). Thus, bluefish that would have normally spent the summer months feeding and spawning along a stretch of the coast from northern New Jersey to southern New England and feeding along northern New England were prevented from doing so. Upon encountering the anoxic water these migrants apparently reversed their direction and headed southward. During most of July, August and September they milled about off the coast of southern New Jersey and northern Delmarva

(Delaware, Maryland and Virginia). Fishermen in the coastal states from New York to Maine reported catching few fish of this size (Weston Eayrs, III, S. Portland, Maine and Nicholas Karas, St. James, New York, pers. comm.).

A study of New Jersey charter boat anglers' catch records in 1976 show that from early May to about mid-June the bluefish were more or less evenly distributed along the entire coast of New Jersey (Figures 6a and b). But starting in the last week of June, the catches fell off in the northern part of the state where the anoxic water first appeared and they tended to be greater along the central and southern parts of the coast where normal conditions still prevailed (Figure 6d). This and the fact that the first return from June 8 tagging was off Cape Henlopen on June 25 indicate that the bluefish may have detected and avoided the anoxic water at least a week before the earliest reported fish mortality. During early and mid-July, the bluefish were caught almost entirely outside of the anoxic water (Figure 7a). The catches made over the anoxic water, especially in the Barnegat Ridge area, were from schools concentrated above the thermocline (Capts. Theodore Weeks, Jr. and Donald Myers, Barnegat Light, New Jersey, pers. comm.) or in small isolated areas where the bluefish apparently found tolerable levels of dissolved oxygen (Capt. John Larson, Jr., Barnegat Light, New Jersey, pers. comm.). This could explain the occurrence of large quantities of surf clams (*Spisula solidissima*) in the stomachs of bluefish caught off Barnegat Light during the first week or so in August as reported by various captains. Throughout the remainder of the summer, the general condition prevailed where most of the bluefish were caught outside of the anoxic water or along its edge (Figures 7 and 8). As stated previously, the catches made within areas having anoxic water were often from specimens occurring high in the water column that apparently had not fed for some time. And as would be expected under these conditions, the catch rates were often very high. No bluefish were caught in the area having a hazardous hydrogen sulfide concentration (Figure 8b).

The inshore contingent of bluefish, i.e., those weighing between 1 and 3 pounds and migrating close along the ocean shore, seemed not to have been affected. Throughout most of the summer the anoxic water remained at least several miles away from shore; thus, the usual pathway for these fish remained open almost all the time. This is supported by small-sized fish that had been tagged off New Jersey and were captured off New York City. And it is also supported by fishing reports of normal catches of this size fish from along the south shore and eastern end of Long Island and along the shores of Rhode Island and southern New England (Nicholas Karas, pers. comm.).

The offshore contingent of bluefish seemingly were not affected by the anoxic water and proceeded on their northward migration uninhibited. The usual pathway for these 6 to 15 pound fish was apparently seaward of the farthest extent of the anoxic water.

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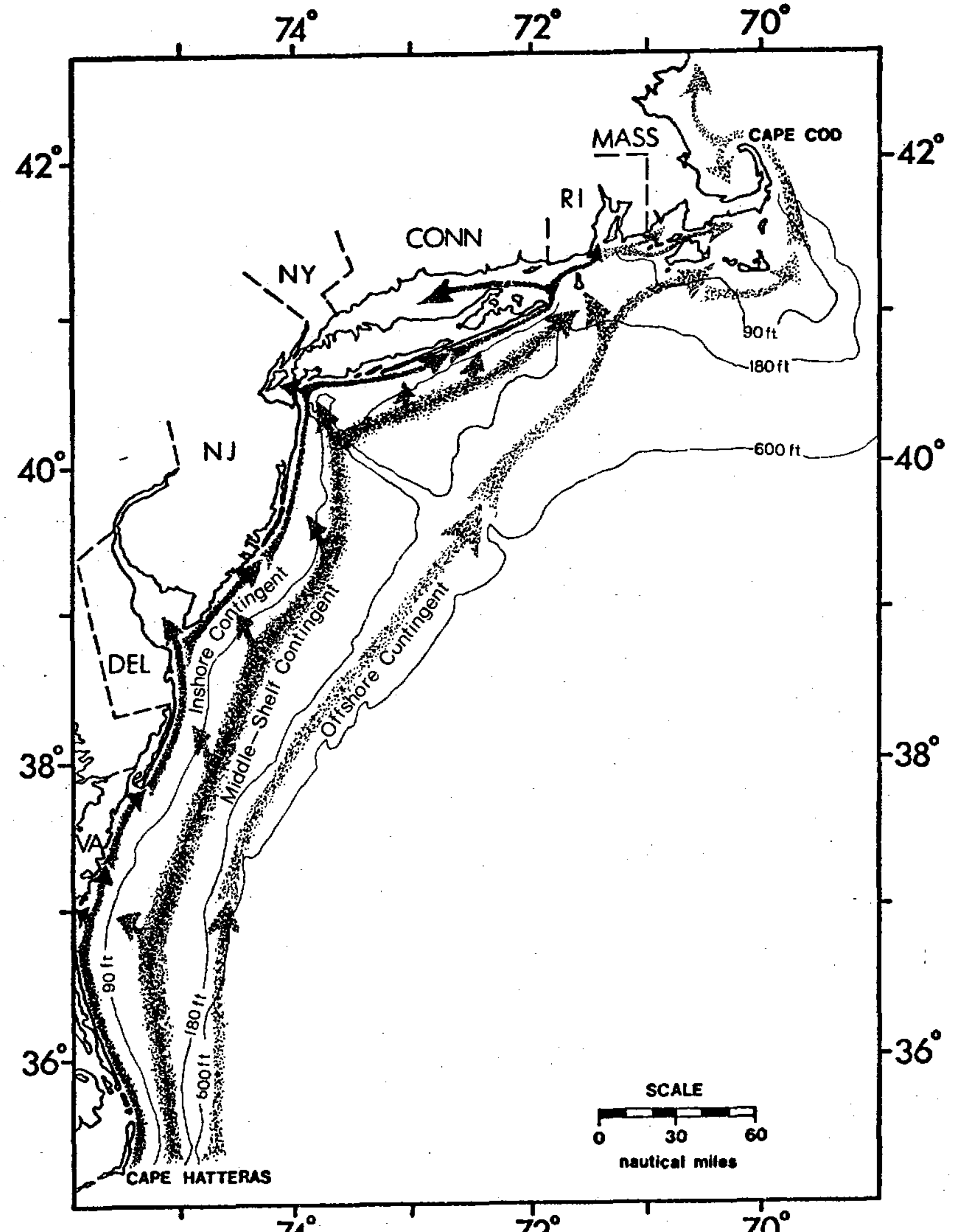

Figure 1. The migratory routes for bluefish during spring and early summer.

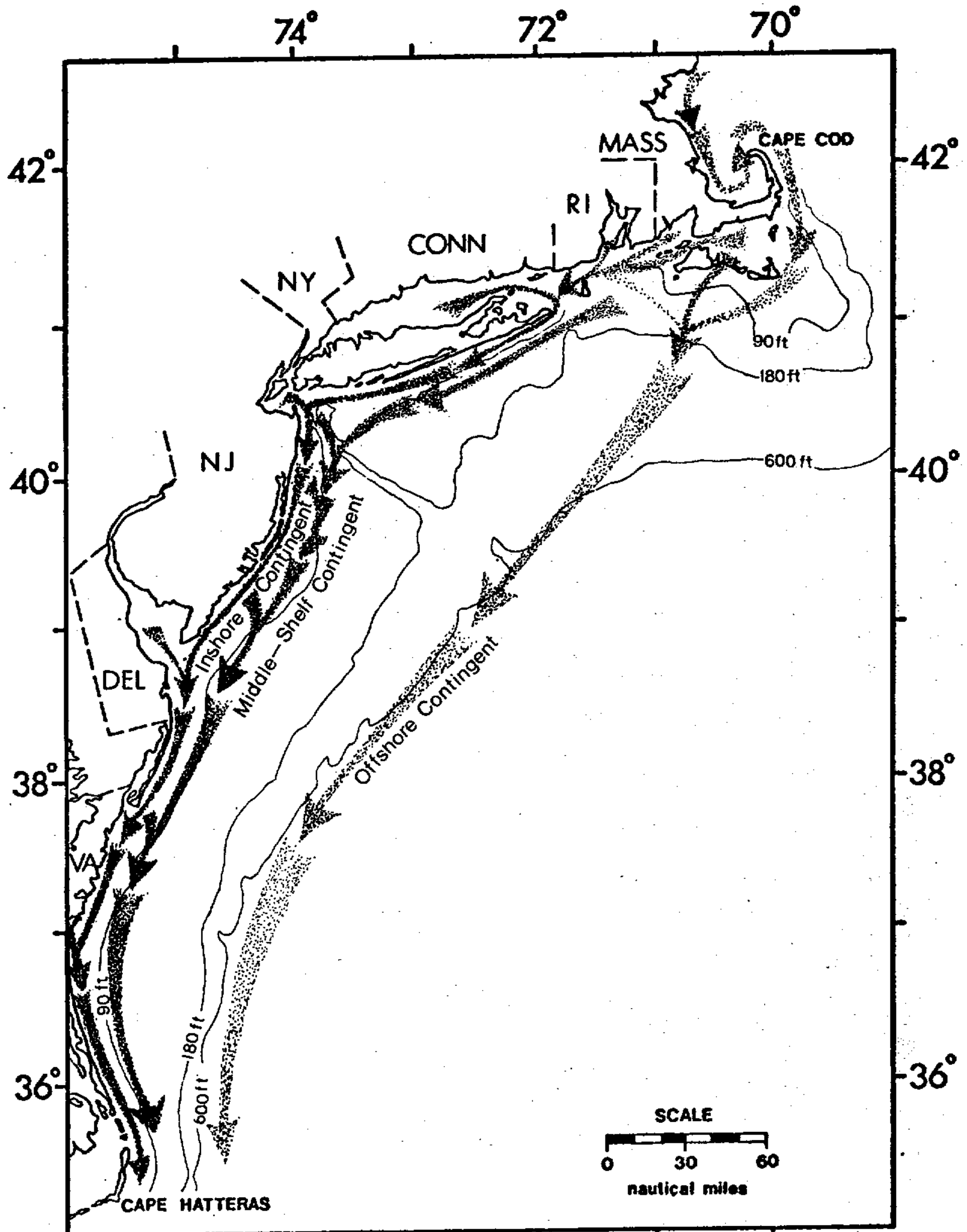

Figure 2. The migratory routes for bluefish during late summer and fall.

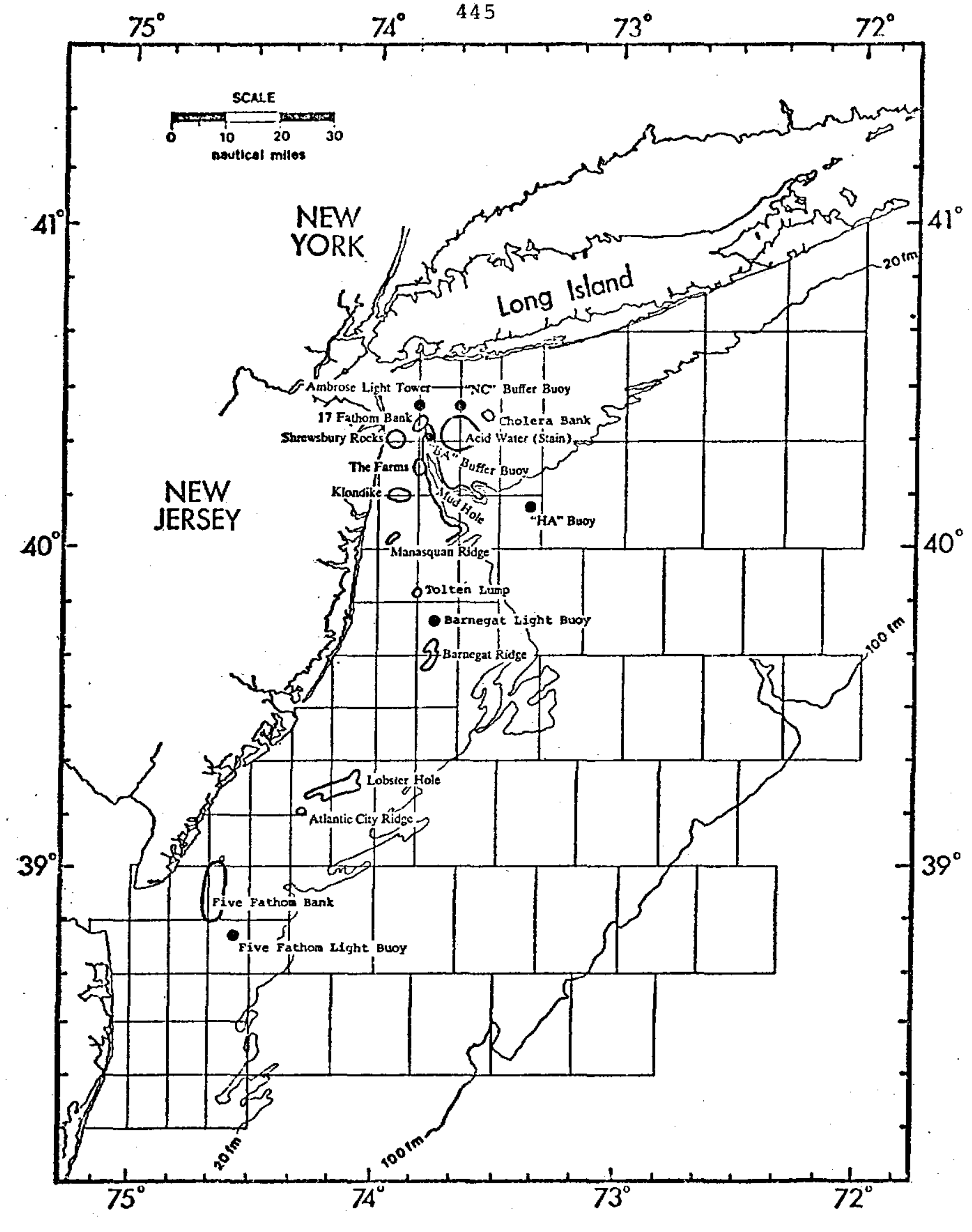

Figure 3. Map showing the principal fishing grounds for bluefish along the New Jersey coast.

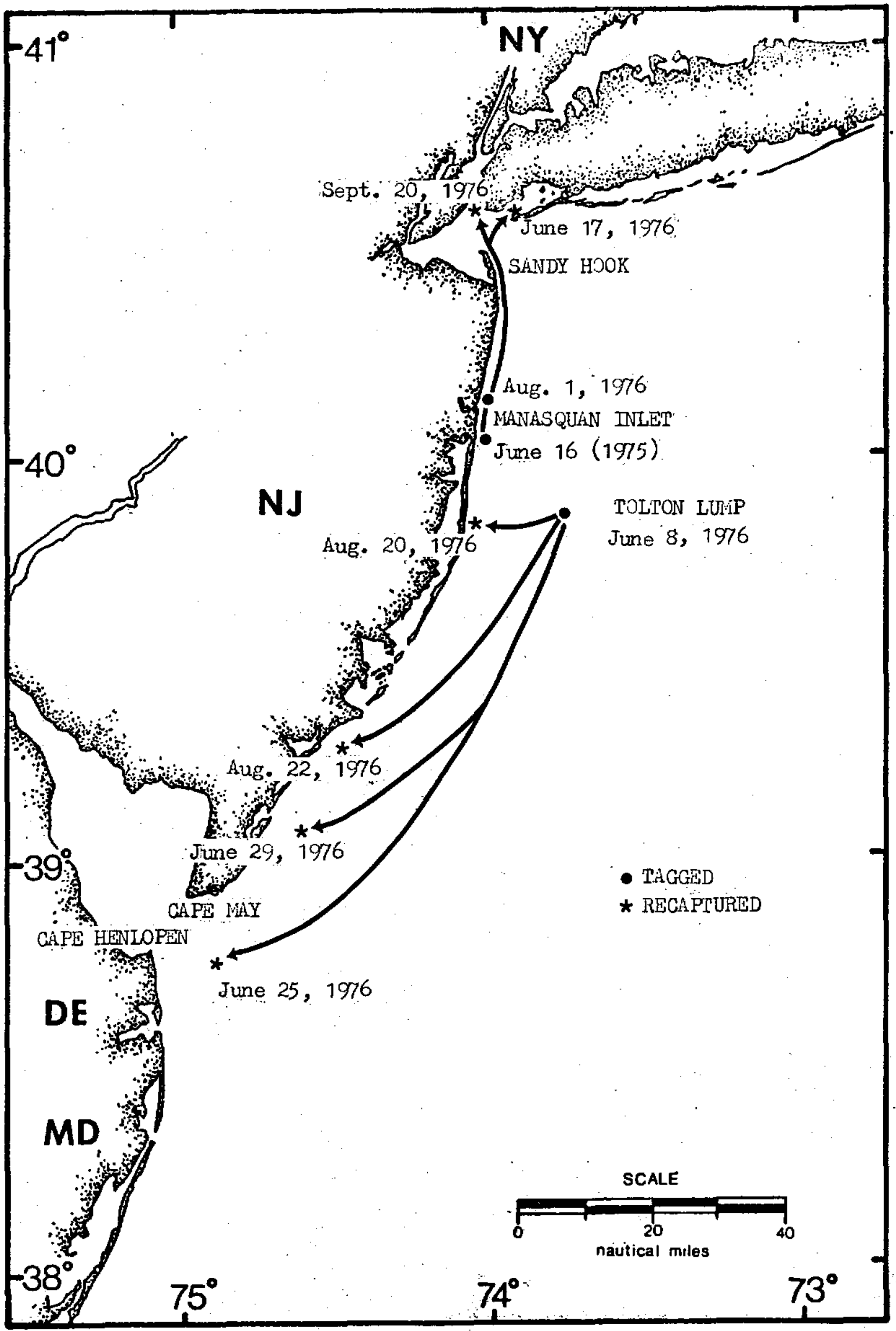

Figure 4. Tagging and recapture of bluefish during the 1976 summer season.

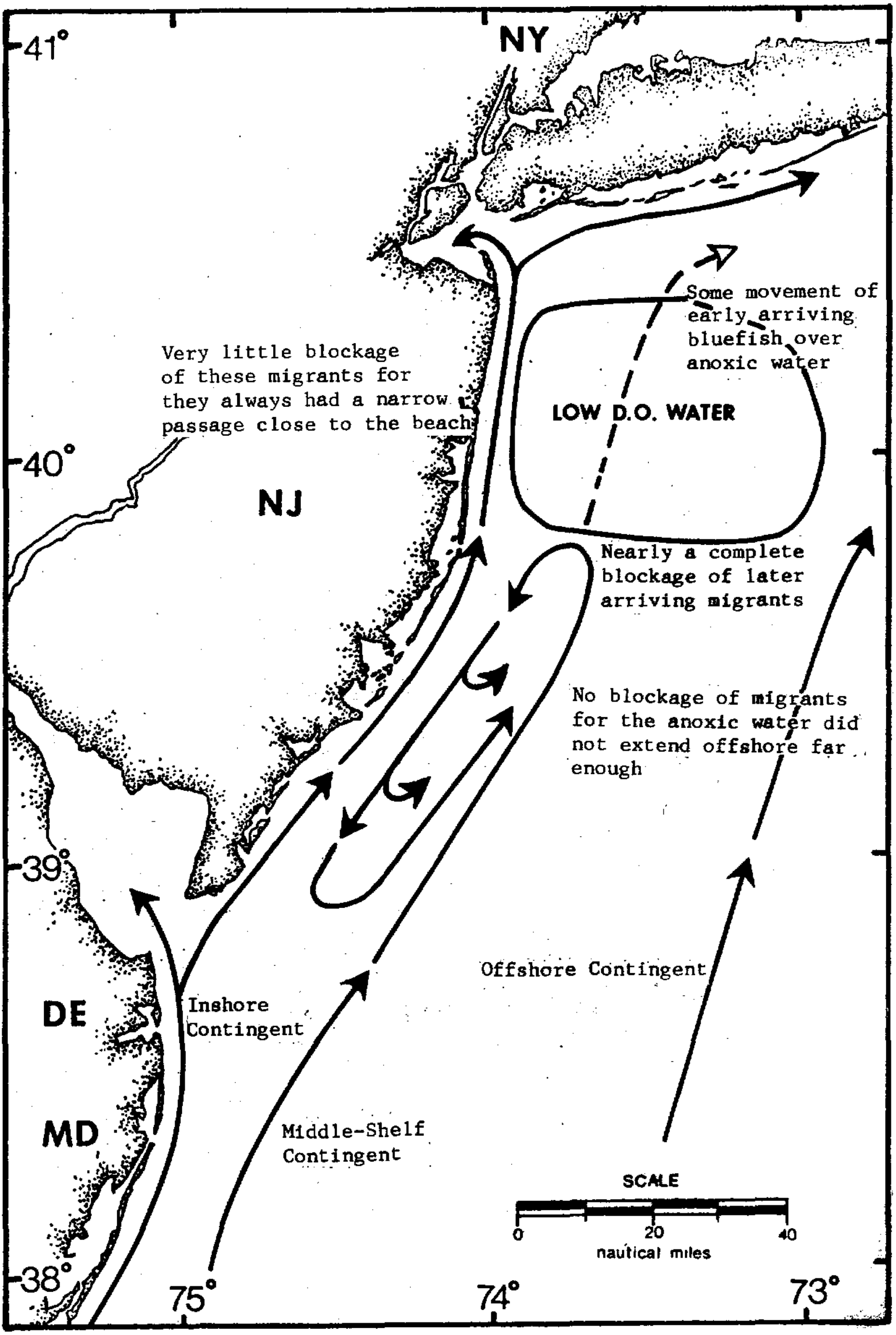

Figure 5. Migratory pathway for the various contingents of bluefish.

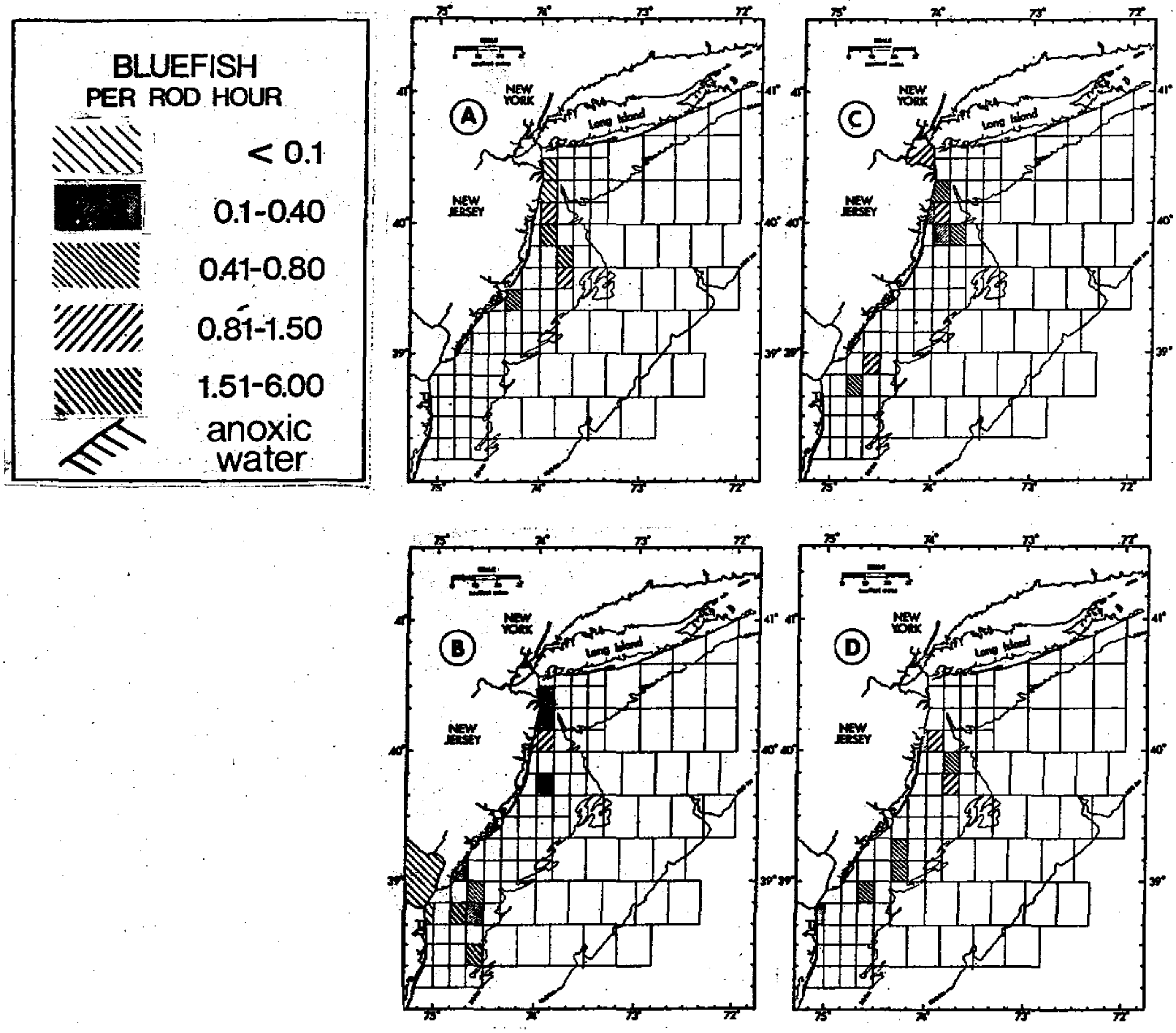

Figure 6. Bluefish catches made by charter-boat anglers while trolling along the New Jersey coast during 1976: a, May 16 to 29; b, May 30 to June 12; c, June 13 to 26; and d, June 27 to July 3.

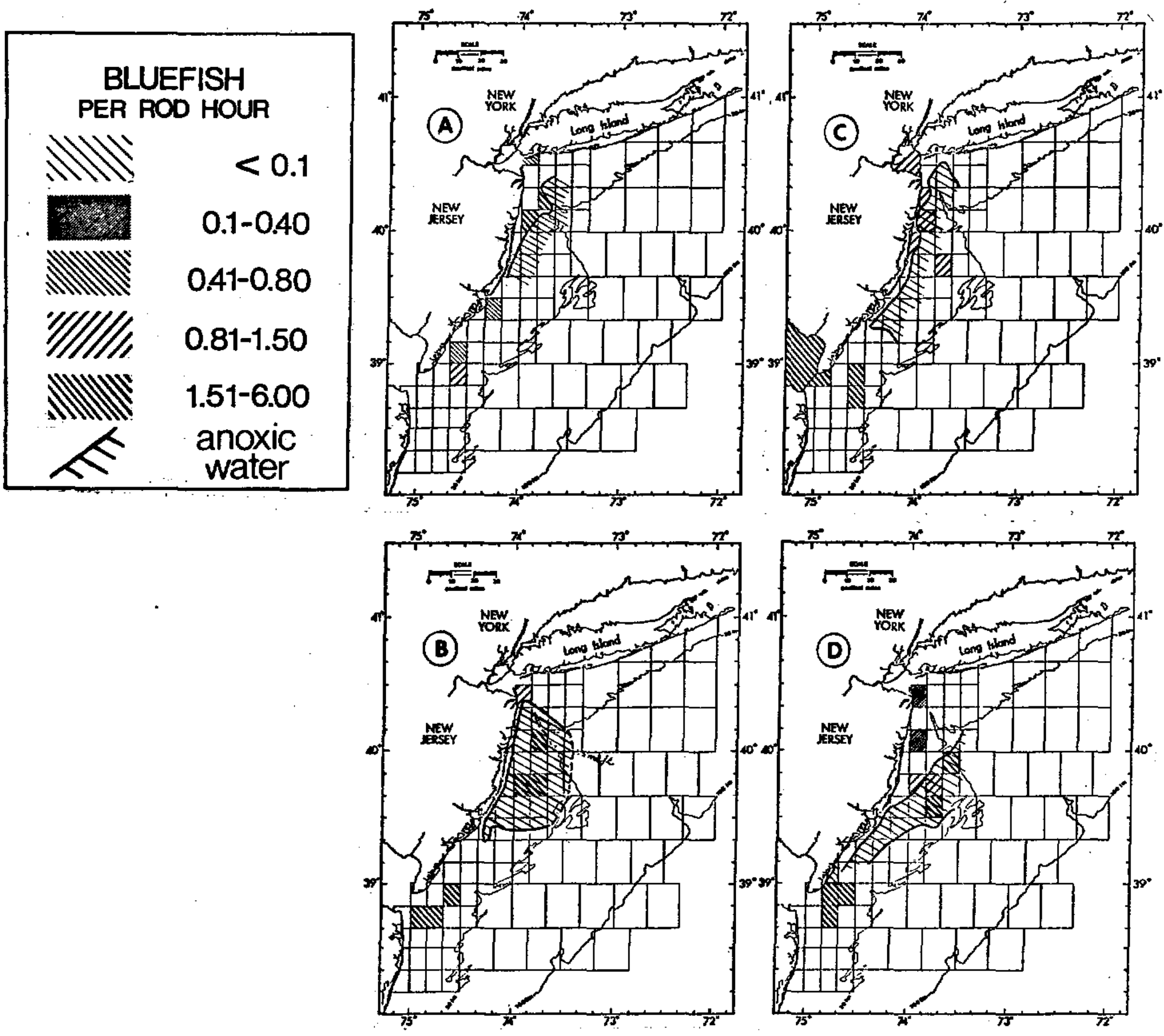

Figure 7. Bluefish catches made by charter-boat anglers while trolling along the New Jersey coast and extent of anoxic water during 1976: a, July 4 to 10; b, July 11 to 17; c, July 18 to 24; and d, July 25 to 31.

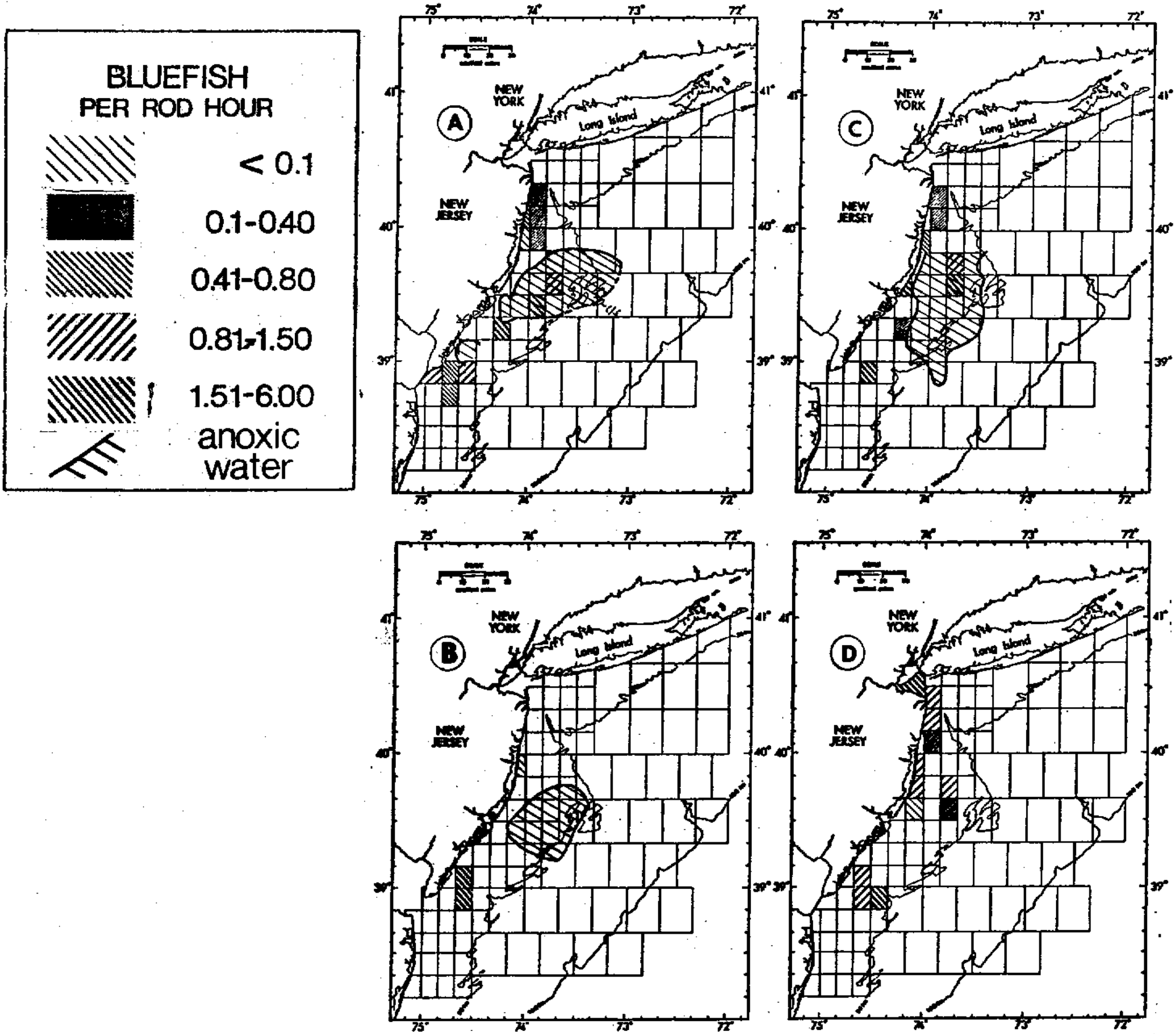

Figure 8. Bluefish catches made by charter-boat anglers while trolling along the New Jersey coast and extent of anoxic water during 1976: a, August 1 to 7; b, August 8 to 14 (hazardous hydrogen sulfide concentration); c, August 15 to 21; d, August 22 to September 4.

APPENDIX VI

THE EFFECTS OF ANOXIC WATER ON THE SUMMER FLOUNDER (PARALICHTHYS DENTATUS), A BOTTOM DWELLING FISH

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IMPORTANCE OF THE SUMMER FLOUNDER AND GENERAL NATURAL HISTORY

The summer flounder, (*Paralichthys dentatus*) locally called fluke, is among the most prized of the bottom dwelling fishes occurring along the middle Atlantic states. It is sought by commercial fishermen who annually catch between six and nine million pounds, mostly by otter trawl (Wheeland, 1973). It brings a high price in the market, often higher than any of the other flatfishes except the halibut. Undoubtedly, the fluke is of excellent eating quality, and this fact, in addition to its fine sporting quality, makes it extremely desirable among recreational fishermen as well. Indeed, it bites freely on almost any natural bait, often takes lures, and puts up a strong fight when hooked. Recreational fishermen along the middle Atlantic states catch nearly eight million pounds annually, an amount about as great as the commercial catch (Deuel, 1973).

The fluke occurs along every coastal state from Maine to Florida at one time or another during the course of a year. Nonetheless, while the specimens occurring over its entire geographical range belong to a single species, various biological studies indicate that there are several separate spawning contingents, perhaps genetically distinct populations (Smith, 1973). Even in the area of its greatest abundance, i.e., between Cape Cod, Massachusetts and Cape Lookout, North Carolina, there appear to be three separate contingents (Smith, 1973). The contingent of concern here is the northernmost one which lives and spawns in the area north of Delaware Bay.

The fluke is a migratory species. It spends the cold months offshore along the outer half of the continental shelf and the warm months inshore along the barrier beaches. The adult migration inshore extends through the spring and into early summer and is principally for feeding. Throughout the summer and early fall, fluke feed voraciously upon the various forage fishes, as well as the young of other fishes and squids, shrimps, crabs, worms, and other assorted organisms which live in the shallow waters. Beginning early in the fall and continuing into early winter, fluke migrate offshore to their wintering grounds, spawning along the bottom as they move progressively into deeper water. The eggs and larvae are found only in ocean water and juveniles in or near the mouths of estuaries (Smith, 1973).

The migratory pattern of the northern contingent of fluke is one principally of an east-west or inshore-offshore movement, rather than a north-south movement as is common among most of our migratory fishes (Figures 1, 2). Studies have shown that the majority of the fluke tagged when inshore on their summering grounds returned to the same grounds in subsequent years. Those specimens that moved beyond the tagging area, about a third of the fish, tended toward the north and east. Thus, of the fluke tagged off Cape May, New Jersey, two-thirds returned off Cape May the following year, while a third were from off the coast north of Cape May, mostly between there and Sandy Hook, New Jersey. Of the fluke tagged off Sandy Hook, two-thirds were recaptured there the following year, while a third were from off New York, Rhode Island, and Massachusetts (Hamer and Lux, 1962; Murawski, 1970).

When inshore during the warm months, the fluke regularly occurs along the ocean shore and in estuaries. The juveniles and small-size specimens occur mostly in the shallow water of estuaries, sometimes even entering the fresh water of tidal streams. But the great majority of large specimens, i.e., those weighing more than four pounds, are along the ocean shore in depths between 15 and 90 feet, with the very largest specimens usually in depths deeper than 50 feet (Freeman and Walford, 1974).

OCCURRENCE AND DISTRIBUTION OF FLUKE OFF NEW JERSEY DURING THE 1976 SEASON

Data calculated from party-boat anglers fishing along the New Jersey coast (See Freeman, Turner and Christensen, 1976) and from fishing reports during 1976 indicate that the fluke arrived inshore in mid-May (Figure 3A). Then and throughout the remainder of the month, anglers' catch rates were relatively low. During the first half of June, however, catch rates increased considerably, especially at the southernmost and northernmost parts of the state (Figure 3B). Later in June, the best catch rates were in the northernmost part of the state along the ocean beaches (Figure 3C). During the last of June and beginning of July, the time when fish were first observed dead along the ocean floor off northern New Jersey, presumably due to hypoxia, the catch rates of fluke were highest close along the ocean beaches in nearby areas (Figure 3D). Throughout the remainder of July and August, fluke were caught only in areas free of the anoxic water (Figures 4,5). During this time, catch rates were highest at places along the coast where the anoxic water pressed closest to the coast (Figures 4B, C, D). Indeed,during these times, party-boat anglers were fishing for fluke almost in the surf and in inlets and bays, a condition very unusual for these boats, some of which are more than 100 feet long.

DISCUSSION

From the analysis of recreational survey data, field observations and converstions with fishing boat captains along the New Jersey coast, it is apparent that the distribution of fluke and the catches made by anglers were very unusual throughout most of the 1976 summer season. During the early part of the season, fluke seem to appear in areas where they usually did during past years and in about their expected numbers. However, in the northern part of the state, this normal pattern ended suddenly beginning late in June coinciding with the formation of anoxic water close along the sea floor. Our information indicates that fluke were concentrated along the leading edge of the anoxic water. At various times and at various points along the coast, the movement of the anoxic water, controlled presumably by wind-driven currents, caused large numbers of fluke, including many large specimens that usually inhabit deep water, to be pressed into the surf zone and into inlets and bays where dissolved oxygen levels could sustain aquatic life. This resulted in placing large numbers of a very desirable species of fish within easy reach of anglers. Consequently, large catches were made by anglers fishing from shore as well as from boats (Capts. Fredrick Farwell, Atlantic Highlands, N. J., Andrew Applegate, Atlantic City, N. J., and Mr. Jay Amberg, Barnegat Light, N. J., pers. comm.). Such was the case in Sandy Hook Bay during mid-July and off Long Beach Island and Atlantic City in mid and late July (Figures 4B, C, D).

Knowledgeable fishermen, some of whom have been fishing along New Jersey for 20 to 30 years, remarked that they have never seen anything like the conditions that prevailed during 1976. An exception to this was a three-day period during the summer of 1957 and a ten-day period during the summer of 1964 off northern New Jersey (Capt. Fredrick Farwell, pers. comm.). Then, as well as during the summer of 1976, large numbers of fluke occurred along the edges of channels as well as along the shallow areas within Sandy Hook Bay. The great abundance of 1/2-to 2-pound fluke in the shallow water of the Bay is especially noteworthy, for specimens of this size normally occur along the ocean beaches off Sandy Hook. The unusual catches made in Sandy Hook Bay were four to thirteenfold what they were during the rest of the season (Capt. Fredrick Farwell, pers. comm).

Biological studies have shown that anglers can account for as much as half of the total number of fluke removed from the sea (Hamer and Lux, 1962; Murawski, 1970). The removal of large numbers of fluke by anglers during the summer season, the removal of normal numbers of fluke by commercial fishermen throughout the year, and the possible deaths caused by the anoxic water as well as the physiological stress placed on the surviving ones, probably led to the removal of more individuals from the population in 1976 than would normally be the case.

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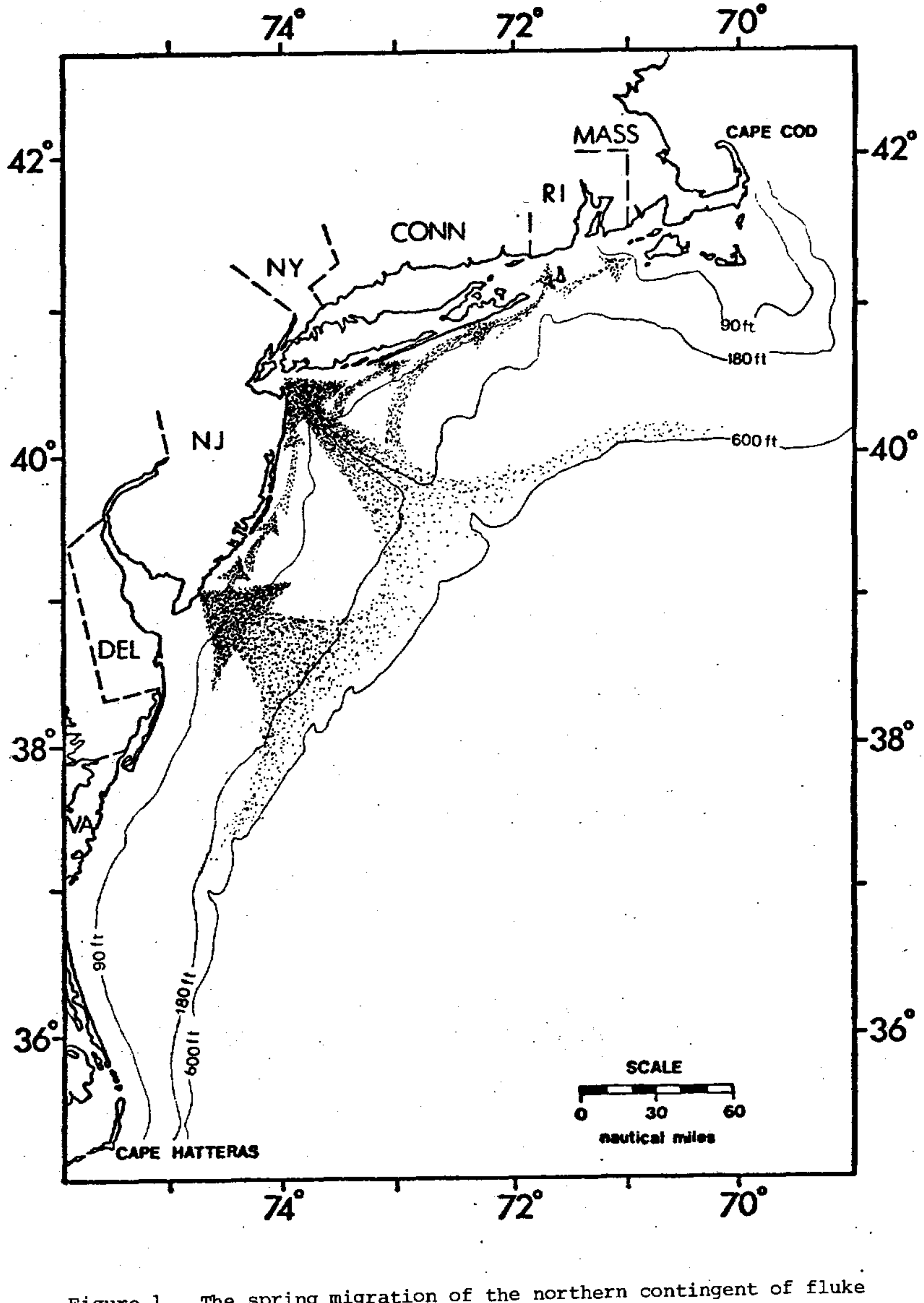

Figure 1. The spring migration of the northern contingent of fluke to the waters of New Jersey.

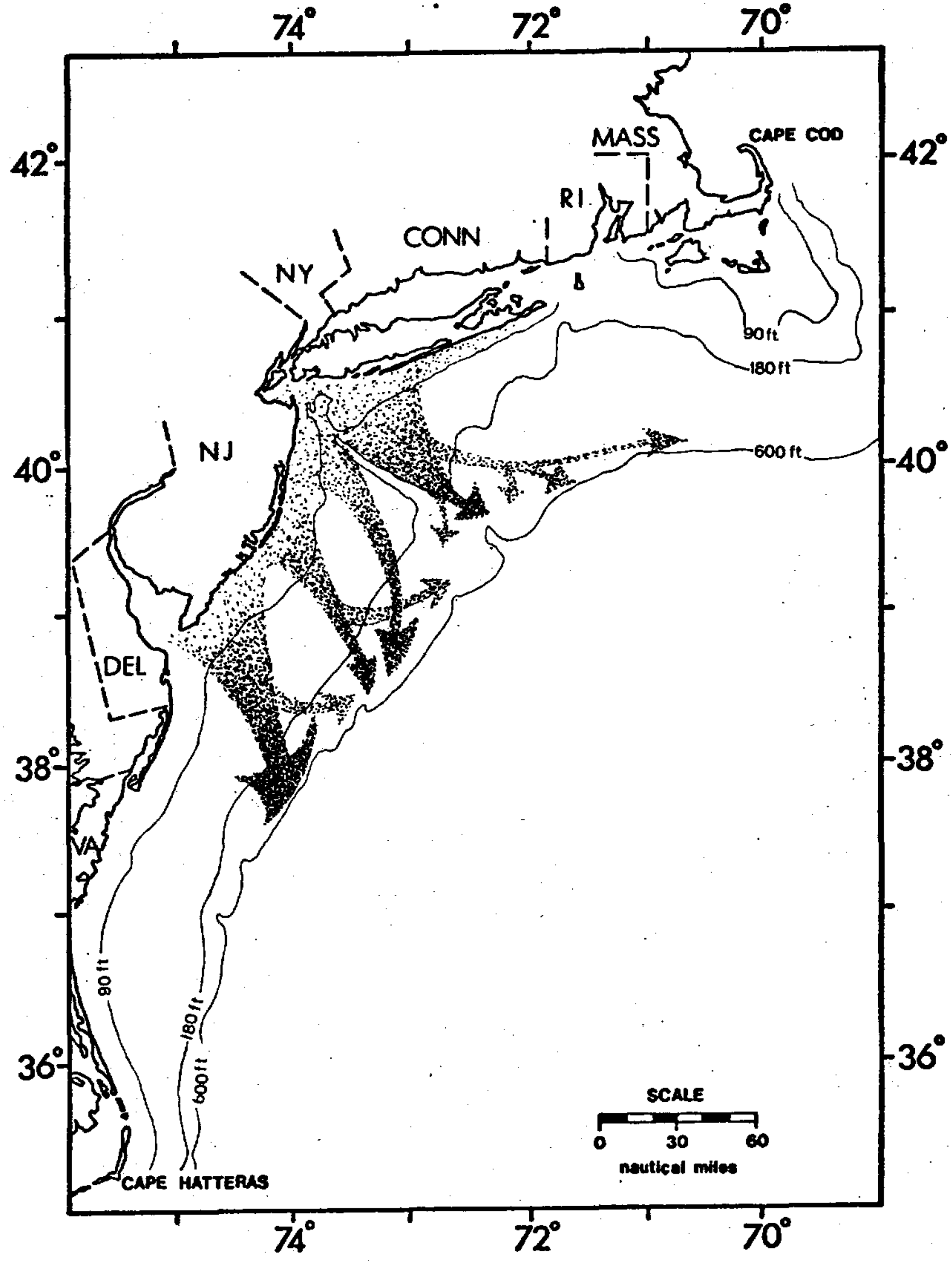

Figure 2. `The fall and early winter migration of the northern contingent of fluke from the waters of New Jersey.

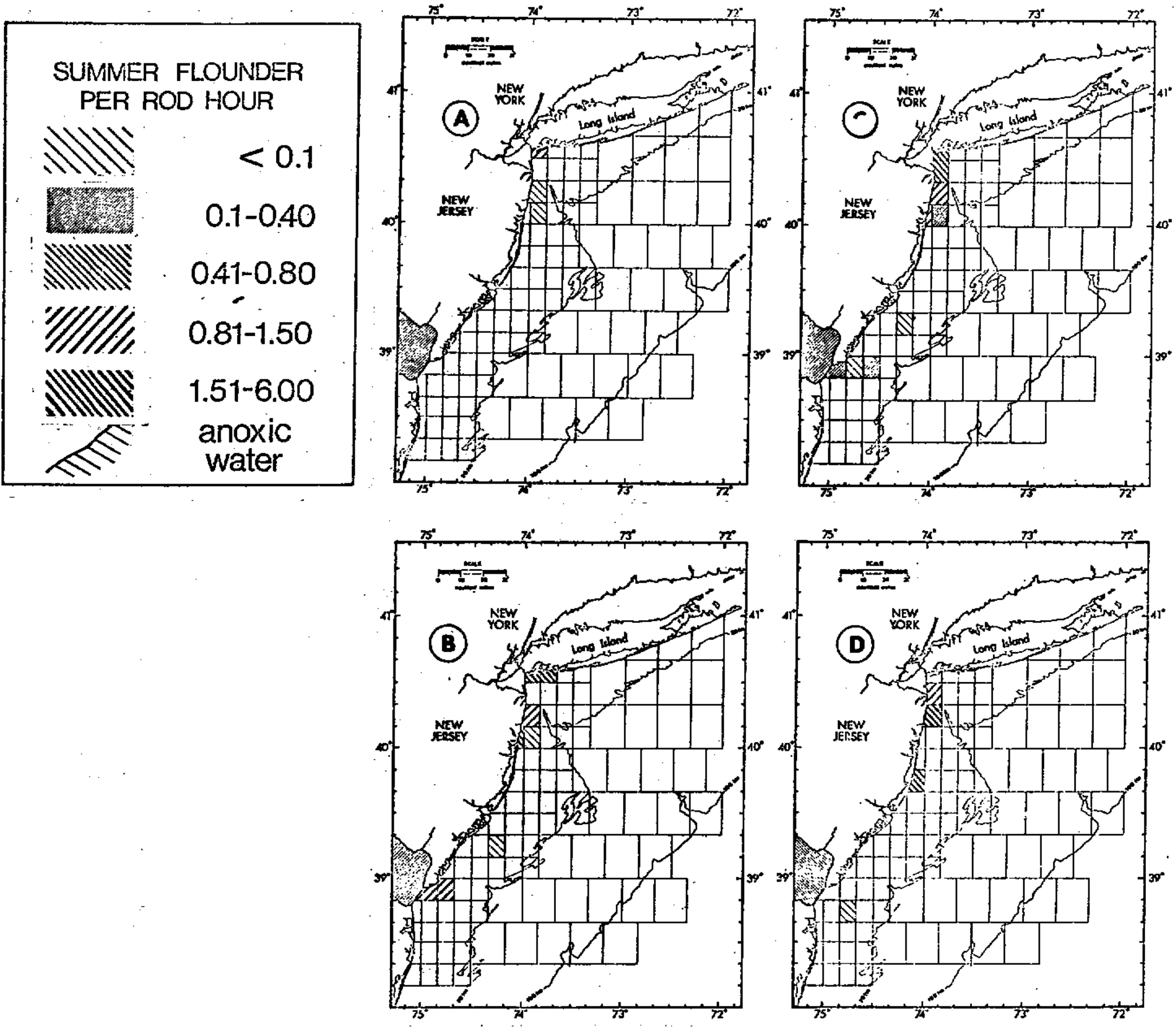

Figure 3. Catch rates of fluke by party-boat anglers fishing along the New Jersey coast during 1976: A, May 16-29; B, May 30-June 12; C, June 13-26; D, June 27-July 3.

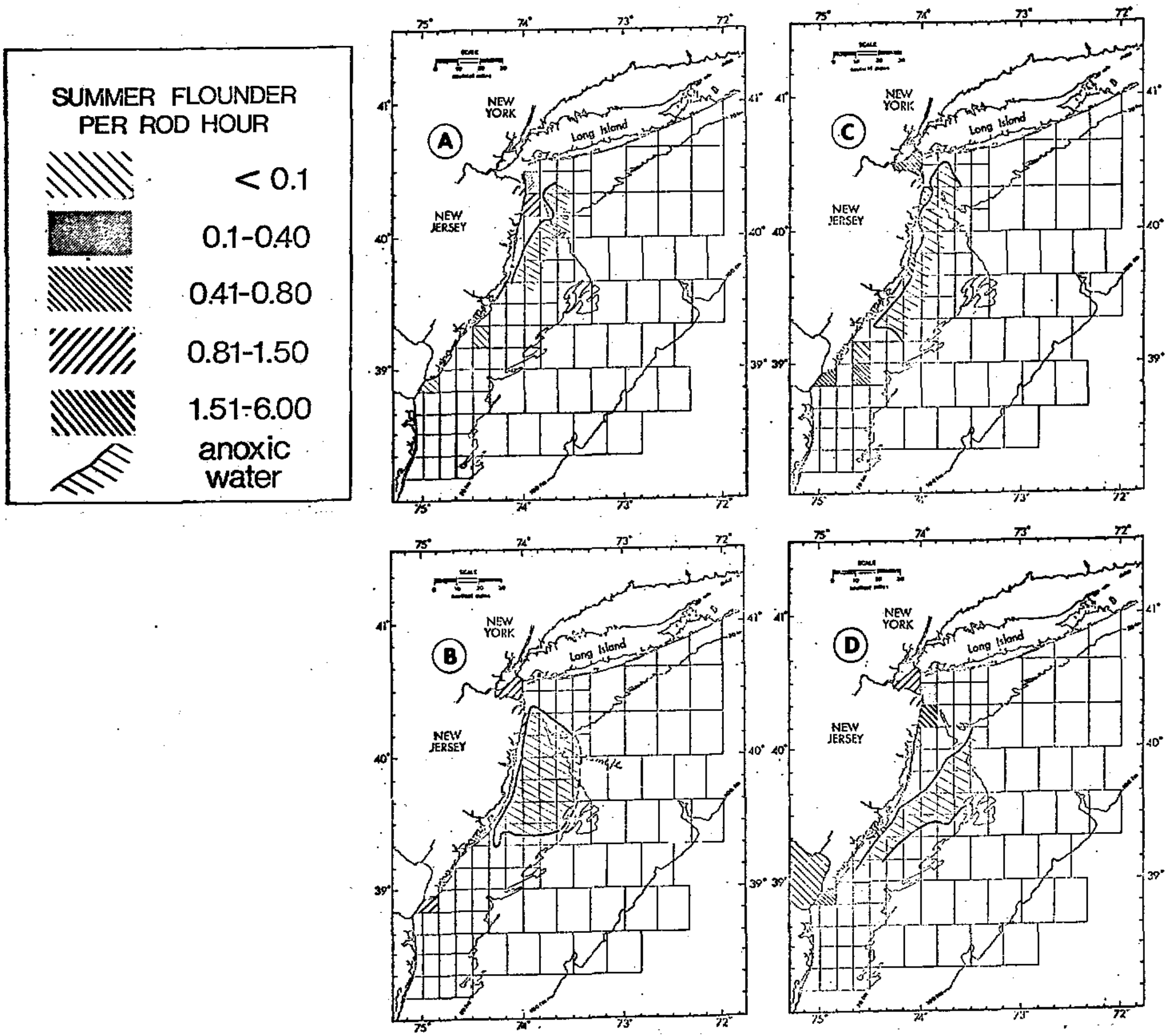

Figure 4. Catch rates of fluke by party-boat anglers fishing along the New Jersey coast during 1976: A, July 4-10; B, July 11-17; C, July 18-24; D, July 25-31.

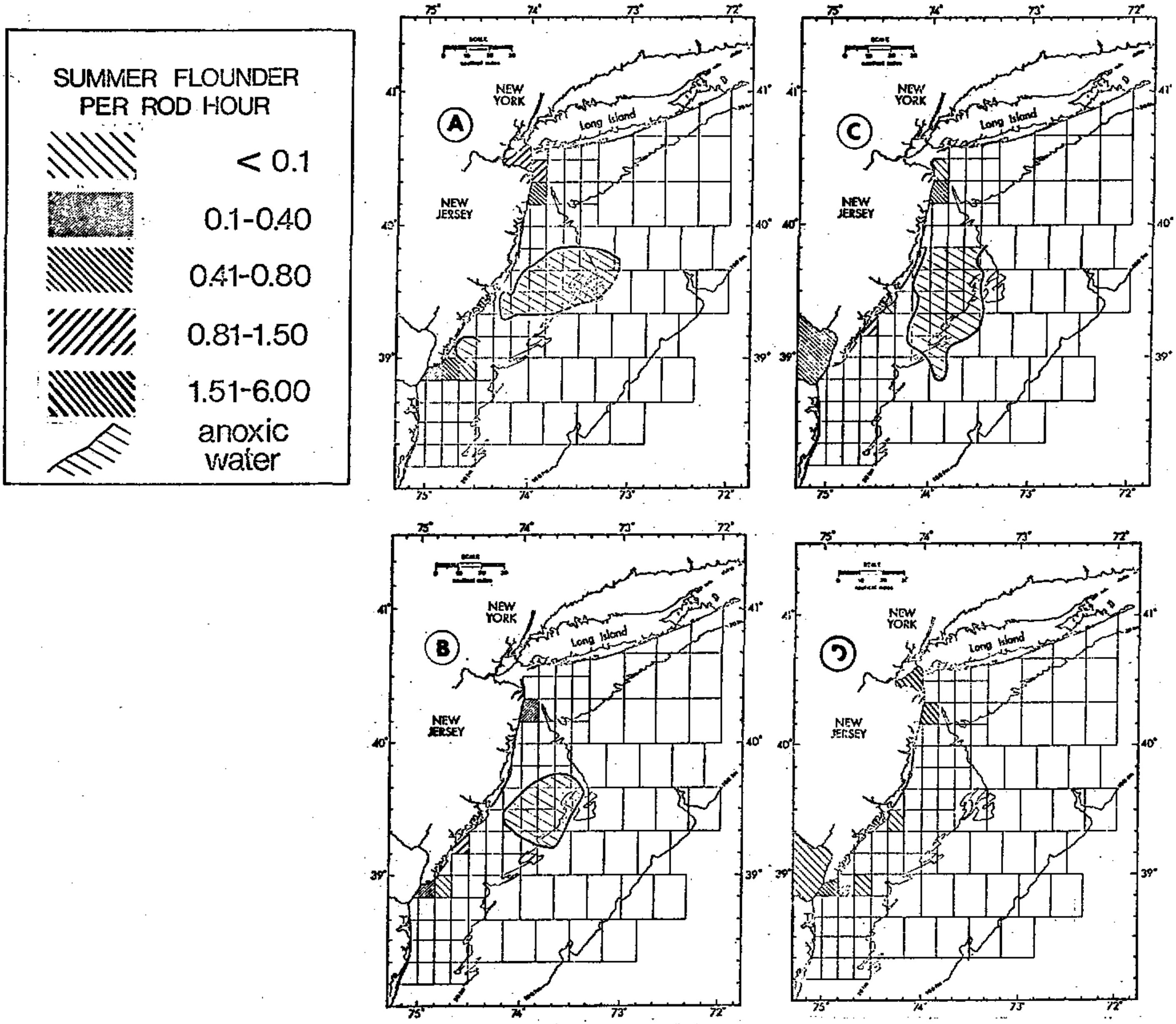

Figure 5. Catch rates of fluke by party-boat anglers fishing along the New Jersey coast during 1976: A, August 1-7; B, August 8-14; C, August 15-21; D, August 22-September 4.

APPENDIX VII

OBSERVATIONS ON THE SUMMER FLOUNDER (PARALICHTHYS DENTATUS) SPORT FISHERY IN GREAT BAY, N.J. DURING THE SUMMER OF 1976 IN REFERENCE TO ANOXIC WATER CONDITIONS.

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Introduction

The small boat sport fishery for summer flounder (*Paralichthys dentatus*) has been monitored by creel census for ten years (1967-1976). The survey population consists of anglers utilizing small (16 to 22 ft) private and rental boats which dock or launch from a marina on Great Bay Boulevard. Small boats containing 1 to 6 anglers dominate the bay and inshore fishery in the area accounting for 88% of angler man-days expended in Great Bay during 1970 (McClain, Makai and Hamer 1971).

The census is conducted during the months of June, July and August with the intent of determining trends in angler success and stock recruitment. During 1976, the census frequency was reduced from three to one day a week at which level it will be maintained during upcoming years. Figure 1 and Table 1 provide mean catch per completed angler trip statistics by month over the history of the census.

The 1976 Fishery

During the survey months of 1976, anglers in Great Bay averaged 3.3 summer flounder per completed trip. This value represents the second highest seasonal mean in the history of the census. The July 1976 mean of 5.63 summer flounder per trip is the highest monthly average to be recorded in the survey and is attributable to the extreme daily figures of 10.6 and 7.1 recorded on 7/15 and 7/26 (Table 2, Figure 2). These extremely high values are separated by a low value of 1.13 summer flounder/trip recorded on 7/22. The high variability in catch rates during July appears to be directly related to movement of the anoxic water mass which extended to proximal ocean waters in July and actually entered inlet and bay waters on 7/21. At this time the most reasonable explanation of July catch patterns is thought to be the following

During early July, the anoxic water mass, moving south and inshore, forced large numbers of summer flounder, which were previously utilizi ocean waters, into inlet and near inlet bay areas. The fish were concentrated and vulnerable to sport fishing effecting the high catch rates recorded on 7/15/76. The movement of anoxic water into inlet and near inlet bay areas on 7/21 severely stressed and scattered these flounder resulting in the decline in catch rate recorded on 7/22. On the evening of 7/21, boaters observed summer flounder swimming near the surface. Many fish were dazed to a point where they could be captured with dip nets. On 7/22, Division biologists observed at least 500 dead summer flounder in waters of nearby Little Egg Harbor Bay which shares the inlet with Great Bay. The bay waters were flushed of anoxic water in a few days with catch rates recovering by 7/26. The following decline in catch/trip values occurred as the trapped fish were depleted by angling or managed to move out of the bay area during periods when the anoxic mass withdrew from inlet and beachfront waters.

During eight of the ten census years, catch rates declined during August indicating that, in general, the fish move out of the system in the later part of that month. 1976 followed the same pattern with activity in the bay fishery becoming negligible by the end of August. During the middle of September, however, an exceptionally large concentration of summer flounder occurred in inlet waters. This concentration coincided with a second inshore movement of anoxic waters, climaxing with an influx into the inlet on 9/20/76. Unfortunately, catch rates during the approximately two week period were not documented. From personal observation and after the fact angler interviews, it appeared that catch/trip values during this time exceeded any figures recorded in July. Large party boats, charter boats and possibly 300 or more small boats fished the approximately 1.5 mile waterway on weekend days during the period of concentration. Given the apparent scarcity of fish within bay waters during late August and early September, it is assumed that this group of summer flounder was composed of fish which had begun their offshore migration and were forced back into inlet areas by the anoxic water mass. The lack of catch data precludes any firm estimates on the harvest related to the September fishery. It seems reasonable to assume, however, that this harvest was comparable with the entire summer fishery.

Remarks

Substantial efforts are presently being made to assess the biological impacts of the 1976 anoxic water condition. Such assessments should include consideration of summer flounder stocks. By concentrating summer flounder in inshore waters readily accessible to sport anglers, a situation favoring over exploitation was created. During "normal" years, the recreational fishery amounts to three times the commercial harvest (Chang, Pacheco 1975). Thus increases in catch rates within the sport fishery substantially affect the overall harvest. Chang and Pacheco estimate a sustainable harvest of 20,000 to 22,000 tons for summer flounder in the Middle Atlantic Bight. This figure was exceeded in 1974 and probably again in 1975. If anoxic water conditions resulted in a significant increase in harvest during 1976, the compounded impact on the future of the fishery may well be critical.

Based on total angler effort figures for June, July and August of 1970 for the summer flounder grounds in Great Bay (McClain, Makai, and Hamer 1971), the seasonal harvest estimate for 1976 amounts to 106,734 individuals. These fish averaged 421.1 gms, amounting to a total harvest of 58,703 pounds. Increased catch rates in July attributible to the anoxic water condition, may have accounted for the harvest of 40,000 individuals or 37,000 lbs., 35% of the total summer harvest. This figure does not include the September harvest which consisted of somewhat larger sized fish and may have surpassed 50,000 lbs.

It must be remembered that the increased July harvest and the September harvest represent, to some degree, a transfer in catch from the ocean sport fishery and the commercial trawl fishery. The proportion of any 1976 stock over-exploitation attributable to the anoxic condition depends on the extent of this transfer.

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Acknowledgment:

Barry Preim assisted with data analysis.

TABLE 1

Catch per Completed Angler Trip 1966 - 1976

Month	1966*	1967	1968	1969	1970	1971
June	2.829	0.613	0.037	0.459	0.283	0.721
July	1.069	0.698	0.450	0.412	1.194	0.881
August	0.125	0.292	0.574	0.068	0.775	0.380
Season:	1.473	0.572	0.391	0.317	0.792	0.695

TABLE 1 (Cont'd)

Month	1972	1973	1974	1975	1976
June	1.158	2.864	2.359	4.994	1.72
July	2.235	2.254	2.415	4.503	5.73
August	2.274	2.023	0.509	1.840	2.13
Season:	2.096	2.270	1.779	3.814	3.30

*Census at Avalon, New Jersey

FIG. I.

CATCH OF SUMMER FLOUNDER / ANGLER TRIP
1966-1976

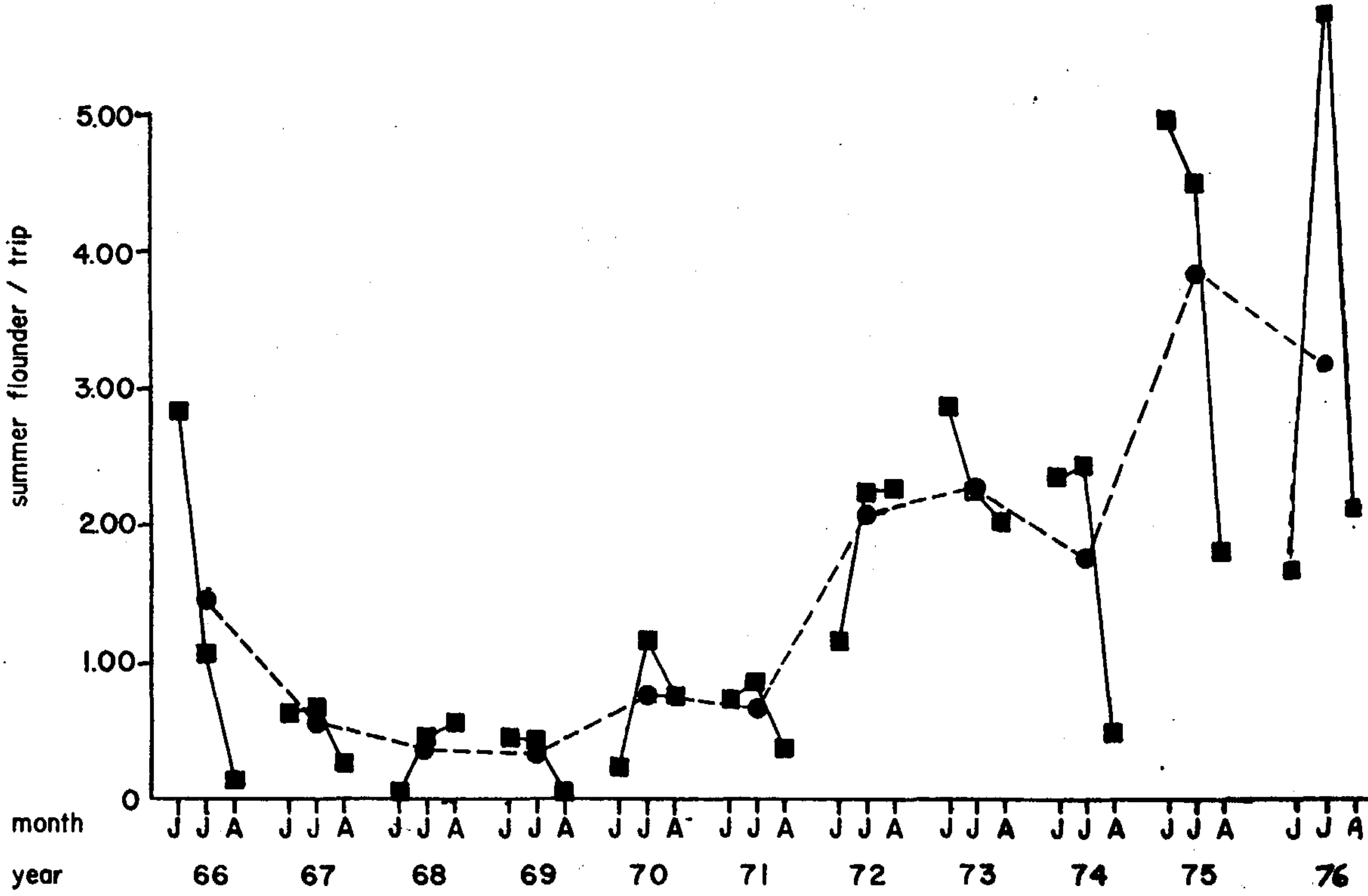

TABLE 2

Summer Flounder Catch per Angler per Angler Trip in Great Bay 1976

Survey Date	Number of Anglers trips Interviewed	Reported Catch of S. flounder	Catch per Angler trip
6/3/76	19	19	1.00
6/4/76	11	4	0.36
6/8/76	30	26	0.87
6/17/76	10	2	0.20
6/22/76	24	76	3.17
6/29/76	50	121	2.42
June Total	144	248	1.72
7/6/76	55	182	3.31
7/15/76	39	415	10.64
7/22/76	31	35	1.13
7/26/76	62	440	7.10
July Total	187	1072	5.73
8/2/76	57	225	3.95
8/12/76	23	18	0.78
8/17/29	29	52	1.79
8/24/76	37	68	1.84
8/25/76	31	37	1.19
8/27/76	16	11	0.69
August Total	193	411	2.13
Seasonal Total	524	1731	3.30

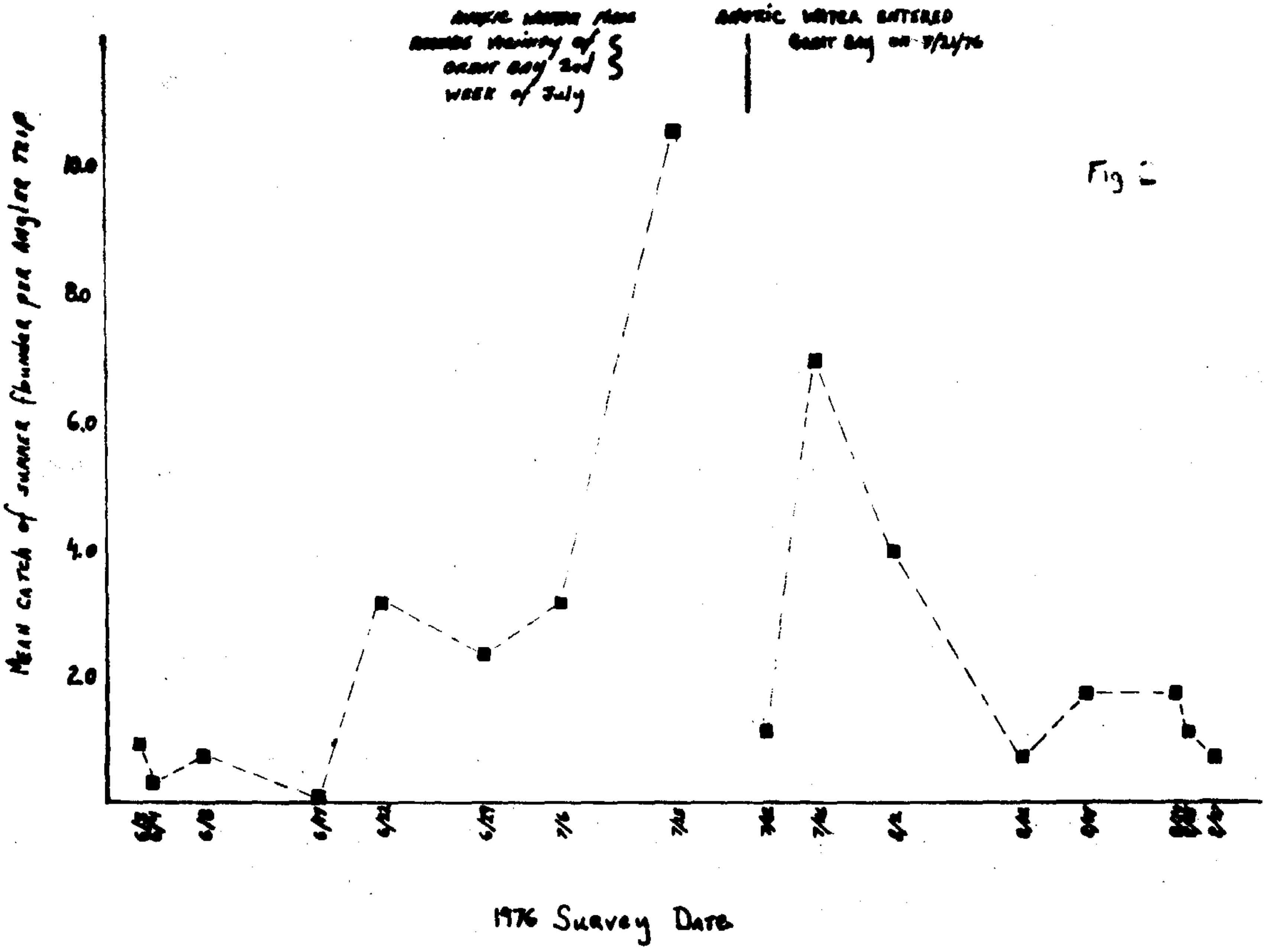
ANOXIC WATER MASS
ENTERS VICINITY OF
GREAT BAY 2nd
WEEK of July
ANOXIC WATER ENTERED
GREAT BAY ON 7/21/76
Mean catch of summer flounder per angler trip
10.0
8.0
6.0
4.0
2.0
6/10
6/22
6/27
7/6
1976 Survey Date

Fig 2