# U.S. ENVIRONMENTAL PROTECTION AGENCY

NEW YORK BIGHT WATER QUALITY

SUMMER OF 1990

ENVIRONMENTAL SERVICES DIVISION
REGION 2
NEW YORK, NEW YORK 10278

**NEW YORK BIGHT WATER QUALITY**

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Prepared By: United States Environmental Protection Agency
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## ABSTRACT

The purpose of this report is to disseminate technical information gathered by the U.S. Environmental Protection Agency (EPA), Region 2, during the 1990 New York Bight Water Quality Monitoring Program. The monitoring program was conducted using the EPA helicopter for water quality sample collection. During the period from May 22 to September 26, 1990, approximately 152 stations were sampled each week, weather permitting. The Bight sampling program consisted of four separate sampling networks. Sampling was conducted 5 days a week and extended to 6 days a week in July and August.

Bacteriological data indicated that fecal coliform densities at the beaches along both the New Jersey and Long Island coastal waters were well within the acceptable Federal guidelines and State limits for primary contact recreation (a geometric mean of 200 fecal coliforms/100ml). Bacteriological data also indicated that the New Jersey and Long Island coastal waters were well within the recommended EPA criterion for enterococci in marine waters (a geometric mean of 35 enterococci/100ml). Based on fecal coliform and enterococci data collected during the sampling period, the coastal waters off Long Island and New Jersey were of excellent quality.

Dissolved oxygen concentrations in 1990 were generally good along the New Jersey perpendiculars, the Long Island perpendiculars, and in the New York Bight Apex. In 1990,

some depressed bottom dissolved oxygen levels occurred in isolated areas of the Bight Apex and off the New Jersey coast, however the low dissolved oxygen levels only persisted a short time. The average dissolved oxygen concentrations along the New Jersey perpendiculars, the Long Island perpendiculars and in the New York Bight Apex remained above 4.0 mg/l, with the exception of the northern New Jersey perpendiculars which experienced an average low of 3.9 mg/l in mid August. Dissolved oxygen averages for the Bight Apex and the New Jersey coast have ranged from 7-17 percent lower than the preceding four years. However, the values remained higher than those of 1985 when, in mid to late summer, approximately 1600 square miles of ocean bottom off New Jersey were plagued with dissolved oxygen concentrations considered stressful for aquatic life, over extended periods of time.

During the summer, phytoplankton blooms were observed over extensive areas. Most beaches along New Jersey were affected by blooms of short duration, during the sampling period. Algal blooms of longer duration occurred in the intercoastal bays of New Jersey and Long Island. Red algal blooms of the dinoflagellate Katodinium rotundetum, were predominant in Raritan and Sandy Hook Bays. The green tide, which occurred along the southern New Jersey coast in 1984 and 1985, did not recur in 1990. The 1984 and 1985 blooms were caused by the organism Gyrodinium aureolum.

Beach closures due to wash-ups of floatable debris were less frequent in 1990 than in 1989. This was largely due to the initiation of the "Short Term Action Plan for Addressing Floatable Debris in the New York Bight" (USEPA, 1988). This was, and will continue to be, a cooperative monitoring and response effort on the part of various federal, state and local government agencies. Also in 1989, New Jersey Department of Environmental Protection (NJDEP) initiated Operation Clean Shores, which effectively removed 5.96 million pounds of floatable debris from impacted shorelines. Continuing the program with cooperation from the participating municipalities and state and federal agencies, 9.55 million pounds of floatables were removed in 1990. Removal of floatables from impacted shorelines, prevents the material from resuspending into the water column and washing up on other shorelines or bathing beaches. Only one beach in New Jersey was closed due to floatable debris, in 1990.

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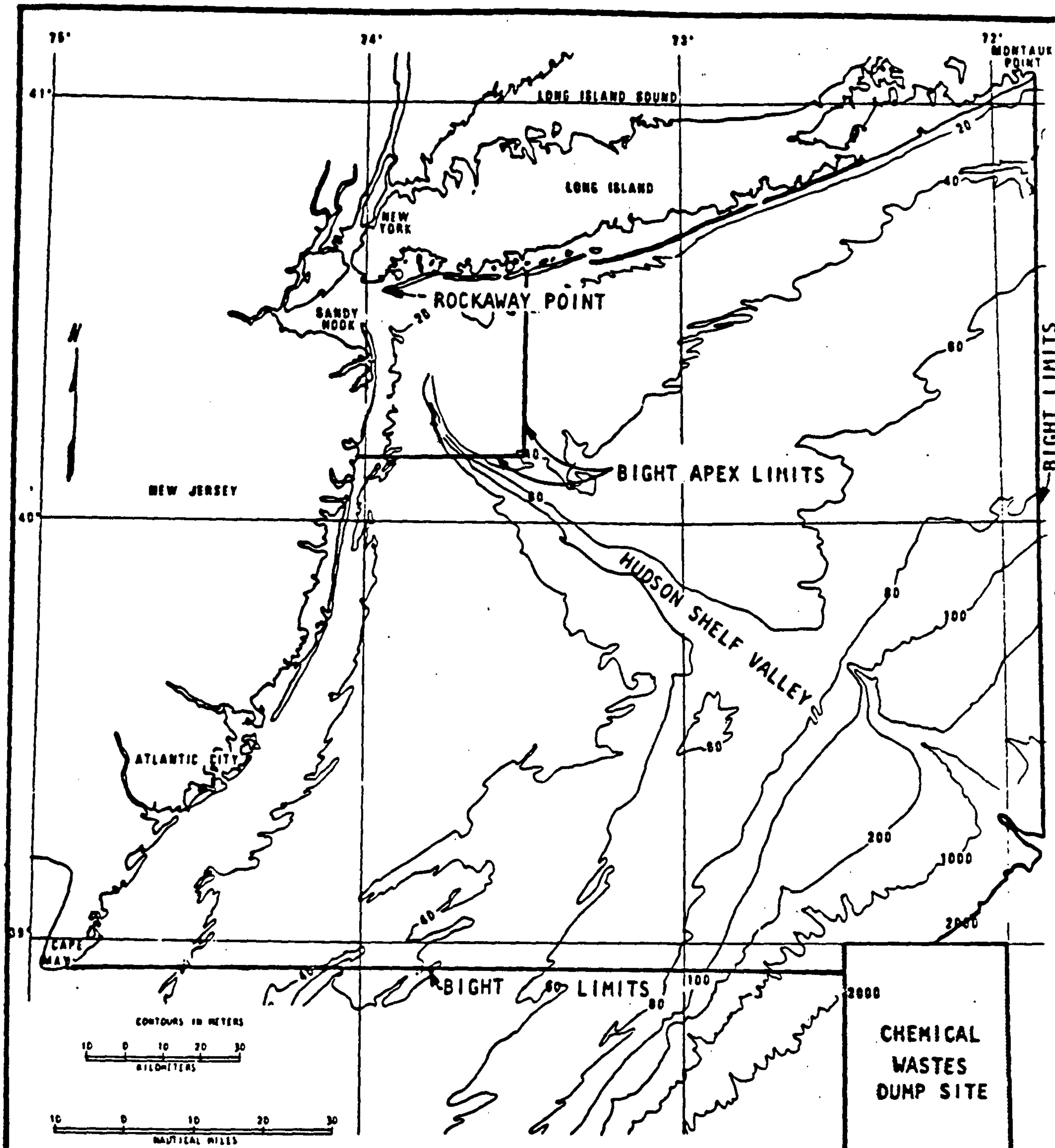
# I. INTRODUCTION

The U.S. Environmental Protection Agency has prepared this report to disseminate environmental data for the New York Bight Apex and the shorelines of New York and New Jersey. The New York Bight is an area of ocean bounded on the northwest by Sandy Hook, the northeast by Montauk Point, the southeast by the 2000 meter contour line, and the southwest by Cape May. Figure 1 shows the limits of the New York Bight. The New York Bight Apex, which contains the inactive sewage sludge and acid waste disposal sites, and the active dredged material and cellar dirt disposal sites, is shown in Figure 2.

This report is the seventeenth in a series and reflects the monitoring period between May 22, 1990 and September 26, 1990. The New York Bight Water Quality Monitoring Program is EPA's response to its mandated responsibilities as defined under the Marine Protection, Research and Sanctuaries Act of 1972, the Water Pollution Control Act Amendments of 1972 and 1977, and the Water Quality Act of 1987.

Since its initiation in 1974, the New York Bight Water Quality Monitoring Program has been modified several times to be more responsive to the needs of the general public, the states, the counties, and EPA; and to concentrate on specific areas of concern during the critical summer period. Most of these changes occurred after the summer of 1976, when anoxic conditions caused a fishkill in the Bight




# THE NEW YORK BIGHT

Figure 1

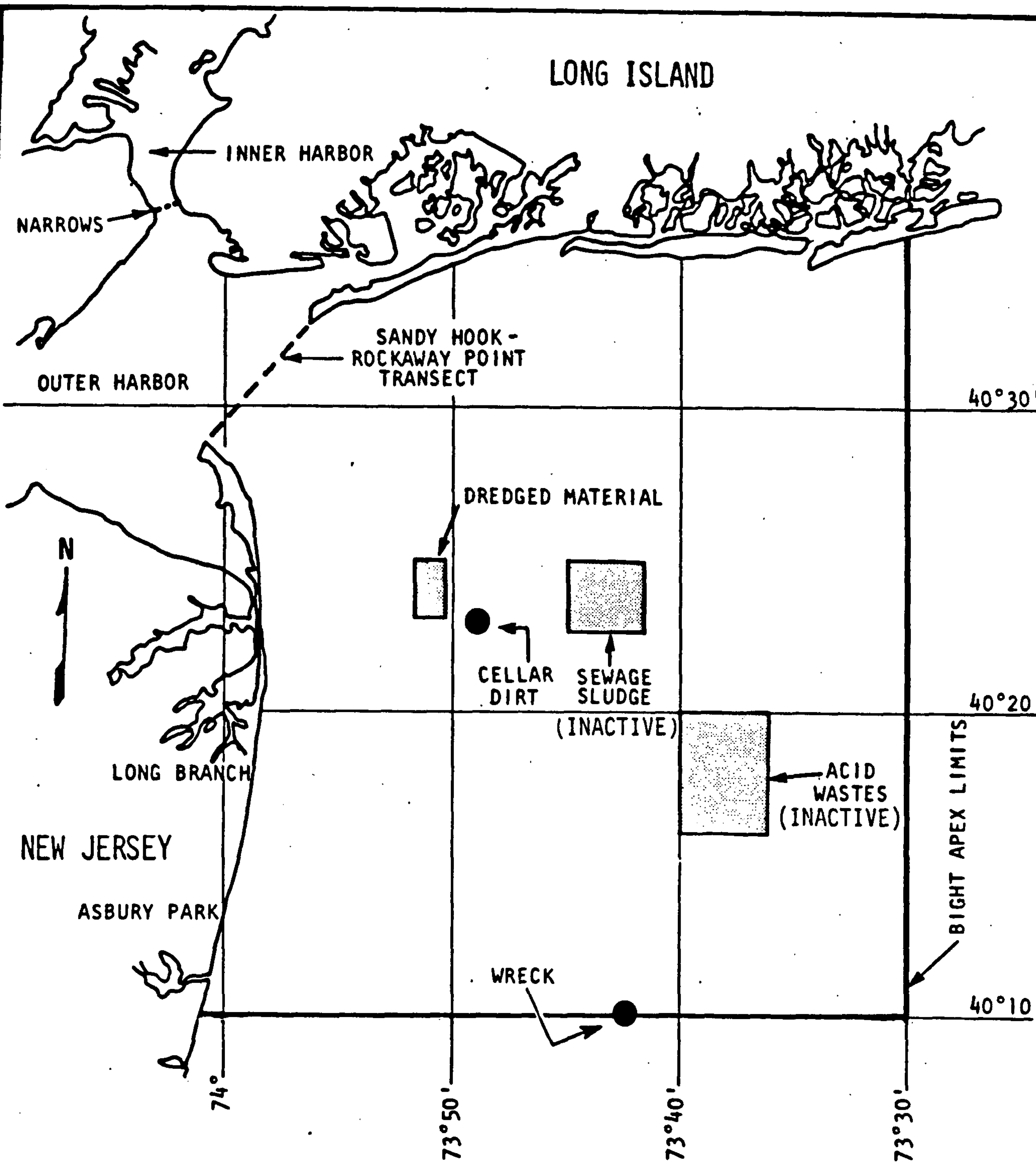
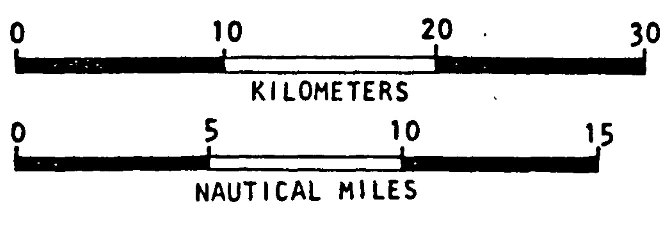



Figure 2

## BIGHT APEX AND EXISTING DUMP SITES



and an unusually heavy wash-up of debris occurred on Long Island beaches. It was clear that summer conditions in the Bight called for more intensive monitoring in order to predict environmental crises, investigate the origins of these crises, and direct any decisions regarding protection of the Bight's water quality.

In 1986, the monitoring program was modified to intensify sampling activities along the southern New Jersey beaches. During mid to late summer in 1985, beaches along the southern New Jersey coast were affected by algal blooms, which caused "green tide", and high bacterial counts which resulted in beach closings. To improve monitoring coverage, four additional beach stations between Long Beach Island and Wildwood were sampled weekly for phytoplankton. In addition, bacteria samples were collected weekly rather than bimonthly along the southern New Jersey beaches.

National Oceanic Atmospheric Administration (NOAA) and EPA have documented improvement of dissolved oxygen levels near the inactive sewage sludge disposal site (NOAA, 1989). The 12-mile disposal site has been inactive since 1987. The New York Bight sampling stations have shown average dissolved oxygen levels above 4 mg/l since 1983, with the exception of September 1985. In view of this improvement, the New York Bight Apex sampling stations have been modified to exclude 8 of the 20 original stations.

In 1990, a cooperative monitoring program between EPA and New York State Department of Environmental Conservation (NYSDEC) was established, to assist NYSDEC's Shellfish Sanitation Program. Bacteriological samples were collected at all Long Island Beach stations plus seven additional stations, three at inlets, two at ocean outfalls, one at Ocean Beach and one at Quantuck Beach. Because of these additional samples, aircraft space limitations precluded the collection of phytoplankton and chlorophyll samples along the Long Island Beaches. NYSDEC will be preparing a report on this monitoring at a later date.*

In August 1987, a 50-mile slick of garbage washed ashore along mid to southern New Jersey. In 1988, daily floatables observations were recorded from the helicopter. This surveillance was carried over into 1989 and 1990 in response to the "Short Term Action Plan for Addressing Floatables Debris in the New York Bight" (USEPA, 1988). Essentially, a monitoring and response network was established to locate and coordinate cleanup operations for slicks found in the New York Harbor Complex. The intent was to prevent slick materials from escaping the harbor and potentially stranding on regional beaches. Details can be found in the action plan.

*For further information please contact Charlie de Quillfeldt of New York State Department of Environmental Conservation Shellfisheries Division, Building 40-SUNY, Stony Brook, New York, 11790.

## II. SAMPLE COLLECTION PROGRAM

During the period of May 1990 through September 1990, water quality monitoring was carried out using a Bell Jet Ranger helicopter in May and June, and the EPA Huey Helicopter in July, August and September. Under the established protocol, sampling normally occurred 5 days a week and was extended to 6 days a week during July and August. Table 1 outlines the 1990 sampling program and the parameters analyzed for each station group.

The monitoring program was composed of four separate sampling networks. The beach station network was sampled to gather bacteriological water quality information at 26 Long Island coast stations and 46 New Jersey coast stations. The New York Bight station network was sampled to gather chemical information at 12 stations in the inner New York Bight. The perpendicular station network consisted of 12 transects extending from the New Jersey and Long Island coasts. Three transects extended south from the Long Island coast, with 4 stations in each transect, and 9 transects extended east from the New Jersey coast, with 5 stations in each transect. The transects covered the inner Bight from Jones Beach on Long Island, to Strathmere on the New Jersey coast. Samples were collected for dissolved oxygen and temperature. The phytoplankton sampling network consisted of 11 stations. Samples for phytoplankton identification were collected along the New

Table 1

Outline of 1990 Sampling Program

| Station Group | Frequency per Week | Parameter | Sample Depth |
|---|---|---|---|
| Long Island Beaches (Rockaway Pt. to Shinnecock Inlet) | 1 | Fecal Coliform<br>Enterococci | Top[1] |
| New Jersey Beaches (Sandy Hook to Cape May) | 1 | Fecal Coliform<br>Enterococci | Top[1] |
| Inner New York Bight | 1 | Temperature<br>Dissolved Oxygen | Top[1],<br>Bottom[2] |
| Long Island Perpendiculars | 1 | Dissolved Oxygen<br>Temperature | Top[1],<br>Bottom[2] |
| New Jersey Perpendiculars (Long Branch to Strathmere) | 1 | Dissolved Oxygen<br>Temperature | Top[1],<br>Bottom[2] |
| New Jersey Phytoplankton Station Network | 1 | Phytoplankton<br>Chlorophyll a | Top[1] |

[1] One meter below the surface
[2] One meter above the ocean floor

Jersey coast and in Raritan Bay, Sandy Hook Bay, and Delaware Bay. The weekly sampling program averaged 152 stations.

Beach stations along New York and New Jersey were sampled once a week for fecal coliform and enterococcus bacteria densities. This portion of the sampling program totaled 72 stations per week. At the beach stations, samples were collected just offshore in the surf zone, while the helicopter hovered approximately 3 meters from the surface. Sampling was accomplished by lowering a 1-liter Kemmerer sampler approximately 1 meter below the water surface. The sample was transferred to a sterile plastic container, iced and subsequently transported (within 6 hours) to the Edison Laboratory for fecal coliform and enterococcus analyses. Results of bacteriological analyses are contained in Appendix A.

The twelve stations in the Bight Apex were sampled once a week. Depending upon sea conditions, the EPA helicopter hovered or landed at the designated station and a 1-liter Kemmerer sampler was used to obtain water samples. Samples are taken at 1 meter below the surface and 1 meter above the ocean floor. Immediately after collection, the water sample was transferred to a biochemical oxygen demand bottle for dissolved oxygen analysis. The dissolved oxygen sample was then fixed at the station by the addition of 2 ml of manganous sulfate followed by 2 ml of alkali-iodide-azide reagent. The sample was shaken to facilitate floc formation and then placed in a metal rack. The samples were held for less than 6 hours before returning to the laboratory, where 2 ml of sulfuric acid were added, and the samples were titrated with 0.0375N sodium thiosulfate.

The third scheduled sampling portion of the program consisted of sampling perpendicular stations once a week for dissolved oxygen and temperature. Again, as with the inner Bight stations, samples were collected while hovering or landing, at 1 meter above the ocean bottom.

The fourth routinely scheduled sampling component involved the collection of water samples for phytoplankton identification and quantification, and chlorophyll analysis. Phytoplankton and chlorophyll samples collected along the New Jersey coast were analyzed by the New Jersey Department of Environmental Protection (NJDEP). The samples were collected as close to the surface as possible, using 1-liter Kemmerer samplers. A 1-liter plastic cubitainer was filled for phytoplankton analysis and identification, and cooled to $4^0$C for preservation. The NJDEP picked up their phytoplankton samples at our Edison laboratory within 24 hours of collection. At the laboratory, the NJDEP removed an aliquot of sample from the cubitainer for chlorophyll analysis. The results of NJDEP'S analysis are contained in Appendix B.

# III. DESCRIPTION OF SAMPLING STATIONS

## Beach Stations

A total of 72 bathing beach areas were sampled routinely for bacteriological water quality along the Long Island and New Jersey coastlines. The Long Island sampling stations extend from the western tip of Rockaway Point 130 km eastward to Shinnecock Inlet for a total of 26 stations (LIC 01-LIC 28). Sample station locations, nomenclature, and descriptions are given in Table 2 and Figure 3. There are 46 New Jersey coast stations, beginning at Sandy Hook extending south to Cape May Point (JC 01A-JC 99). These stations are described and identified in Table 3 and in Figures 4 and 5.

## New York Bight Stations

The New York Bight stations, established as part of the original ocean monitoring program, cover the east and south boundary of the inner Bight area in approximately 3 km intervals via two transects as follows: New Jersey Transect (NYB 20-NYB 25), extending from Sandy Hook 15 km eastward to the 12-mile inactive sewage sludge dump site; and the Long Island Transect (NYB 41-NYB 45), extending from Atlantic Beach, Long Island, southward to the northwest corner of the 12-mile inactive sewage sludge dump site. In addition, station NYB 35 is sampled for coverage of the Christiansen Basin. The locations of the New York Bight stations are shown in Figure 6.

Table 2

Long Island coast station locations

| Station No. | Location |
|---|---|
| LIC 01 | Rockaway Point, Breezy Point Surf Club |
| LIC 02 | Rockaway, off foot of B169 Road |
| LIC 03 | Rockaway, off foot of B129 Road |
| LIC 04 | Rockaway, off foot of B92 Road |
| LIC 05 | Far Rockaway, off foot of B41 Road |
| LIC 07 | Atlantic Beach, Silver Point Beach Club |
| LIC 08 | Long Beach, off foot of Grand Avenue |
| LIC 09 | Long Beach, off foot of Pacific Boulevard |
| LIC 10 | Point Lookout, off Hempstead public beach |
| LIC 12 | Short Beach (Jones Beach), off "West End 2" parking lot |
| LIC 13 | Jones Beach |
| LIC 14 | East Overlook |
| LIC 15 | Gilgo Beach |
| LIC 16 | Cedar Island Beach |
| LIC 17 | Robert Moses State Park |
| LIC 18 | Great South Beach |
| LIC 19 | Cherry Grove |
| LIC 20 | Water Island |
| LIC 21 | Bellport Beach |
| LIC 22 | Smith Point County Park |
| LIC 23 | Moriches Inlet West |
| LIC 24 | Moriches Inlet East |
| LIC 25 | West Hampton Beach |
| LIC 26 | Tiana Beach |
| LIC 27 | Shinnecock Inlet West |
| LIC 28 | Shinnecock Inlet East |

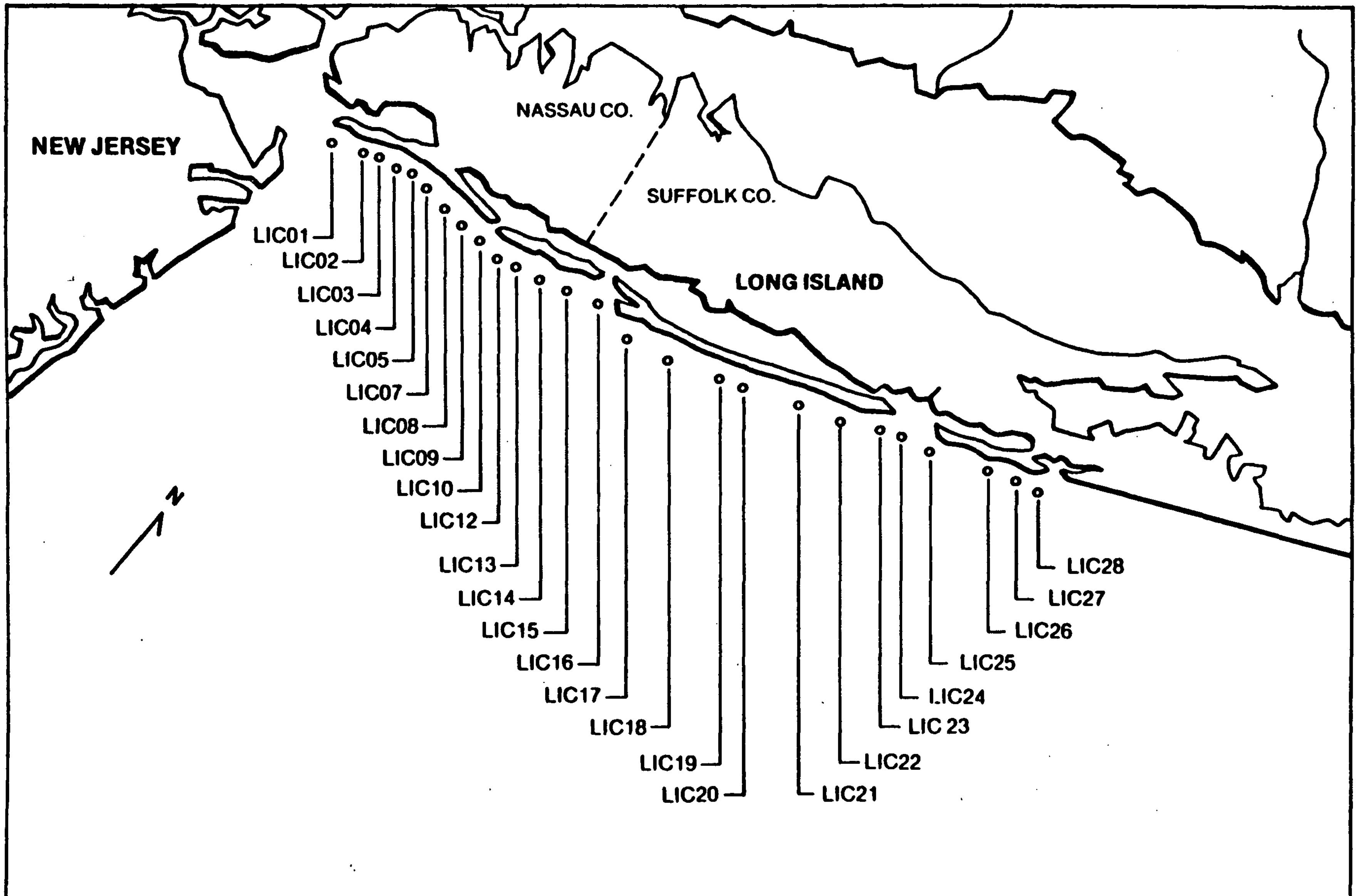



**FIGURE 3**
**LONG ISLAND COAST STATION LOCATIONS**

Table 3

New Jersey coast station locations

| Station No. | Location |
|---|---|
| JC 01A | Sandy Hook, 1.2 km south of tip |
| JC 03 | Sandy Hook, off Nature Center building (tower) |
| JC 05 | Sandy Hook, just north of Park entrance |
| JC 08 | Sea Bright, at public beach |
| JC 11 | Monmouth Beach Bath & Tennis Club |
| JC 13 | Long Branch, Chelsea Avenue |
| JC 14 | Long Branch, off foot of S. Bath Avenue |
| JC 21 | Asbury Park, off building north of Convention Hall |
| JC 24 | Bradley Beach, off foot of Cliff Avenue |
| JC 26 | Shark River Inlet |
| JC 27 | Belmar, off the "White House" near fishing club pier |
| JC 30 | Spring Lake, south of yellow brick building on beach |
| JC 33 | Sea Girt, off foot of Chicago Avenue |
| JC 35 | One block north of Manasquan Inlet |
| JC 36 | Manasquan Inlet, off Third Avenue |
| JC 37 | Point Pleasant, south of Manasquan Inlet |
| JC 41 | Bay Head, off foot of Johnson Street |
| JC 44 | Mantoloking, off foot of Albertson Street |
| JC 47A | Silver Beach, off foot of Colony Road |
| JC 49 | Lavallette, off foot of Washington Avenue |

Table 3 (continued)

| Station No. | Location |
|---|---|
| JC 53 | Seaside Heights, between the amusement piers |
| JC 55 | Island Beach State Park, off white building north of Park Headquarters |
| JC 57 | Island Beach State Park, between two main parking lots in center of park |
| JC 59 | Island Beach State Park, off white house next to the lookout tower |
| JC 61 | Barnegat, first rock jetty south of Barnegat Inlet |
| JC 63 | Harvey Cedars, opposite Harvey Cedars standpipe |
| JC 65 | Ship Bottom, opposite Ship Bottom water tower |
| JC 67 | Beach Haven Terrace, opposite standpipe |
| JC 69 | Beach Haven Heights, opposite the most southern water tower on Long Beach Island |
| JC 73 | Brigantine, off large hotel on beach |
| JC 74 | Absecon Inlet |
| JC 75 | Atlantic City, off the Convention Center |
| JC 77 | Ventnor City, just north of fishing pier |
| JC 79 | Longport, off water tower |
| JC 81 | Ocean City, opposite large apartment building |
| JC 83 | Peck Beach, opposite large blue water tower |
| JC 85 | Strathmere, off blue standpipe |
| JC 87 | Sea Isle City, opposite blue water tower with bridge in the background |

Table 3 (continued)

| Station No. | Location |
|---|---|
| JC 89 | Avalon, off beige building on the beach |
| JC 91 | Stone Harbor, off large blue water tower |
| JC 92 | Hereford Inlet |
| JC 93 | Wildwood, off northern amusement pier |
| JC 95 | Two mile beach, opposite radio tower |
| JC 96 | Cape May Inlet |
| JC 97 | Cape May, off white house with red roof on the beach |
| JC 99 | Cape May Point, opposite lighthouse |

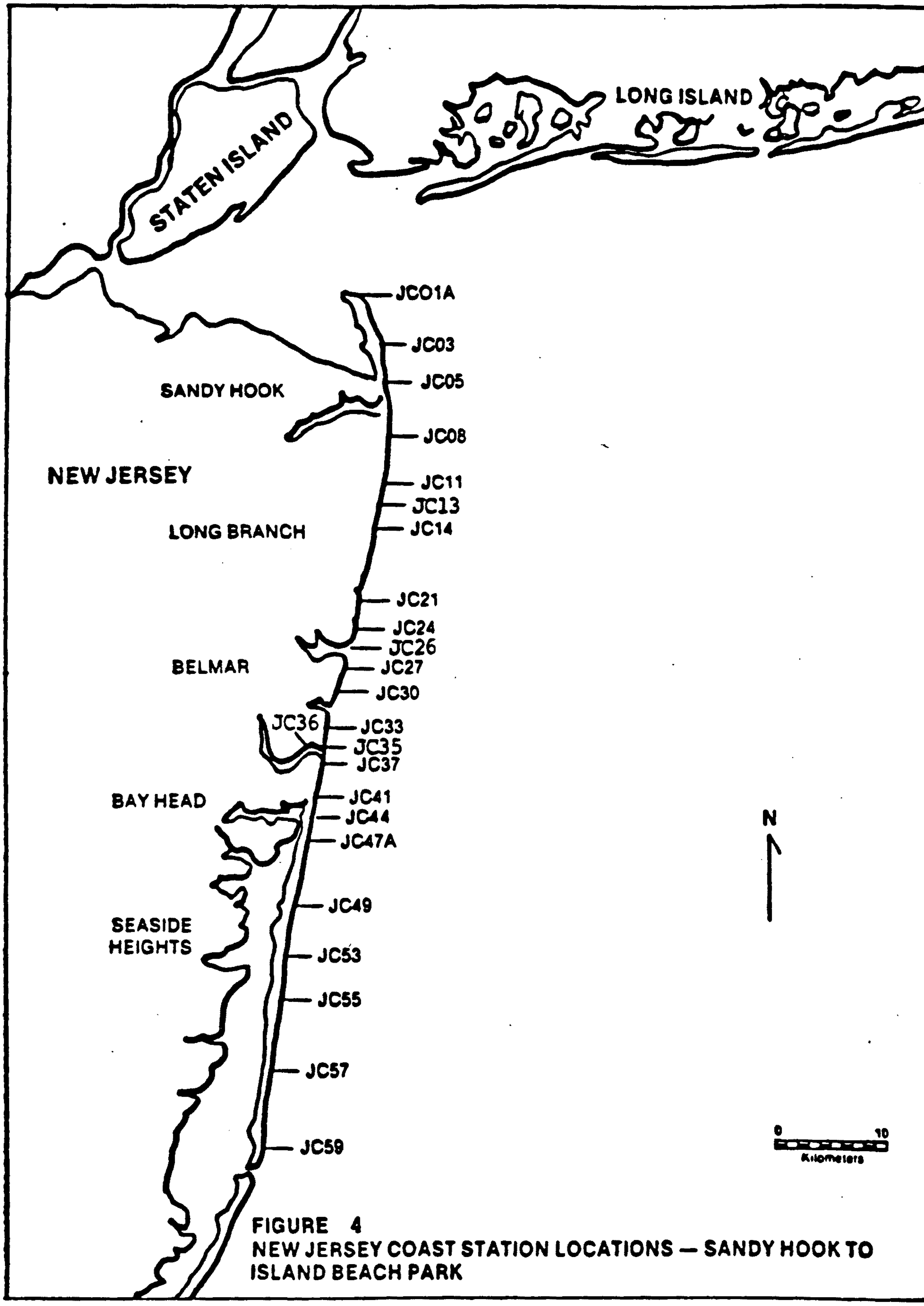



FIGURE 4
NEW JERSEY COAST STATION LOCATIONS — SANDY HOOK TO ISLAND BEACH PARK

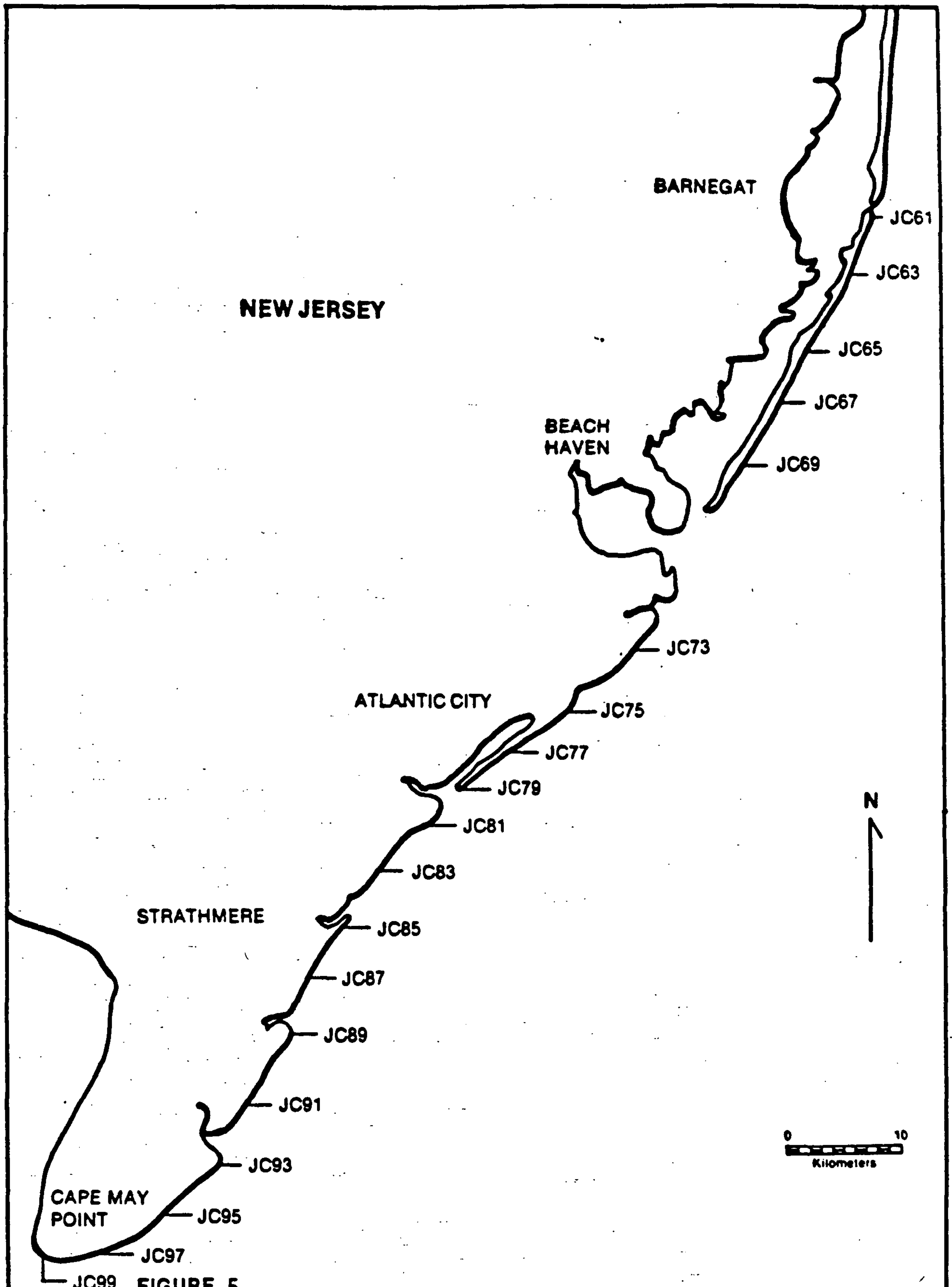



FIGURE 5
NEW JERSEY COAST STATION LOCATIONS — BARNEGAT TO CAPE MAY POINT

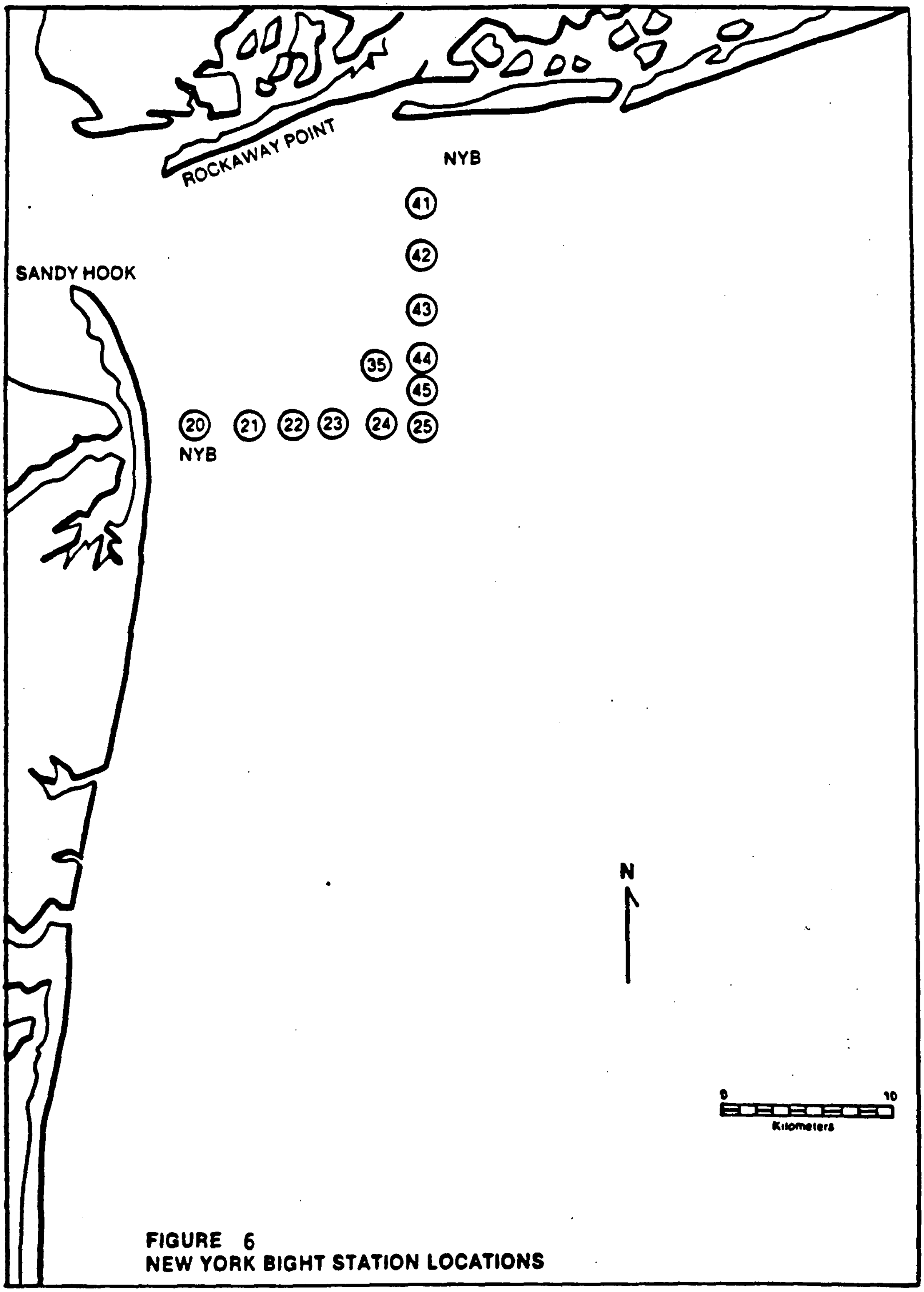



FIGURE 6
NEW YORK BIGHT STATION LOCATIONS

## Perpendicular Stations

Sampling stations perpendicular to the Long Island coastline are 5.4 km, 12.6 km, 19.8 km, and 27 km [3, 7, 11 and 15 nautical miles (nm)] offshore. Sampling stations perpendicular to the New Jersey coastline start at 1.8 km and are spaced every 1.8 km out to 18 km (1 nm, with 1 nm increments, to 10 nm) offshore. These stations are identified by suffixes E through M, with the exception of the Manasquan (MAS) perpendicular stations which have corresponding suffixes 1 through 9. Normally, only every other New Jersey perpendicular station (3.6 km intervals) was sampled; the intermediate stations remained available should dissolved oxygen conditions warrant more intensive sampling.

The perpendicular stations were established to gather surface and bottom dissolved oxygen values in the critical areas of the New York Bight nearshore waters. Previous agreements had been made with the National Oceanic and Atmospheric Administration (NOAA) to provide dissolved oxygen profiles from stations further out in the Bight in conjunction with their existing programs.

The perpendicular stations described above are plotted in Figures 7 and 8. Tables 2 and 3 describe the shore station locations from which the perpendicular stations originate.

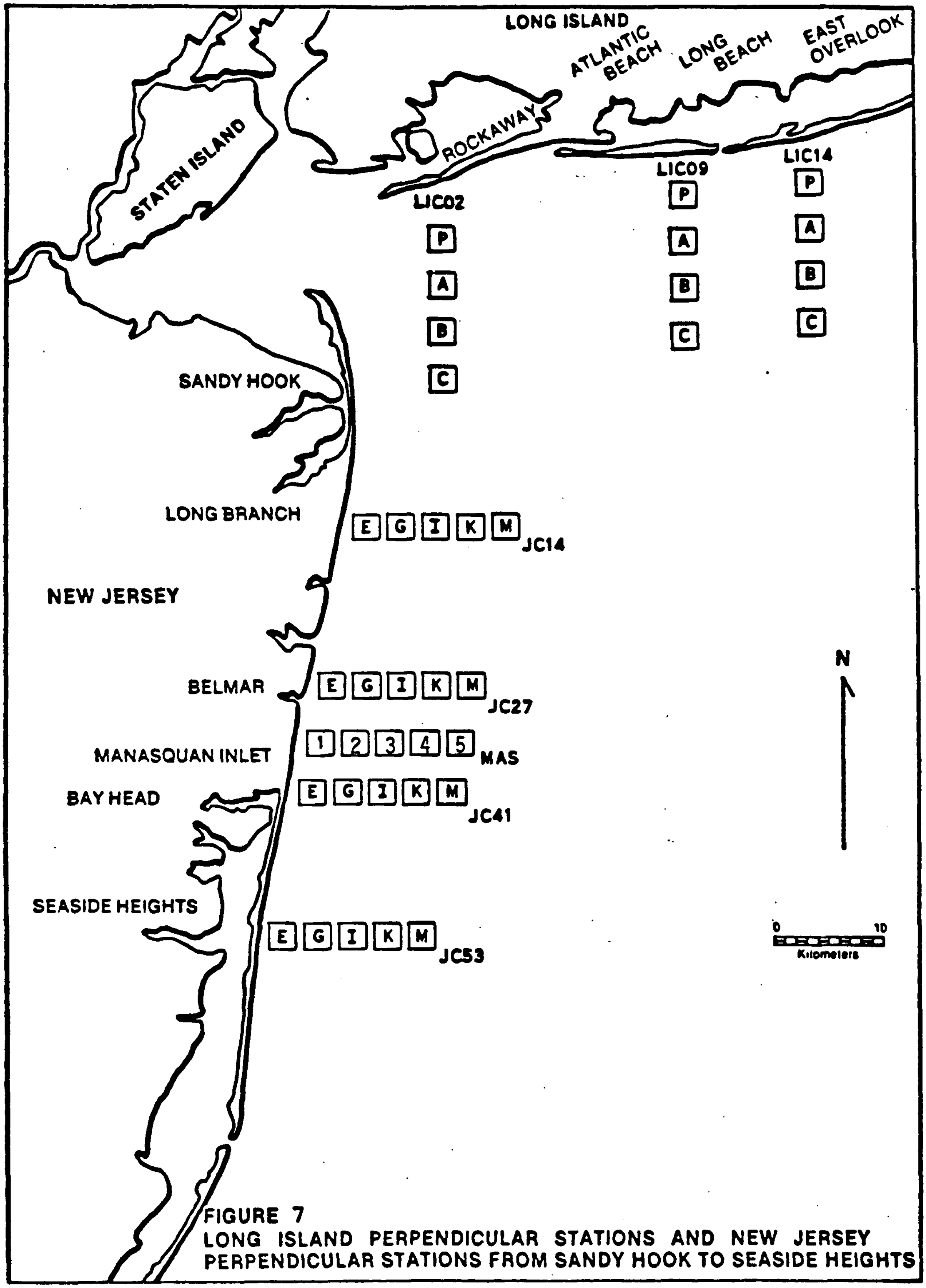



FIGURE 7
LONG ISLAND PERPENDICULAR STATIONS AND NEW JERSEY PERPENDICULAR STATIONS FROM SANDY HOOK TO SEASIDE HEIGHTS

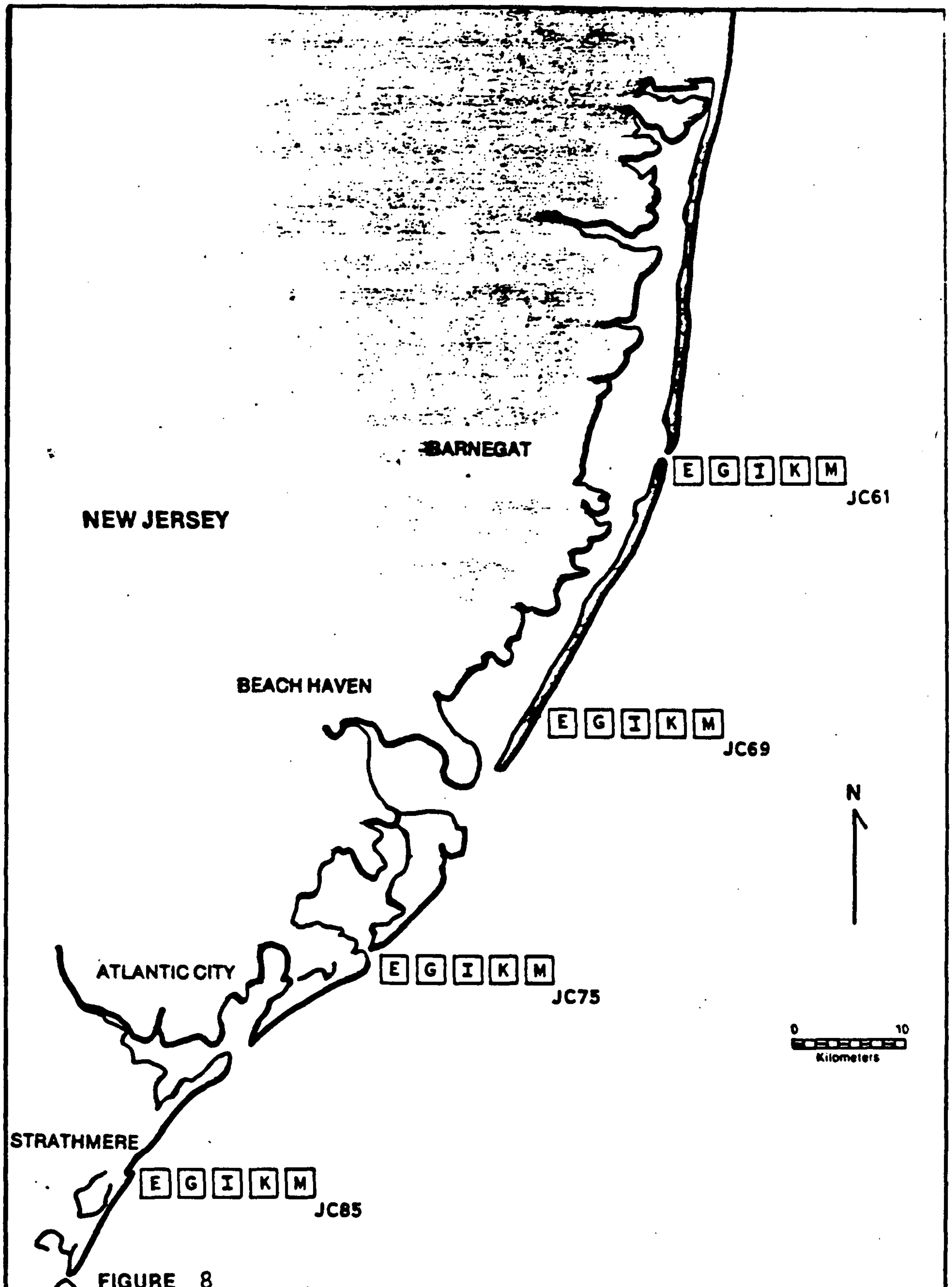



FIGURE 8
NEW JERSEY PERPENDICULAR STATIONS FROM BARNEGAT TO STRATHMERE

## Phytoplankton Stations

Phytoplankton samples were collected once a week along the New Jersey coast and in Raritan Bay, Sandy Hook Bay, and Delaware Bay at the following stations:

| | | | |
|---|---|---|---|
| RB 15 | JC 33 | JC 77 | DB 1 |
| RB 24 | JC 57 | JC 83 | DB 2 |
| JC 14 | JC 65 | JC 91 | |

A discussion of phytoplankton dynamics and bloom incidence in New Jersey waters is presented in Appendix B.

# IV. DISSOLVED OXYGEN RESULTS AND DISCUSSION

## NORMAL TRENDS IN THE OCEAN

Two major processes act to replenish dissolved oxygen in the water column of the New York Bight. These are: the photosynthetic conversion of carbon dioxide to molecular oxygen, and the mechanical reaeration of oxygen across the air-water interface. Subsequent turbulent diffusion then distributes the dissolved oxygen throughout the water column or into the upper warmer surface layer when stratified conditions prevail. Concurrent oxygen utilization (depletion) processes, such as bacterial respiration and sediment oxygen demand, act to influence the amount of oxygen in the water column at any one time or location.

A general description of the oxygen cycle during a calendar year is as follows:

> In early January, the waters of the Bight are completely mixed throughout the water column with temperatures ranging from $4^0C$ to $10^0C$ while dissolved oxygen values are between 8 and 10 mg/l with slightly depressed values at the sediment-water interface. The warm spring air temperatures and solar heating increase the temperature of the upper water layer and, in the absence of high energy input from local storms or

tropical hurricanes, a thermally stratified water column develops. This stratification effectively blocks the free transport of the oxygen-rich upper layer into the cool oxygen-poor bottom waters.

As hot summer weather conditions set in, the warmer upper layer of water remains completely mixed and rich in oxygen (7 to 9 mg/l). This upper layer ranges from 20 to 60 meters in depth depending on time and location. The cooler bottom water is effectively isolated from the upper layer by a $10^0$C temperature gradient. Respiration of bottom organisms, bacterial action on algal remains and detritus, and sediment oxygen demand depress the residual dissolved oxygen values in the bottom waters. In a typical year, the dissolved oxygen concentration in the bottom waters of the bight reaches a minimum in mid to late summer of approximately 4 mg/l. At this time, cool evenings and reduced solar input cause the upper waters to cool, decreasing the temperature gradient between the two water masses. As the two masses become closer and closer in temperature, the energy required to break down the thermocline becomes less and less until finally, in many instances after a local storm, there is a complete mixing of the water column with concomitant reoxygenation of the bottom waters. The annual cycle begins again. Figure 9 depicts a representative history of dissolved oxygen concentration in the general ocean area off of New Jersey, New York, and New England.

## Dissolved oxygen criteria

The dissolved oxygen levels necessary for survival and/or reproduction vary among biological species. Sufficient data have not been accumulated to assign definitive limits or lower levels of tolerance for each species at various growth stages. Rough guidelines are available for aquatic species for purposes of surveillance and monitoring. These are as follows:

| | |
|---|---|
| 5 mg/l and greater | - healthy |
| 4 - 5 mg/l | - borderline to healthy |
| 3 - 4 mg/l | - stressful if prolonged |
| 2 - 3 mg/l | - lethal if prolonged |
| less than 2 mg/l | - lethal in a relatively short time. |

These criteria are consistent with biological information recorded in the New York Bight over the past 15-20 years. Most data concerning the lower tolerance levels were recorded during the summer of 1976. In 1976, widespread and persistent dissolved oxygen levels between 0.0 and 2.0 mg/l occurred over a large area of the Bight. This resulted in extensive fishkills and benthic organism mortality.

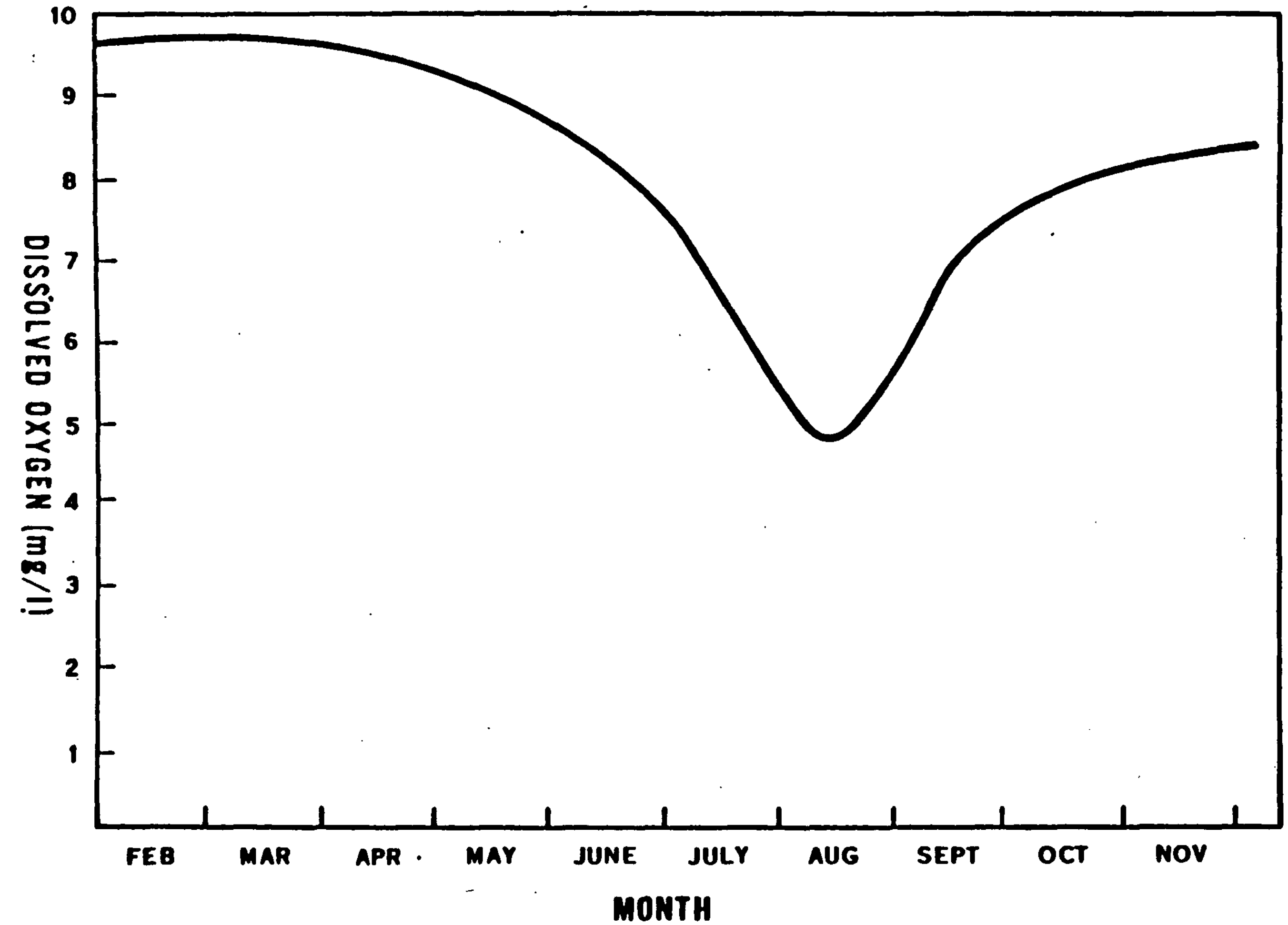



FIGURE 9
GENERALIZED ANNUAL MARINE DISSOLVED OXYGEN CYCLE OFF THE NORTHEAST U.S. (FROM NOAA)

## Surface Dissolved Oxygen - 1990

During the 1990 sampling period, May 22 through September 26, surface dissolved oxygen samples were collected during the months of July, August and September. The completely mixed upper water column had dissolved oxygen levels at or near saturation during the three months of sampling. Data from previous years indicate that, during May and June, the upper water column remained completely mixed. There is no reason to suspect 1990 was any different, therefore, no further discussion of surface dissolved oxygen will be presented in this report.

## Bottom Dissolved Oxygen - 1990

### Long Island Coast

Long Island perpendicular LIC02 was sampled four times, and perpendiculars, LIC09 and LIC14 were sampled three times during the 1990 sampling period. A total of 40 bottom samples were collected for dissolved oxygen. For the most part, dissolved oxygen levels remained well above the 4 mg/l "borderline to healthy" guideline. Only one sample was below this guideline. On September 24, station LIC02A, three nautical miles off Rockaway, had a dissolved oxygen concentration of 3.3 mg/l. Eight dissolved oxygen concentrations were between 4-5 mg/l. These values are only slightly below the standard of 5 mg/l, and are consistent with temporarily depressed values observed in this area in other years during late August and September. These eight values were:

| Station | Date | Dissolved Oxygen (mg/l) |
|---|---|---|
| LIC02A | 8/31/90 | 4.3 |
| LIC09A | 8/31/90 | 4.4 |
| LIC14P | 8/31/90 | 4.5 |
| LIC02P | 9/24/90 | 4.7 |
| LIC02C | 9/24/90 | 4.7 |
| LIC09A | 9/24/90 | 4.8 |
| LIC14A | 9/24/90 | 4.1 |
| LIC14C | 9/24/90 | 4.4 |

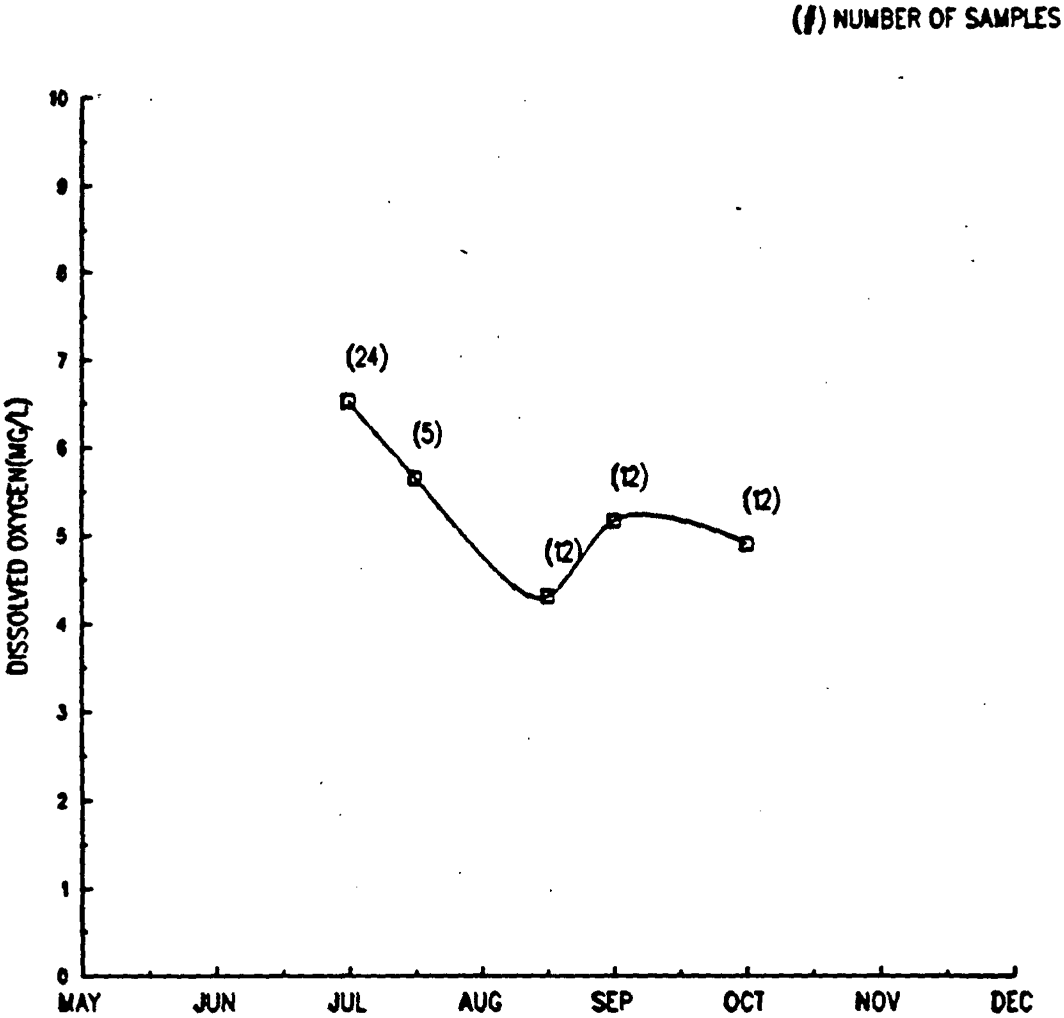
Based on the data, dissolved oxygen remained well above the concentrations considered stressful to aquatic life.

## New York Bight Apex

Figure 10 illustrates the semimonthly dissolved oxygen averages at the New York Bight Apex stations from June to October, 1990. During the summers of 1987, 1988 and 1989, a "double minima" was observed in the New York Bight Apex. A "double minima" was not observed in 1990, Figure 10, and may be due to the decrease in sampling frequency. The dissolved oxygen average in mid June was approximately 6.5 mg/l. It gradually declined to a low of 4.3 mg/l in mid August. It then increased to 5.2 mg/l in mid September, and decreased slightly in October. Recovery probably occurred after the cessation of sampling.

A total of 65 samples were collected in the New York Bight Apex from June 15 to September 20, 1990 and measured

Figure 10




NEW YORK BIGHT BOTTOM DISSOLVED OXYGEN, 1990.
SEMIMONTHLY AVERAGE OF ALL NEW YORK BIGHT STATIONS.

for dissolved oxygen. Sixteen dissolved oxygen values, or 24.6 percent, were between 4-5 mg/l. Seven samples, or 10.8 percent, were between the 3-4 mg/l level considered "stressful if prolonged" for aquatic life, and one dissolved oxygen value was in the 2-3 mg/l level considered "lethal if prolonged" for aquatic life. The eight dissolved oxygen values below 4 mg/l were:

| Station | Date | Dissolved Oxygen (mg/l) |
|---|---|---|
| NYB 22 | 7/14/90 | 3.9 |
| NYB 21 | 8/14/90 | 3.8 |
| NYB 25 | 8/14/90 | 3.7 |
| NYB 35 | 8/14/90 | 3.8 |
| NYB 43 | 8/14/90 | 2.9 |
| NYB 44 | 8/14/90 | 3.5 |
| NYB 24 | 9/20/90 | 3.7 |
| NYB 35 | 9/20/90 | 3.9 |

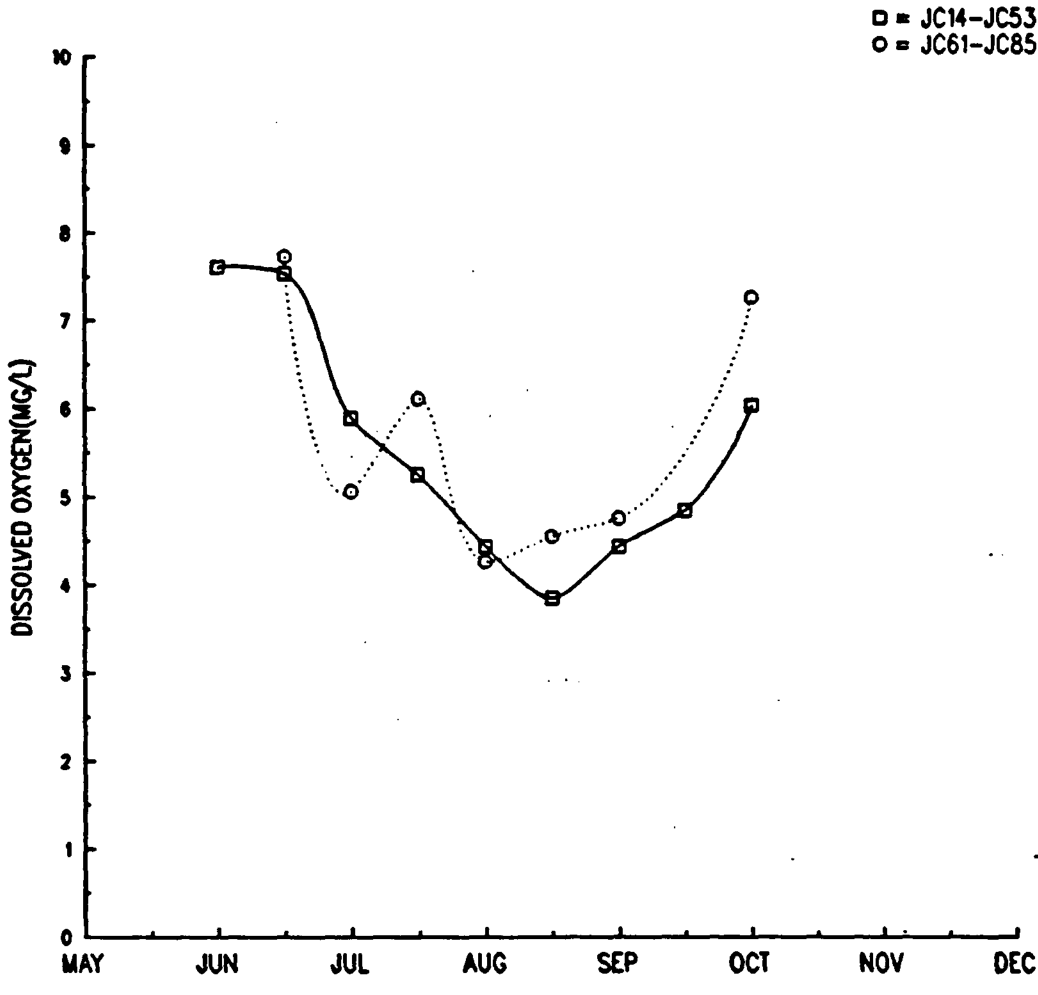
This is consistent with the normal dissolved oxygen sag curve in the New York Bight Apex.

**New Jersey Coast**

Figure 11 illustrates the semimonthly dissolved oxygen average off the New Jersey coast during the summer of 1990, with separate lines for the northern (JC 14-JC 53) perpendiculars and the southern (JC 61-JC 85) perpendiculars. The dissolved oxygen average along the southern perpendiculars exhibited a "double minima". In mid June, the dissolved oxygen average was approximately 7.7 mg/l. It then decreased to 5.1 mg/l, reaching the first low in early July. The dissolved oxygen average then increased to 6.1 mg/l in mid July. It subsequently declined to a second low, of approximately 4.3 mg/l, in early August. Recovery occurred in early September. Along the northern New Jersey perpendiculars, the dissolved oxygen average follows the dissolved oxygen cycle for the northeast United States, Figure 9. In mid June, the dissolved oxygen average was approximately 7.5 mg/l. It decreased slowly, reaching a low of approximately 3.9 mg/l in mid August. This was followed by a strong dissolved oxygen recovery in early October.

Table 4 summarizes the bottom dissolved oxygen values for the New Jersey coast perpendiculars. There were 406 samples collected along the New Jersey perpendiculars between May 25 and September 21, 1990 and analyzed for dissolved oxygen. Of these samples, 189 values (46.6 percent) were below 5 mg/l. Of the 189 samples below 5 mg/l, 109 values occurred in August. There were 104 values

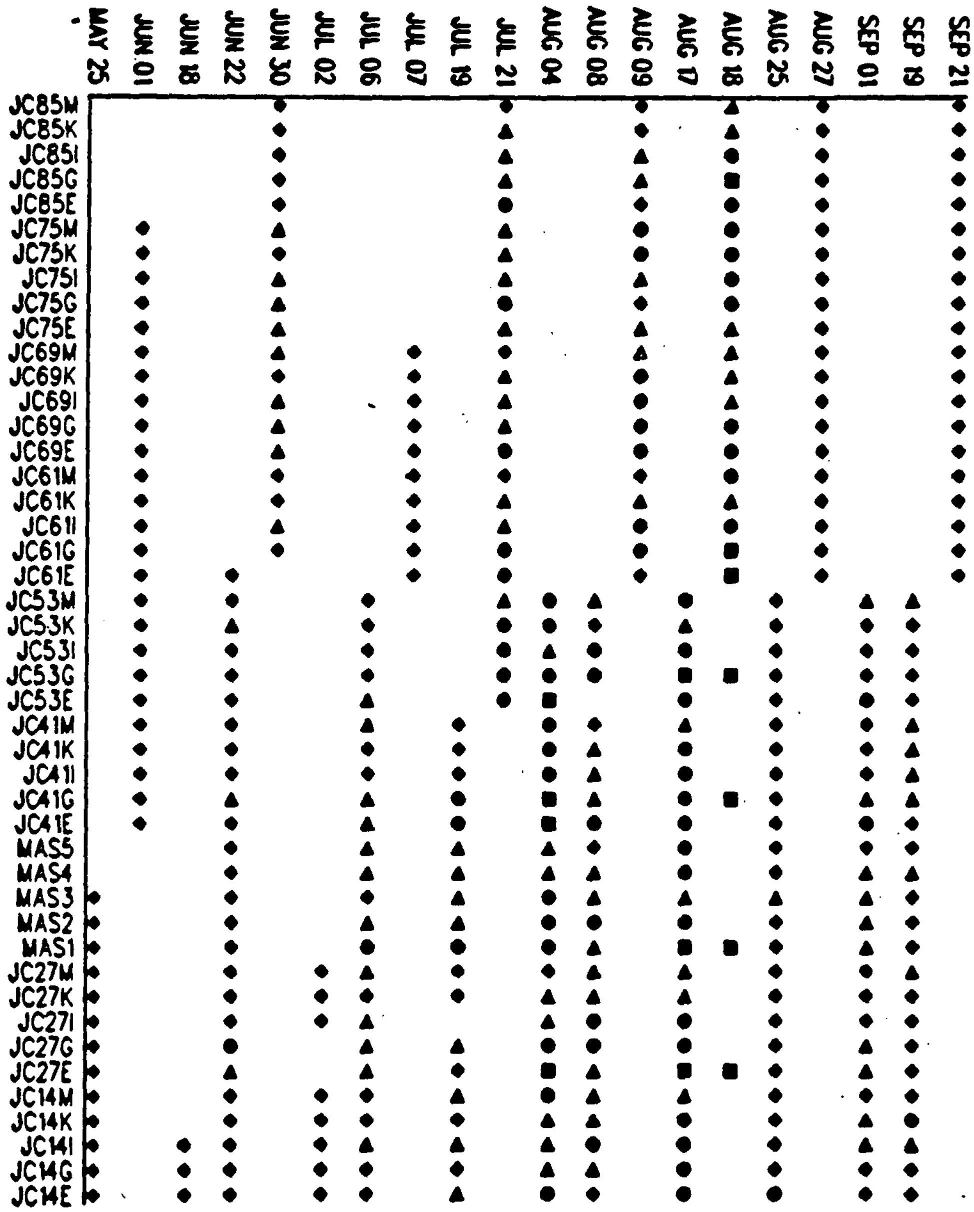
Figure 11




NEW JERSEY COAST BOTTOM DISSOLVED OXYGEN, 1990.
SEMIMONTHLY AVERAGES OF ALL NORTHERN (JC14-JC53) AND
SOUTHERN (JC61-JC85) PERPENDICULAR STATIONS.

Table 4

1990 NJ DO DISTRIBUTUION (BOTTOM VALUES)



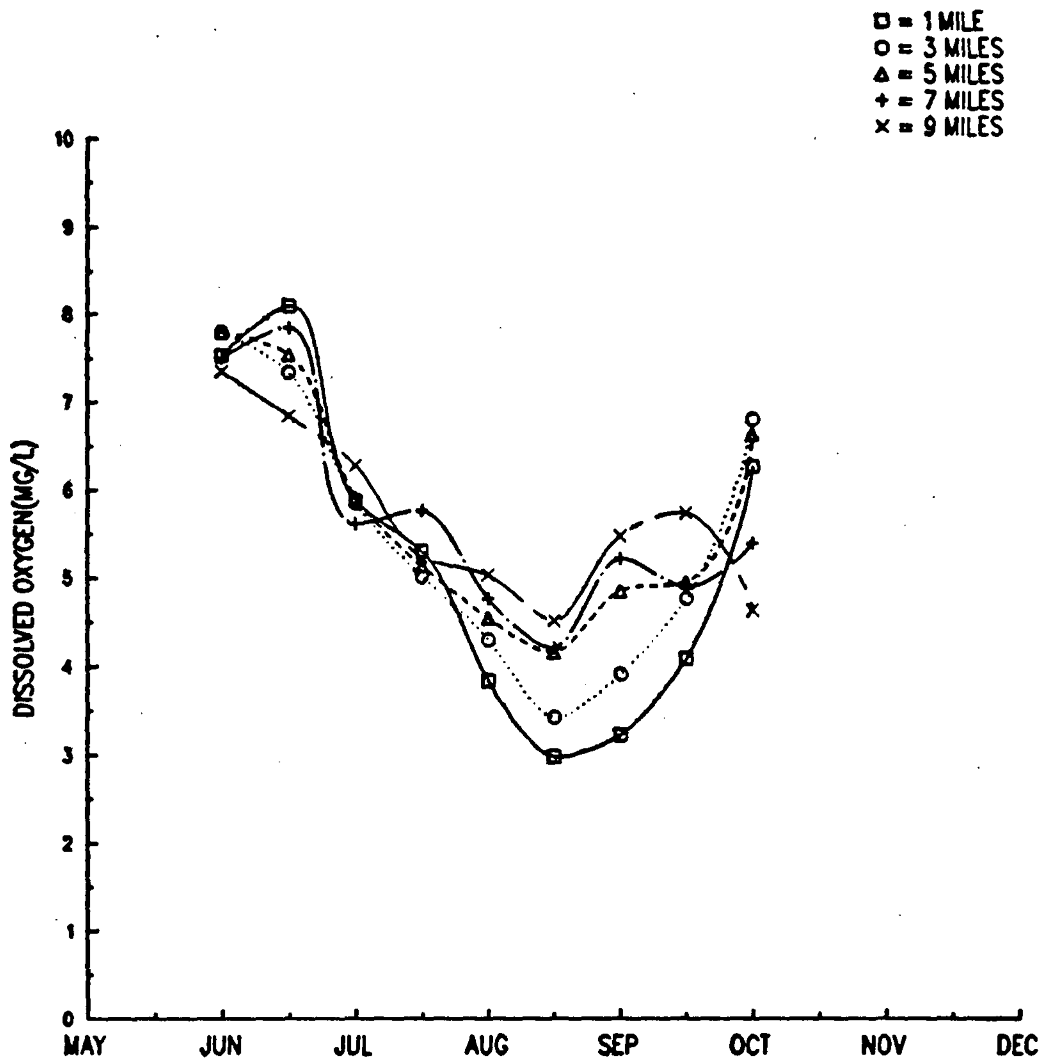

KEY: ◆ - > 5 mg/L ▲ - 4-5 mg/L ● - 2-4 mg/L ■ - 0-2 mg/L

(25.6 percent of all samples collected) between 4-5 mg/l, 71 values (17.5 percent) were between 2-4 mg/l, and 14 values (3.4 percent) were between 0-2 mg/l. All 14 values below 2 mg/l occurred in August. In comparison, during the summer of 1989, 347 samples were collected. A total of 106 values (30.5 percent) were below 5 mg/l. Of these, 60 values (17.3 percent of all samples) were between 4-5 mg/l, 42 values (12.1 percent) were between 2-4 mg/l, and four values (1.2 percent) were between 0-2 mg/l. Overall, dissolved oxygen values in 1990 were lower than those encountered in 1989.

Historically, dissolved oxygen at the bottom reaches a minimum in late August/early September due to a lack of reaeration and sediment oxygen demand. Values usually improve later in the season when storms and/or increased winds aid reaeration.

Figure 12 compares the shore to seaward distribution of dissolved oxygen along the northern New Jersey perpendiculars. The dissolved oxygen values increased with distance offshore from July through September. At all distances from shore, dissolved oxygen values generally followed the dissolved oxygen cycle for the northeast United States, Figure 9, reaching a low in August. The dissolved oxygen values increased considerably at all distances from shore in September and October. The lower values at the nearshore stations in northern New Jersey are attributed to the influence of river discharges, treatment

Figure 12

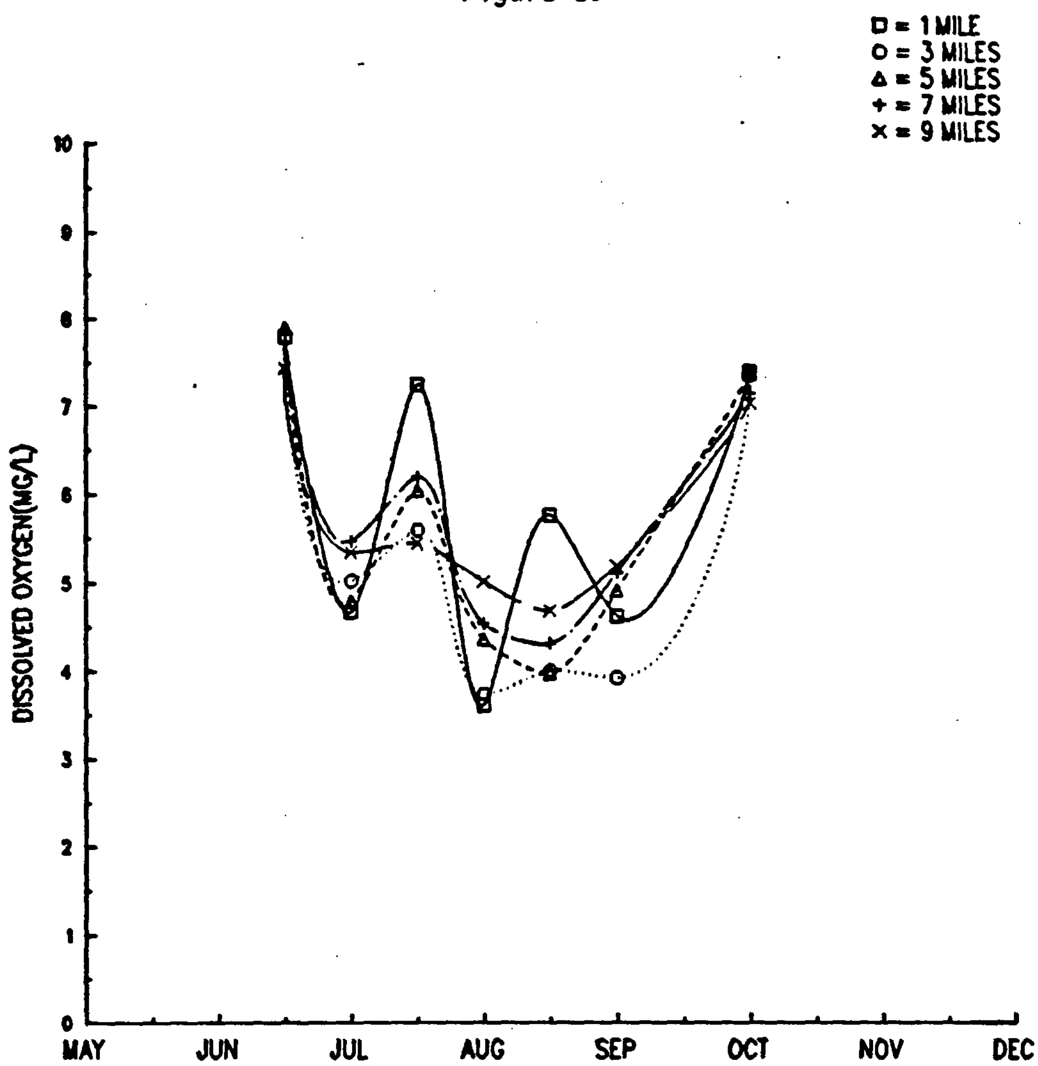



SHORE-TO-SEAWARD DISTRIBUTION OF BOTTOM DISSOLVED OXYGEN, 1990. SEMIMONTHLY AVERAGES OF ALL NORTHERN PERPENDICULAR STATIONS (JC14-JC53), AT FIXED DISTANCES FROM SHORE.

plant effluents, stormwater runoff, benthic oxygen demand from inlet dredged material disposal sites, and the plume from the Hudson-Raritan River Estuary system.

Figure 13 compares the shore to seaward distribution of dissolved oxygen values along the southern New Jersey perpendiculars. A "double minima" occurred at the stations 5, 7, and 9 miles off the coast with dissolved oxygen lows in late June and mid August. The stations one mile offshore, had dissolved oxygen levels drop sharply to a low of 4.7 in early July. The average dissolved oxygen then rose to 7.5 mg/l in mid July and fell to a low of 3.6 mg/l in early August. This was followed by another sharp rise to 6.0 mg/l in mid-August, and a decrease to 4.6 mg/l in early September. All dissolved oxygen values significantly increased in late September.

Figure 13




SHORE-TO-SEAWARD DISTRIBUTION OF BOTTOM DISSOLVED OXYGEN, 1990. SEMIMONTHLY AVERAGES OF ALL SOUTHERN PERPENDICULAR STATIONS (JC61-JC85), AT FIXED DISTANCES FROM SHORE.

## Dissolved Oxygen Trends

Figures 14, 15 and 16 display the number of dissolved oxygen observations below 4 mg/l during July, August and September 1986-1990, for each New Jersey perpendicular. August 1990 had the greatest number of dissolved oxygen values less than 4 mg/l, Figure 15. In August 1990, 68 dissolved oxygen values below 4 mg/l were observed, with the majority of samples occurring along the northern perpendiculars. Most values below 4 mg/l, occurred in the beginning of August, Table 4, and were temporary. Figure 16 illustrates a recovery in September, 1990, with only 3 dissolved oxygen values less than 4 mg/l.

Figure 17 displays the five year dissolved oxygen arithmetic mean of all semimonthly averages for the northern New Jersey perpendicular stations. The average dissolved oxygen in early May was 8.0 mg/l, decreasing slowly to 5.3 mg/l in late July. The dissolved oxygen average stayed at this level until dropping to a low of 4.8 mg/l in late August. This was followed by an increase to 5.3 mg/l in early October, a slight decrease in mid October, and a dissolved oxygen recovery in early November.

Figure 18 displays the five year dissolved oxygen arithmetic mean of all semimonthly averages for the southern New Jersey perpendicular stations. The dissolved oxygen starts off at 8.3 mg/l in mid May, and drops at a fairly consistent rate to 6.1 mg/l in early August. The dissolved oxygen level remains between 5.1 and 5.5 mg/l

Figure 14

DISSOLVED OXYGEN CONCENTRATIONS
BELOW 4 MG/L
NEW JERSEY COAST
JULY 1990

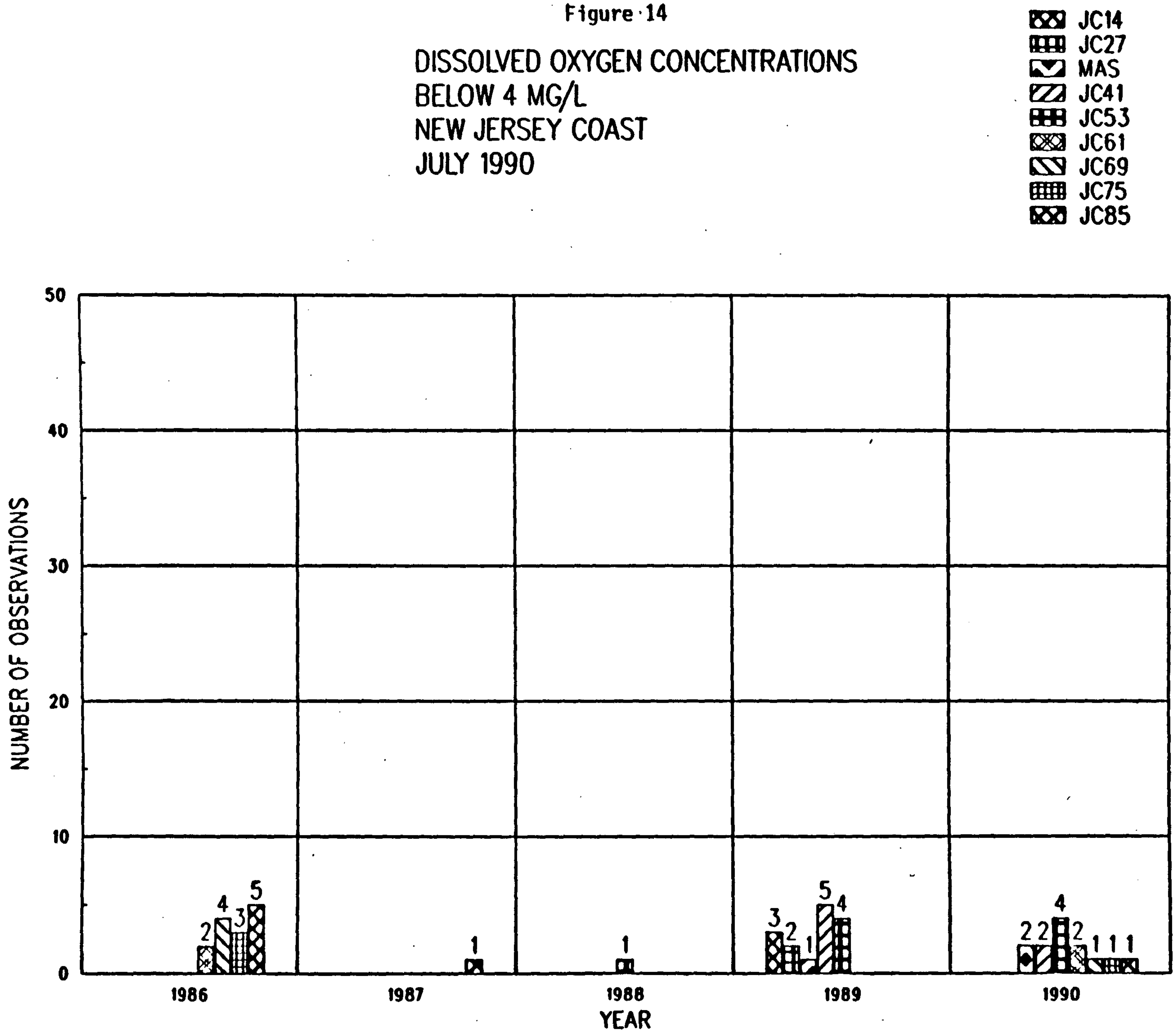


Figure 15

DISSOLVED OXYGEN CONCENTRATIONS
BELOW 4 MG/L
NEW JERSEY COAST
AUGUST 1990

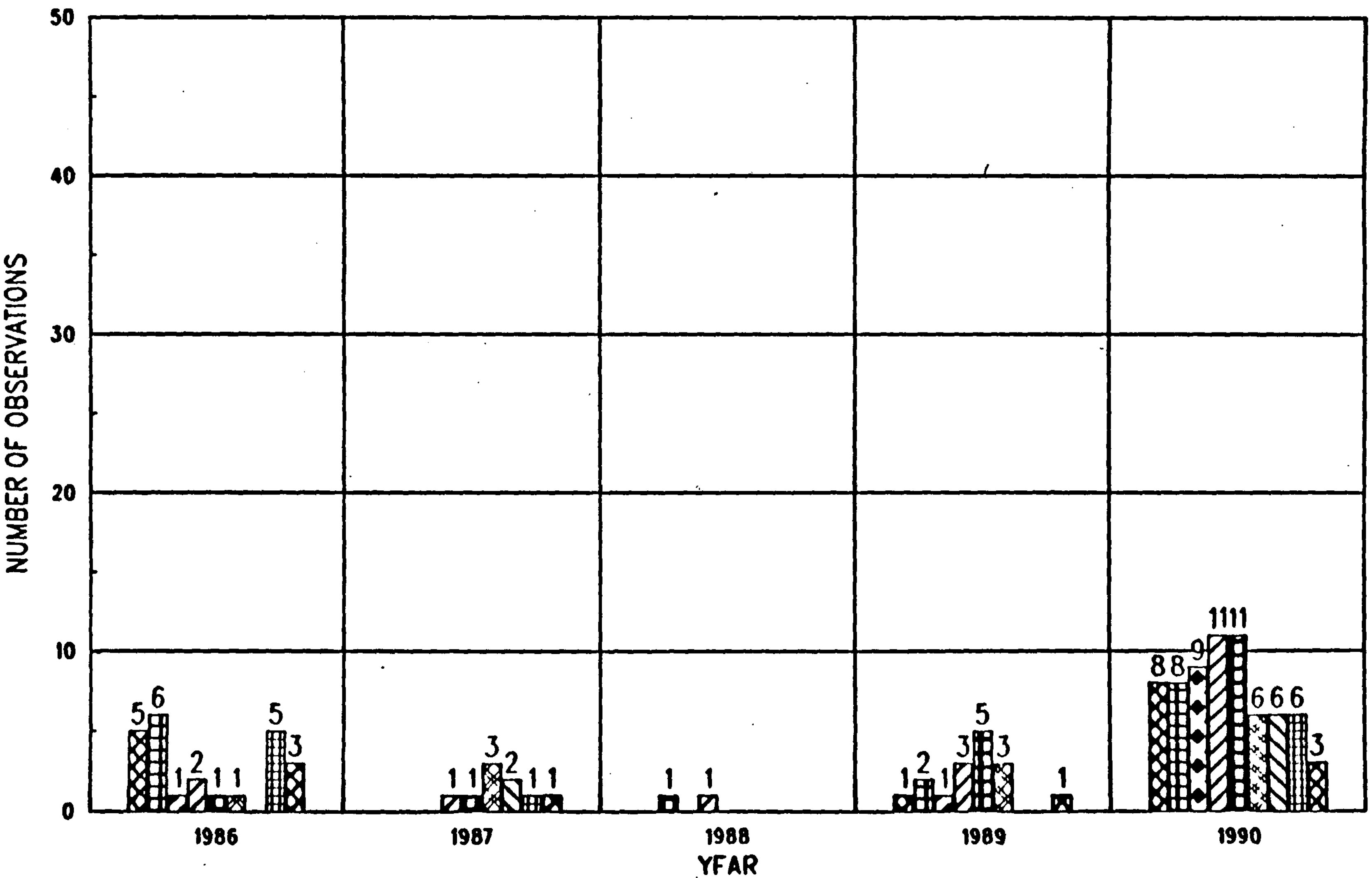


Figure 16

DISSOLVED OXYGEN CONCENTRATIONS
BELOW 4 MG/L
NEW JERSEY COAST
SEPTEMBER 1990

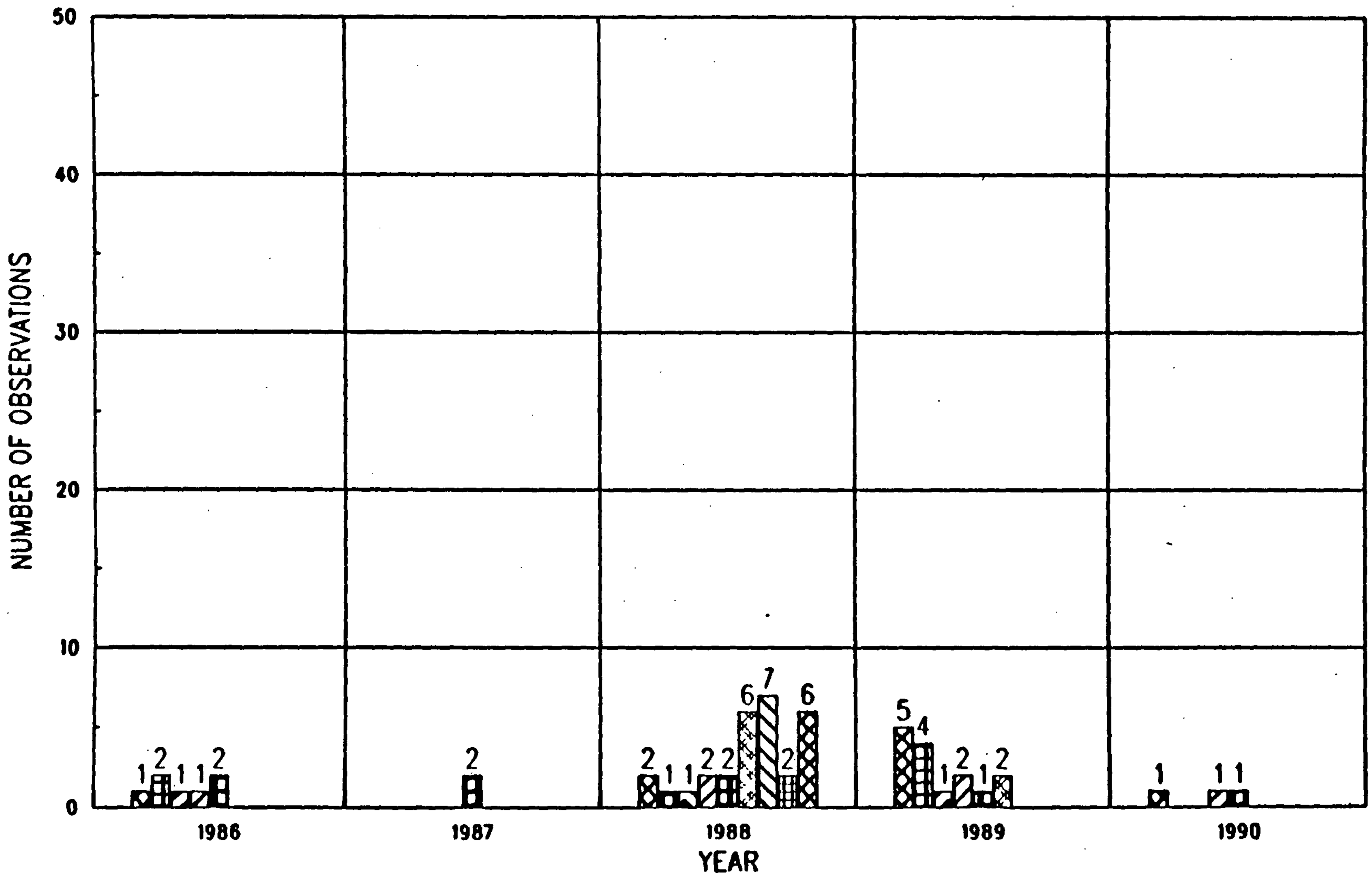
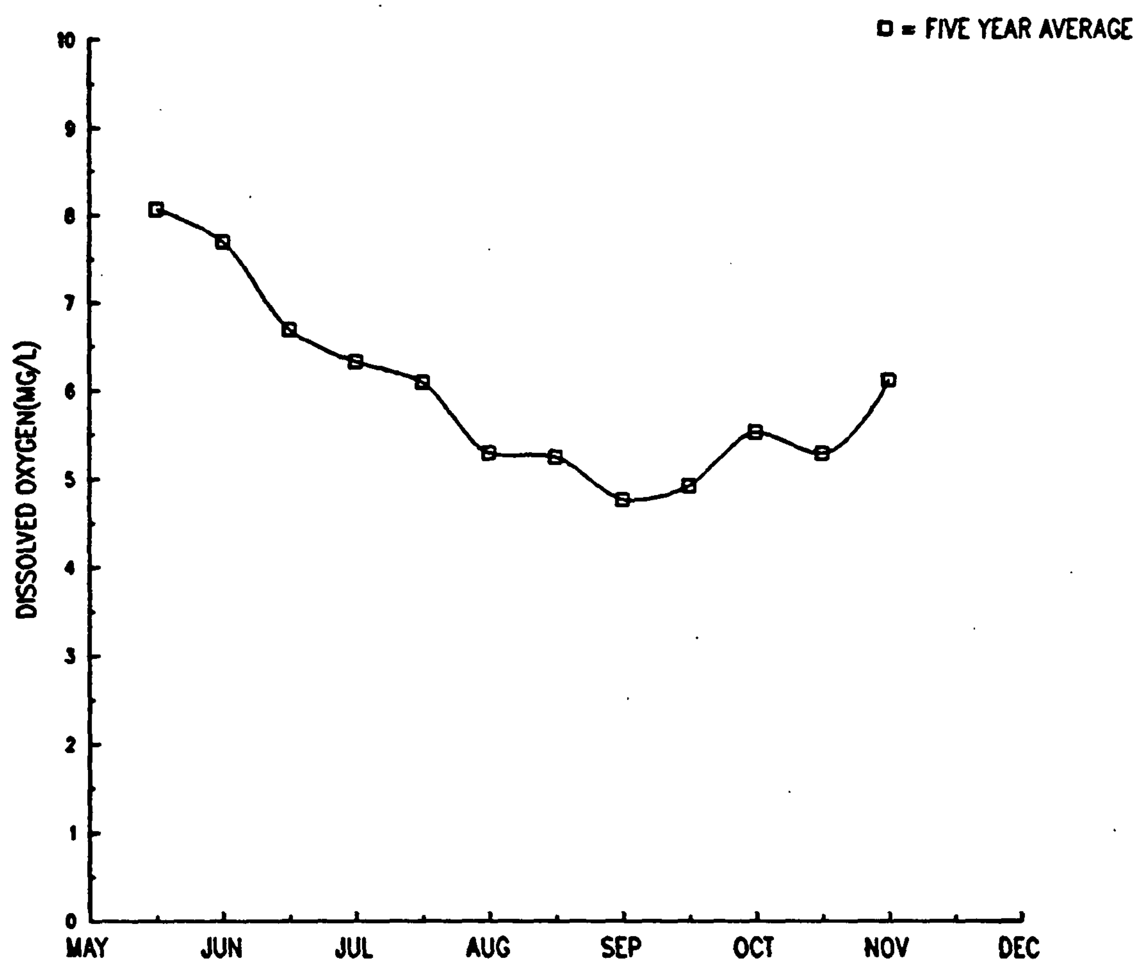
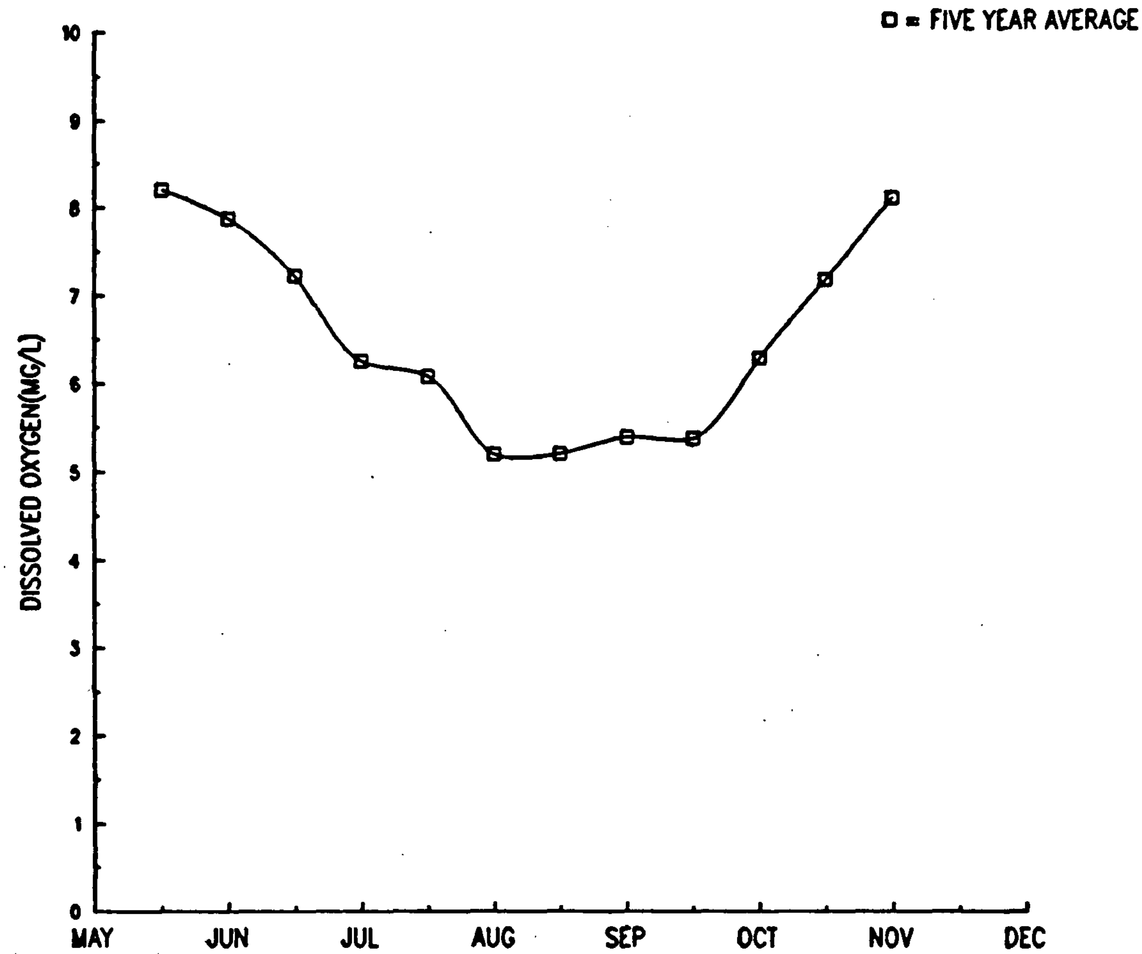


Figure 17




NORTHERN NEW JERSEY COAST BOTTOM DISSOLVED OXYGEN, FIVE YEAR AVERAGE OF THE INDIVIDUAL SEMIMONTHLY AVERAGES, 1986 TO 1990.

Figure 18



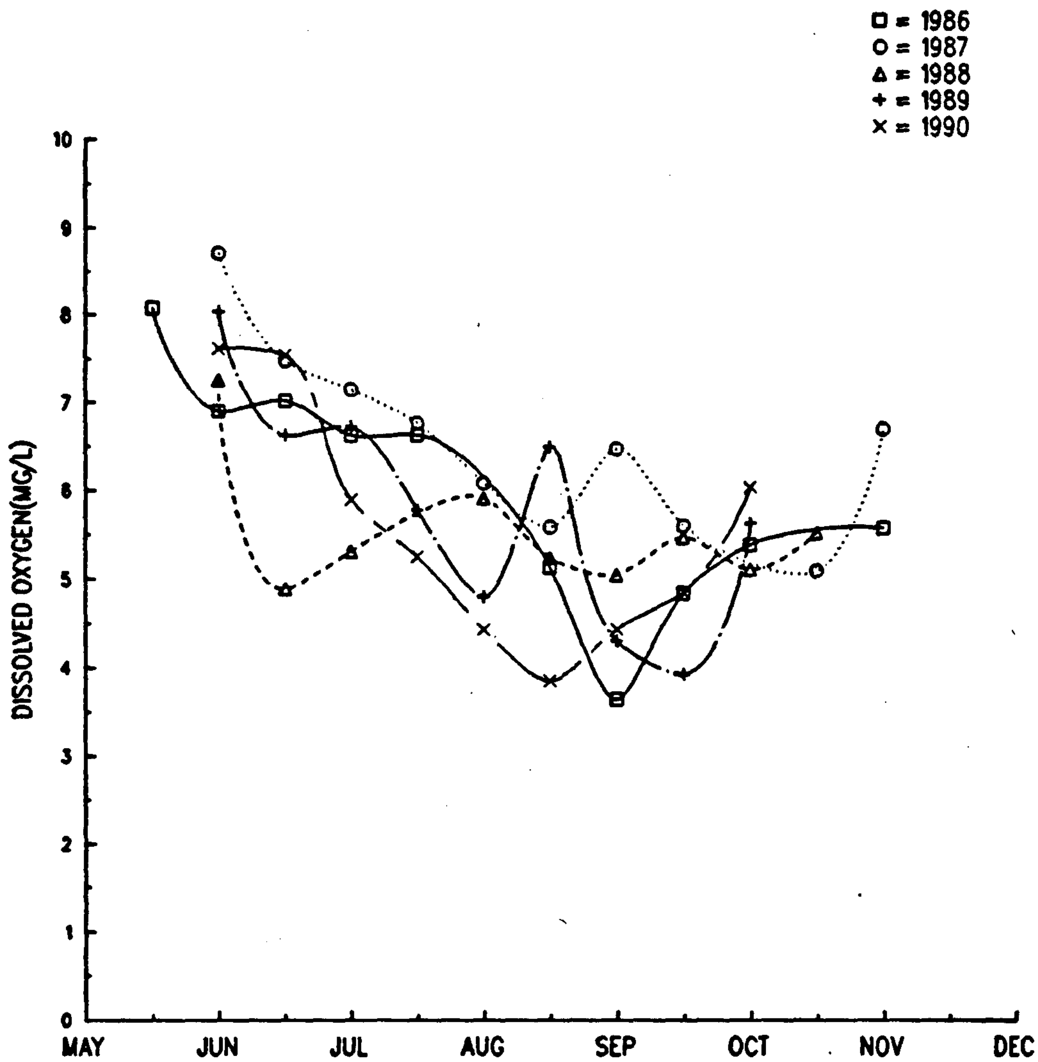

SOUTHERN NEW JERSEY COAST BOTTOM DISSOLVED OXYGEN, FIVE YEAR AVERAGE OF THE INDIVIDUAL SEMIMONTHLY AVERAGES, 1986 TO 1990.

until it begins a recovery in late September, rising quite rapidly in October.

Figures 19 and 20 illustrate the five year dissolved oxygen trends for the northern and southern New Jersey perpendicular stations, respectively. Figure 19, the northern New Jersey perpendiculars, shows that in 1987 and 1989 a dissolved oxygen "double minima" occurred. In 1987, the first low occurred in mid August, followed by the second low in mid October. The "double minima" was more pronounced in 1989, with lows occurring in late July and mid September. During 1986 and 1990 the dissolved oxygen sag curves follow the general dissolved oxygen cycle for the northeast United States, Figure 9. The lowest dissolved oxygen average, (3.6 mg/l) occurred in September of 1986, while the second lowest average, (3.7 mg/l) occurred in mid August, 1990. The summers of 1987 and 1988 have had the highest dissolved oxygen averages since 1986.

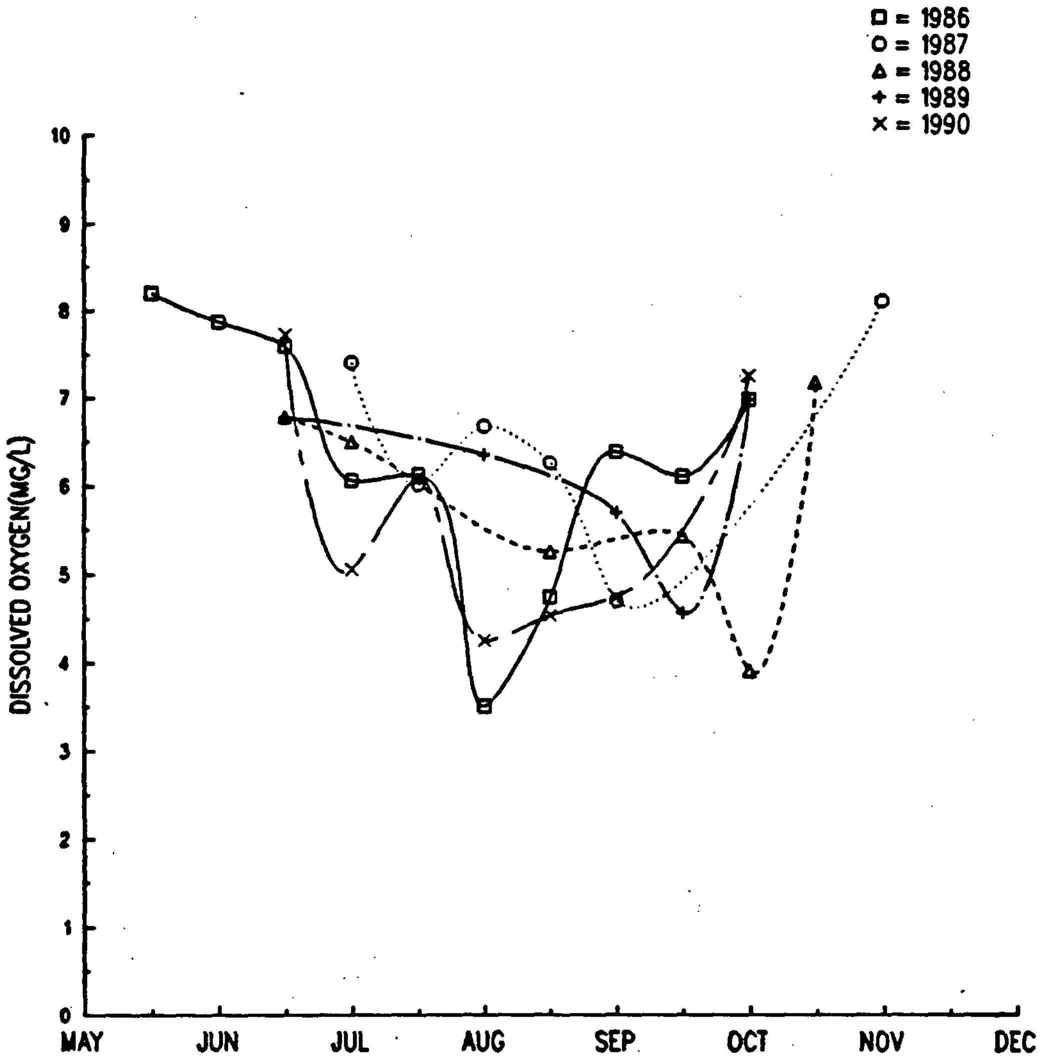
Figure 20 illustrates that, the dissolved oxygen averages along the southern New Jersey perpendiculars were approximately 1-2 mg/l lower in early July of 1990, than they have been in the previous four years. The dissolved oxygen levels were also approximately 1-2.5 mg/l lower in early August of 1990, than they have been in the previous three years. In mid July, and from mid August through September, the dissolved oxygen levels were approximately equal to or above the dissolved oxygen averages of the previous four years.

Figure 19




NORTHERN NEW JERSEY COAST BOTTOM DISSOLVED OXYGEN 1986–1990 COMPARISON. SEMIMONTHLY AVERAGES OF ALL JC14–JC53 PERPENDICULAR STATIONS.

Figure 20




SOUTHERN NEW JERSEY COAST BOTTOM DISSOLVED OXYGEN 1986-1990 COMPARISON. SEMIMONTHLY AVERAGES OF ALL JC61-JC85 PERPENDICULAR STATIONS.

Figure 21 displays the percentages of bottom dissolved oxygen samples with concentrations below 4 mg/l along the New Jersey perpendiculars over the last five years. The highest percentage of low dissolved oxygen values, 20.9 percent, occurred in 1990. Of the past 5 years, 1987 has the smallest percentage of low dissolved oxygen values, only 3.7 percent. The graph indicates that there has been a gradual increase in the occurrence of low dissolved oxygen values since 1987.

Figure 22 shows a five year comparison of the semimonthly averages for the New York Bight Apex stations for the years 1986-1990. The average dissolved oxygen concentrations remained above 4 mg/l throughout the five year period. The highest dissolved oxygen averages in the Apex occurred in 1987. A dissolved oxygen "double minima" has been observed in 1987, 1988, and 1989. The first and second low of the "double minima" occurred earlier in 1989 as compared to 1987 and 1988. The dissolved oxygen averages for 1986 and 1990 are similar, with the exception of the low which occurred in mid August in 1990, and early September in 1986. Generally, the dissolved oxygen averages in 1990 are approximately 1-2 mg/l lower than the dissolved oxygen averages in 1987 and 1988.

The dissolved oxygen trend graphs for the New Jersey perpendicular stations and the New York Bight Apex stations, show slightly lower dissolved oxygen concentrations in 1990 compared to previous years. These

Figure 21

# PERCENT OF BOTTOM DO VALUES BELOW 4mg/l

OFF THE NJ COAST OVER THE LAST 5 YEARS

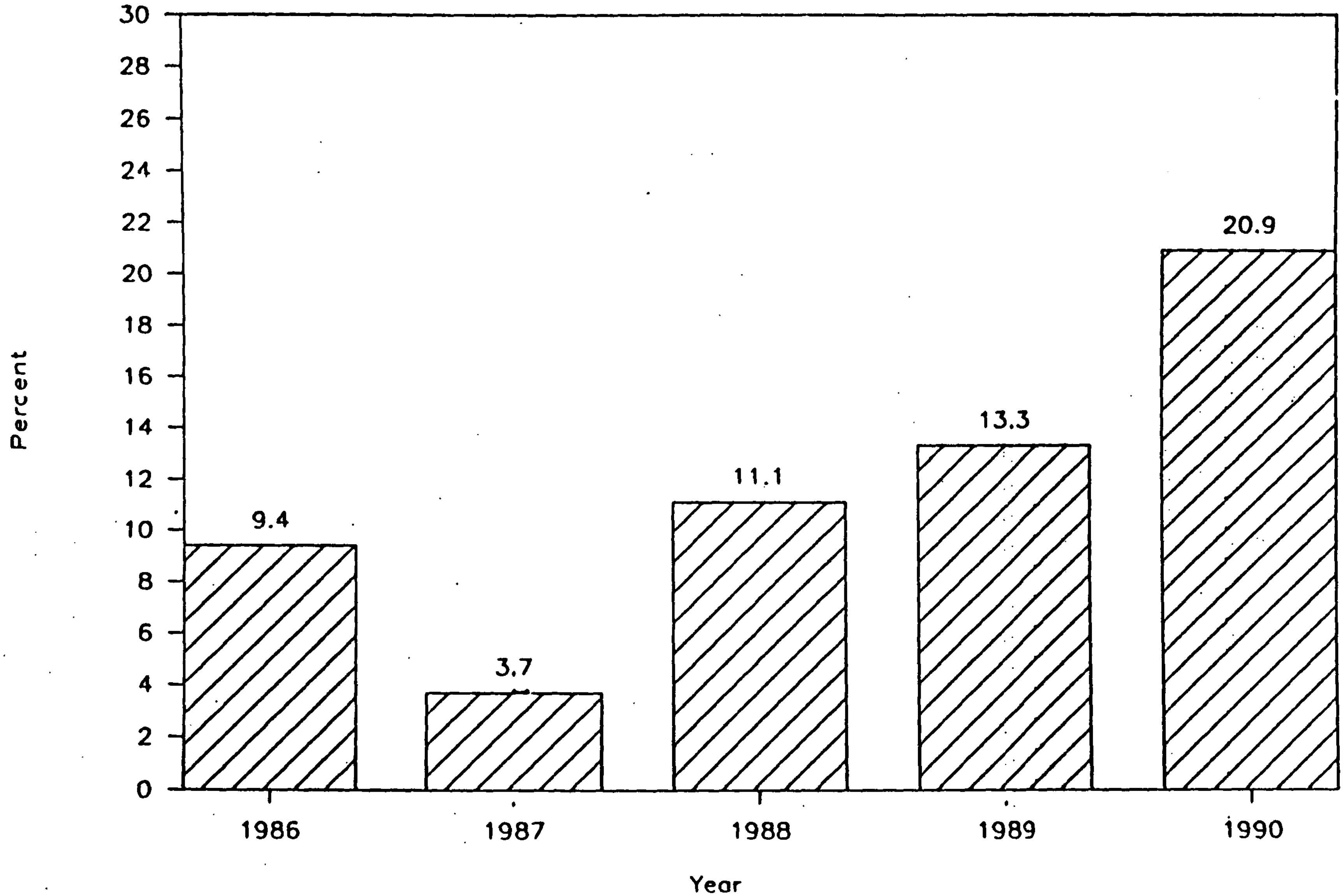
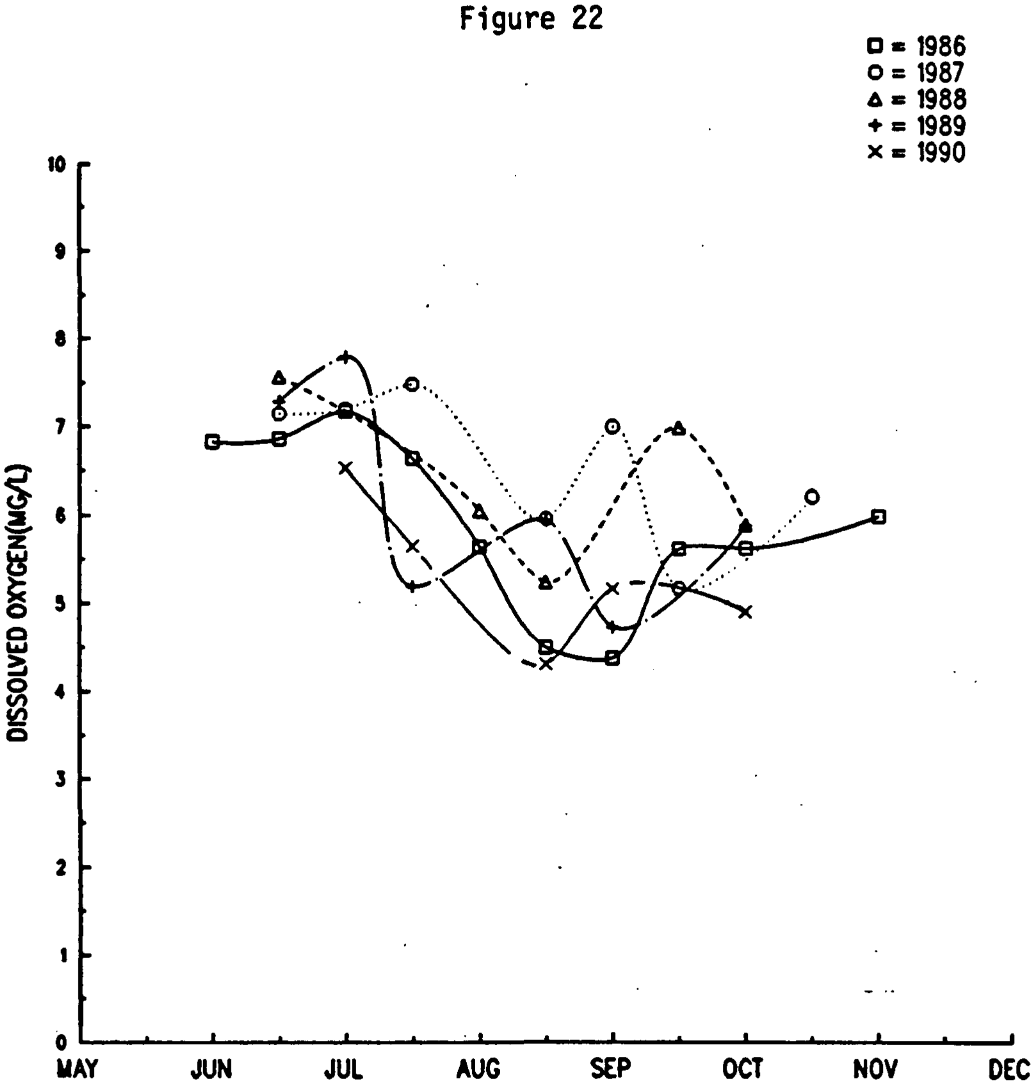


Figure 22




NEW YORK BIGHT BOTTOM DISSOLVED OXYGEN, 1986–1990 COMPARISON. SEMIMONTHLY AVERAGES OF ALL NEW YORK BIGHT STATIONS.

depressed levels occurred in specific isolated areas and did not remain low for extended periods of time. The low dissolved oxygen in certain areas of the Bight is attributed to the combined effects of the respiration of organisms in organic-rich sediments, the decomposition of organic materials and dead algal blooms which occur in the nutrient-rich areas of the Bight, thermal water column stratification, and no vertical mixing due to a lack of storm activity. The dissolved oxygen levels increased considerably in mid September during periods of high winds, cold temperature and local storms.

## V. BACTERIOLOGICAL RESULTS

Bacteriological data indicated that fecal coliform densities at the beaches along both the New Jersey and Long Island coasts were well within the acceptable Federal guidelines and State limits for primary contact recreation (a geometric mean of 200 fecal coliforms/100ml). A total of 506 samples were collected for fecal coliform and enterococcus analysis along the New Jersey coast. A total of 248 samples were collected for fecal coliform and enterococcus analysis along the Long Island coast. No fecal coliform densities exceeded 200 fecal coliforms/100ml. The recommended EPA criterion for enterococci in marine waters is a geometric mean of 35 enterococci/100ml. Individual enterococcus densities exceeded 35 enterococci/100ml only seven times during the summer along the New Jersey coast, and not at all along the Long Island coast. All the enterococci geometric means were below the criterion.

A further discussion of the bacteriological data prepared by the EPA Regional laboratory, which includes a discussion of the standards, indicator bacteria, materials, methods and results, is presented in Appendix A.

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**Appendix A**

Microbiological Water Quality

New York Bight

Summer 1990

MICROBIOLOGICAL WATER QUALITY

NEW YORK BIGHT

SUMMER 1990

## Introduction

A study of the density* of fecal coliform and enterococcus organisms was conducted in 1990 as part of the continuing annual monitoring of the nearshore waters off the Long Island and New Jersey coasts.

By determining the bacteriological water quality, one can estimate potential health risks associated with the presence of sewage pollution. Epidemiological studies have attempted to assess the incidence of illness with bathing in water containing fecal contamination. Evidence exists that there is a relationship between bacterial water quality and transmission of certain infectious diseases (1).

Investigations have shown that agents of bacterial disease, enteropathogenic/toxigenic *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella*, *Salmonella*, and *Shigella* are excreted in large numbers in the feces of infected individuals, and are thus potentially present in sewage. It is common practice to use an indicator organism to detect fecal contamination because of the ease of isolating and quantitating certain microorganisms on membrane filters. Elaborate procedures are usually required for the detection of most pathogens in mixed populations. When numerous indicator organisms are present, the likelihood of pathogens being found is far greater.

A fecal coliform bacterial guideline for primary contact recreational waters was recommended by the U.S. Environmental Protection Agency (USEPA) in 1976, and subsequently adopted by most of the states. The EPA standard stated that fecal coliforms should be used as the indicator to evaluate the suitability of recreational waters, and recommended that fecal coliforms, as determined by MPN or MF procedure and based on a minimum of not less than five samples taken over not more than a 30-day period, shall not exceed a log mean of 200 fecal coliform per 100 ml, nor shall more than 10% of the total samples during any 30-day period exceed 400 fecal coliforms per 100 ml. The rationale for the limits was developed using data collected from studies at the Great Lakes (Michigan) and the Inland River (Ohio) which showed an epidemiological detectable health effect at levels of 2300-2400 coliforms/100 ml. Subsequent investigations conducted on the Ohio River suggested that fecal coliforms represent 18% of the total coliforms. This would indicate that detectable health effects may occur at a fecal coliform level of approximately 400/100 ml. A limit of 200 fecal coliforms per 100 ml would therefore provide a quality of water which should exceed that which would cause a detectable health effect (10).

* Bacterial density in this study is referred to as the number of fecal coliforms and enterococci per 100 ml of water.

New York State, for its primary contact recreational coastal waters, adopted the standard of 200 fecal coliforms/100 ml, provided that the log mean is not exceeded during 5 successive sets of samples. New Jersey also has the standard of 200 fecal coliforms/100 ml. By 1978, most of the states adopted the fecal coliform indicator with geometric mean limits at 200 fecal coliforms/100 ml.

Fecal Coliform Indicator Bacteria

Fecal coliforms comprise all of the coliform bacteria that ferment lactose at 44.5 $\pm$0.2°C. This group, according to traditional theory, more accurately reflects the presence of fecal discharges from warm-blooded animals. As an indicator, fecal coliforms have the advantage of being less subject to regrowth in polluted waters. Their increased specificity to fecal sources made them the choice over other coliform organisms.

Enterococcus Group: Indicator Bacteria

Enterococci are a subgroup of the fecal streptococci. The occurrence of fecal streptococci in water indicates fecal contamination from warm-blooded animals. One is able to pinpoint the source of fecal contamination (such as human, equine, bovine, avian) by identifying the species utilizing biochemical tests. The enterococcus group includes the following species: Streptococcus faecalis; Streptococcus faecalis, subspecies liquefaciens; Streptococcus faecalis, subspecies zymogenes; and Streptococcus faecium. Streptococcus faecalis, one of the group D streptoccal species, grows in broth containing 6.5% NaCl, hydrolyzes arginine and utilizes pyruvate (2-4). Streptococcus faecium grows in 6.5% NaCL broth, hydrolyzes arginine, but does not utilize pyruvate. Streptococcus bovis does not grow in 6.5% NaCl broth, does not hydrolyze arginine, and does not utilize pyruvate. These are the three most common species of group D streptococci found as pathogens in human infection. Streptococcus durans is located occasionally, and Streptococcus equinus is found rarely (5).

EPA has recently published the results of two research projects which compared the relationship between illnesses associated with bathing in recreational waters and ambient densities of several indicator organisms (6). One study was performed on marine bathing beaches and one on freshwater beaches. Studies at marine and fresh water bathing beaches indicated that gastroenteritis is directly related to the quality of the bathing water and that enterococci is a better indicator of water quality than fecal coliforms (1, 10).

EPA has issued a criteria guidance document recommending enterococci and Escherichia coli for inclusion into state water quality standards for the protection of primary contact recreational uses in lieu of fecal coliforms. The EPA (1986) recommended criterion for enterococci for marine waters is 35/100 ml. This information was published in the Federal Register on March 7, 1986.

## Pseudomonas Aeruginosa: A Pathogenic Indicator Bacteria

Pseudomonas aeruginosa is a non-fermentive gram negative aerobic bacillus capable of producing water soluble pigments. It is one of the species of Pseudomonas that is pathogenic for man. The pathogenesis of the Pseudomonas disease is complex and involves a number of extracellular bacterial products, among which is an exotoxin. The pathogenicity in man is more or less determined by the patient's state of resistance. Severe infections can occur in the compromised host. The organism has been implicated in infected wounds, urinary infections, eye infections and otitis externa among swimmers. It has also been known to cause gastroenteritis. Pseudomonas aeruginosa has been isolated from over 90% of samples of sewage, and from 11% of human fecal specimens (7).

## Materials and Methods

Marine water samples were collected by helicopter from May to September 1990. The samples were collected using a Kemmerer sampler and transferred to 500 ml sterile, wide-mouthed plastic containers, and then transported in an ice chest to the Region II Edison laboratory for analysis.

Fecal coliform determinations were conducted according to the membrane filtration (MF) procedures described in Standard Methods, 17th edition, 1989 and Microbiological Methods for Monitoring the Environment, Water and Wastewater, EPA-600/8-78-017, 1978. Enterococci determinations were conducted according to the MF procedure described by Levin (8), and DuFour (9), using the modified mE media. Confirmation of enterococci colonies were conducted following procedures outlined in Microbiological Methods for Monitoring the Environment, Water and Wastewater, EPA-600/8-78-017, 1978.

Pseudomonas aeruginosa determinations were conducted according to the membrane filter procedures described in Standard Methods, 17th edition, 1989, and the formulation described by Brodsky & Cebin (14).

Of the three fluorescent species associated with man, Pseudomonas aeruginosa, Pseudomonas fluorescence and Pseudomonas putida, Pseudomonas aeruginosa is considered the primary pathogen and consequently its differential recognition is important (11).

Levin & Cabelli (12) devised M-PA Agar as a selective membrane filter medium for the isolation of Pseudomonas aeruginosa. A further modification was made by Dutka and Kuan (13), and designated M-PA-B. Brodsky & Ciebin (14), made some additional changes and enhanced the recovery to further selectively isolate these organisms and quantitatively recover Pseudomonas aeruginosa within 24 hours. Our laboratory undertook the initiative to test this ability to recover Pseudomonas aeruginosa using M-PA-C from the marine environment.

## Results and Discussion

### Fecal Coliform - New Jersey

Along the New Jersey Coast, fecal coliform densities equal to or greater than 50/100 ml occurred on 6 occasions at 5 different stations (Tables 1 & 2 and Figure 1). The observations were made at stations JC-36 (Manasquan Inlet, off of Third Avenue), JC-44 (Mantoloking, off of the foot of Albertson Street), JC-92 (Hereford Inlet), JC-93 (Wildwood, off of the Northern amusement pier) and JC-96 (Cape May Inlet).

### Fecal Coliform - Long Island

Fecal coliform densities greater than 50/100 ml did not occur (Table 3 and Figure 2). The highest fecal coliform count occurred at LIC-05 (Far Rockaway, off the foot of B41 Road), which had a maximum of 25 per 100 ml.

### Enterococci - New Jersey

Enterococci densities exceeding the standard of 35/100 ml (10) (Tables 4 & 5 and Figure 3) were observed on seven occasions at station JC-14 (Long Branch, off of the foot of S. Bath Avenue), JC-30 (Spring Lake, south of the yellow brick building on the beach), JC-35 (one block north of Manasquan Inlet), JC-36, JC-55 (Island Beach State Park, off of the white building north of the Park Headquarters), and JC-93.

### Enterococci - Long Island

The standard enterococci density of 35/100 ml were not exceeded. The maximum density of 18/100 ml occurred at station LIC-28 (Shinnecock Inlet East) (Table 6 and Figure 4).

For the majority of New Jersey and Long Island Coastal Stations low fecal coliform geometric mean densities per 100 ml were observed. This profile is visually presented in the geometric mean value of FC densities in Figures 1 and 2.

Geometric mean densities for enterococci along the New Jersey and Long Island Coastal Stations were even lower. These profiles are visually evident in Figures 3 and 4.

Along the New Jersey coast 56% of the samples analyzed for Pseudomonas aeruginosa were positive.

On June 27, 1990 a high count was noted at station JC-24 (Bradley Beach, off the foot of Cliff Avenue). This is presented in Table 7.

Along the Long Island coast 85% of the samples analyzed for Pseudomonas aeruginosa were positive. On June 26, 1990, LIC-13 (Jones Beach) and LIC-17 (Robert Moses State Park) high Pseudomonas counts were noted. See (Table 8). Of the total number of samples analyzed for Pseudomonas aeruginosa 73% were positive.

This organism is an opportunistic pathogen and has been linked as the causative agent of numerous infections that may be transmitted through the water route. The densities of Pseudomonas aeruginosa isolated are significant.

The fact that we are able to isolate this organism in substantial numbers makes it a more realistic indicator of the condition of the recreational water quality. This is true because the organism is a pathogen. We were able to demonstrate that this pathogen Pseudomonas aeruginosa could be present in marine waters with low fecal coliform and enterococci densities.

Once again we were able to experimentally use mPAC media, and membrane filtration, a procedure for the isolation of Pseudomonas aeruginosa in ocean bathing water samples. There is at present no standard for this organism in the marine environment.

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TABLE 1
GEOMETRIC MEANS OF FECAL COLIFORM DENSITIES
NEW JERSEY COAST STATIONS
SUMMER 1990

| OBS | STATION | MEAN | MINIMUM | MAXIMUM | N |
|---|---|---|---|---|---|
| 1 | JC01A | 2.3291 | 0 | 18 | 14 |
| 2 | JC03 | 1.4262 | 0 | 4 | 14 |
| 3 | JC05 | 1.2917 | 0 | 3 | 14 |
| 4 | JC08 | 1.2809 | 0 | 4 | 14 |
| 5 | JC11 | 1.1942 | 0 | 3 | 14 |
| 6 | JC13 | 3.2683 | 0 | 39 | 13 |
| 7 | JC14 | 1.8803 | 0 | 34 | 13 |
| 8 | JC21 | 1.8591 | 0 | 12 | 13 |
| 9 | JC24 | 2.2480 | 0 | 13 | 13 |
| 10 | JC26 | 4.0465 | 0 | 23 | 13 |
| 11 | JC27 | 2.2629 | 0 | 20 | 13 |
| 12 | JC30 | 2.3603 | 0 | 28 | 13 |
| 13 | JC33 | 2.1070 | 0 | 24 | 13 |
| 14 | JC35 | 1.3591 | 0 | 9 | 13 |
| 15 | JC36 | 11.2966 | 0 | 78 | 12 |
| 16 | JC37 | 2.2608 | 0 | 21 | 13 |
| 17 | JC41 | 1.7744 | 0 | 12 | 13 |
| 18 | JC44 | 1.8020 | 0 | 66 | 13 |
| 19 | JC47A | 1.6458 | 0 | 25 | 13 |
| 20 | JC49 | 1.3895 | 0 | 9 | 13 |
| 21 | JC53 | 2.8474 | 0 | 13 | 13 |
| 22 | JC55 | 1.1125 | 0 | 4 | 13 |
| 23 | JC57 | 1.4452 | 0 | 5 | 13 |
| 24 | JC59 | 1.0595 | 0 | 2 | 12 |
| 25 | JC61 | 1.6531 | 0 | 14 | 11 |
| 26 | JC63 | 1.0000 | 0 | 0 | 10 |
| 27 | JC65 | 1.2311 | 0 | 4 | 10 |
| 28 | JC67 | 1.1962 | 0 | 3 | 10 |
| 29 | JC69 | 1.1487 | 0 | 4 | 10 |
| 30 | JC73 | 1.0718 | 0 | 2 | 10 |
| 31 | JC74 | 2.6560 | 0 | 13 | 10 |
| 32 | JC75 | 2.3844 | 0 | 12 | 10 |
| 33 | JC77 | 1.6438 | 0 | 4 | 10 |
| 34 | JC79 | 1.3559 | 0 | 7 | 10 |
| 35 | JC81 | 2.9987 | 0 | 10 | 10 |
| 36 | JC83 | 1.5148 | 0 | 7 | 9 |
| 37 | JC85 | 1.5784 | 0 | 4 | 10 |
| 38 | JC87 | 1.0905 | 0 | 2 | 8 |
| 39 | JC89 | 1.6883 | 0 | 11 | 8 |
| 40 | JC91 | 1.0905 | 0 | 2 | 8 |
| 41 | JC92 | 4.3121 | 0 | 88 | 7 |
| 42 | JC93 | 2.8920 | 0 | 65 | 6 |
| 43 | JC95 | 1.8171 | 0 | 3 | 6 |
| 44 | JC96 | 5.5548 | 0 | 51 | 6 |
| 45 | JC97 | 1.4142 | 0 | 4 | 6 |
| 46 | JC99 | 1.9442 | 0 | 9 | 6 |

TABLE 2
FECAL COLIFORM DENSITIES > 50 PER 100ML
NEW JERSEY COAST STATIONS
SUMMER 1990

| OBS | STATION | DATE | VALUE |
|---|---|---|---|
| 1 | JC36 | 080890 | 68 |
| 2 | JC36 | 092690 | 78 |
| 3 | JC44 | 080890 | 66 |
| 4 | JC92 | 062090 | 88 |
| 5 | JC93 | 062090 | 65 |
| 6 | JC96 | 062090 | 51 |

FIGURE 1

# GEOMETRIC MEANS OF FECAL COLIFORM DENSITIES

## NEW JERSEY COAST STATIONS

## SUMMER 1990

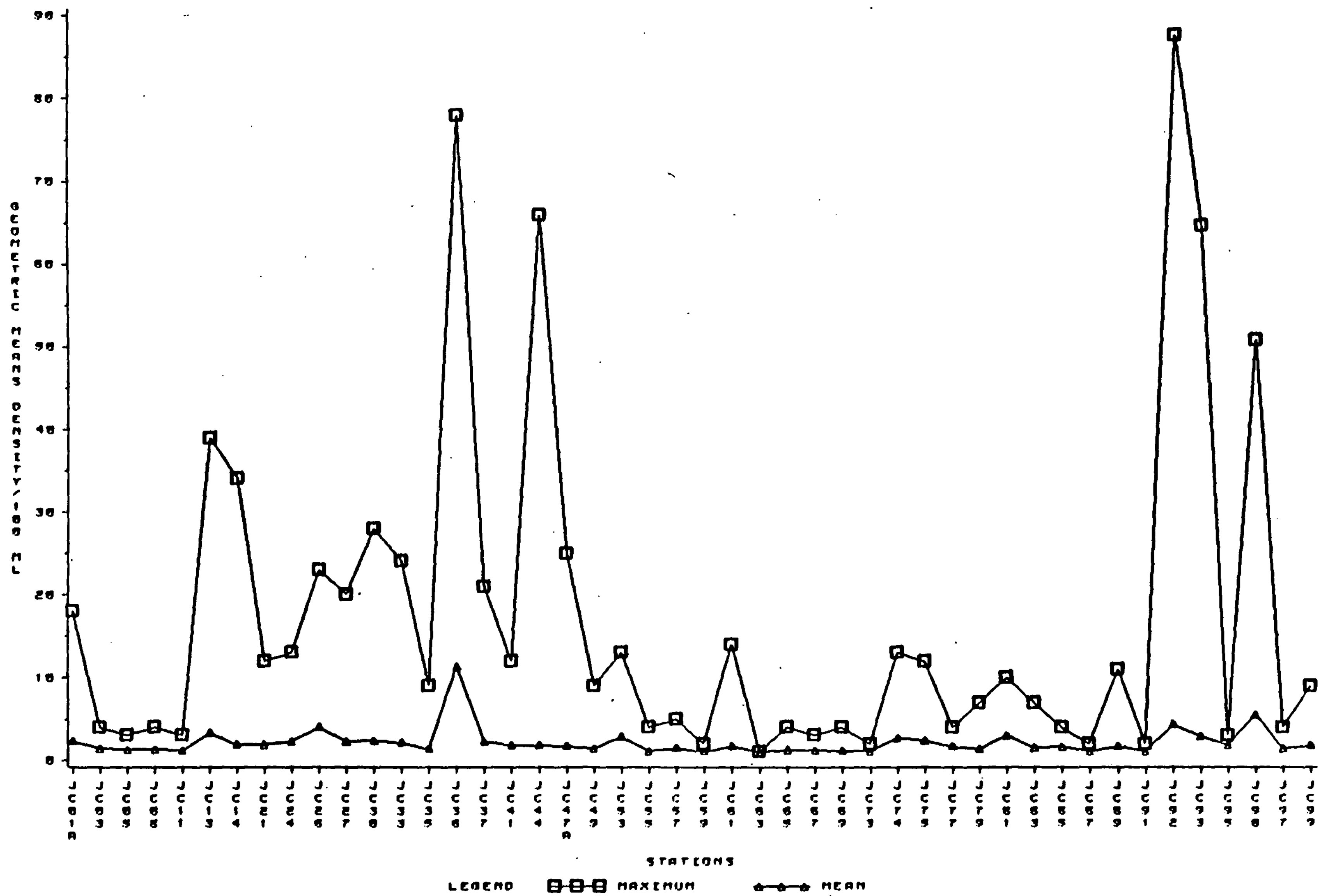

TABLE 3
GEOMETRIC MEANS OF FECAL COLIFORM DENSITIES
LONG ISLAND COAST STATIONS
SUMMER 1990

| OBS | STATION | MEAN | MINIMUM | MAXIMUM | N |
|---|---|---|---|---|---|
| 1 | LIC01 | 1.6693 | 0 | 12 | 10 |
| 2 | LIC02 | 1.2589 | 0 | 10 | 10 |
| 3 | LIC03 | 1.3559 | 0 | 7 | 10 |
| 4 | LIC04 | 1.2821 | 0 | 3 | 10 |
| 5 | LIC05 | 2.9926 | 0 | 25 | 10 |
| 6 | LIC07 | 2.1546 | 0 | 11 | 10 |
| 7 | LIC08 | 2.4991 | 0 | 11 | 10 |
| 8 | LIC09 | 1.9608 | 0 | 10 | 10 |
| 9 | LIC10 | 3.4855 | 0 | 14 | 10 |
| 10 | LIC12 | 1.1962 | 0 | 3 | 10 |
| 11 | LIC13 | 1.3110 | 0 | 5 | 10 |
| 12 | LIC14 | 1.7020 | 0 | 17 | 10 |
| 13 | LIC15 | 1.1487 | 0 | 2 | 10 |
| 14 | LIC16 | 2.2026 | 0 | 7 | 10 |
| 15 | LIC17 | 1.6426 | 0 | 13 | 10 |
| 16 | LIC18 | 1.2311 | 0 | 8 | 10 |
| 17 | LIC19 | 1.3408 | 0 | 7 | 9 |
| 18 | LIC20 | 1.2203 | 0 | 6 | 9 |
| 19 | LIC21 | 1.6361 | 0 | 7 | 9 |
| 20 | LIC22 | 1.0801 | 0 | 2 | 9 |
| 21 | LIC23 | 1.1665 | 0 | 2 | 9 |
| 22 | LIC24 | 1.0000 | 0 | 1 | 9 |
| 23 | LIC25 | 1.0801 | 0 | 2 | 9 |
| 24 | LIC26 | 1.5375 | 0 | 4 | 9 |
| 25 | LIC27 | 1.2510 | 0 | 3 | 8 |
| 26 | LIC28 | 1.0905 | 0 | 2 | 8 |

FIGURE 2

# GEOMETRIC MEANS OF FECAL COLIFORM DENSITIES

## LONG ISLAND COAST STATIONS

## SUMMER 1990

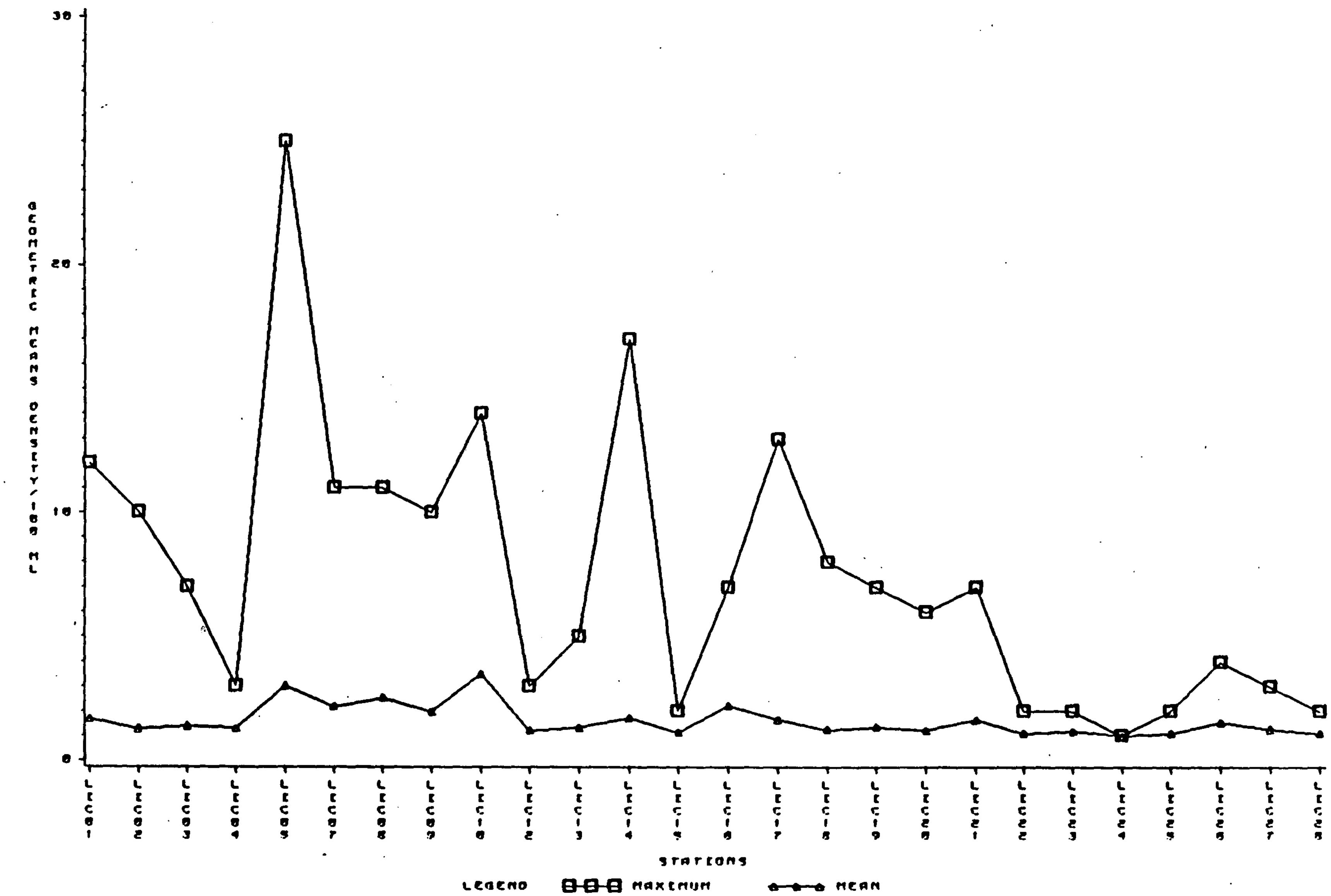

TABLE 4
GEOMETRIC MEANS OF ENTEROCOCCUS DENSITIES
NEW JERSEY COAST STATIONS
SUMMER 1990

| OBS | STATION | MEAN | MINIMUM | MAXIMUM | N |
|---|---|---|---|---|---|
| 1 | JC01A | 1.1041 | 0 | 2 | 14 |
| 2 | JC03 | 1.1942 | 0 | 6 | 14 |
| 3 | JC05 | 1.0816 | 0 | 3 | 14 |
| 4 | JC08 | 1.1365 | 0 | 3 | 14 |
| 5 | JC11 | 1.3459 | 0 | 4 | 14 |
| 6 | JC13 | 1.4206 | 0 | 6 | 13 |
| 7 | JC14 | 1.9465 | 0 | 60 | 13 |
| 8 | JC21 | 1.7744 | 0 | 8 | 13 |
| 9 | JC24 | 2.1375 | 0 | 15 | 13 |
| 10 | JC26 | 1.8661 | 0 | 16 | 13 |
| 11 | JC27 | 2.0551 | 0 | 18 | 13 |
| 12 | JC30 | 4.3578 | 0 | 36 | 13 |
| 13 | JC33 | 2.6768 | 0 | 16 | 13 |
| 14 | JC35 | 1.9964 | 0 | 100 | 13 |
| 15 | JC36 | 3.2235 | 0 | 38 | 12 |
| 16 | JC37 | 2.0609 | 0 | 8 | 13 |
| 17 | JC41 | 1.1478 | 0 | 6 | 13 |
| 18 | JC44 | 1.2106 | 0 | 12 | 13 |
| 19 | JC47A | 1.1735 | 0 | 4 | 13 |
| 20 | JC49 | 1.2377 | 0 | 2 | 13 |
| 21 | JC53 | 1.2769 | 0 | 4 | 13 |
| 22 | JC55 | 1.4641 | 0 | 71 | 13 |
| 23 | JC57 | 1.3145 | 0 | 7 | 13 |
| 24 | JC59 | 1.0000 | 0 | 1 | 12 |
| 25 | JC61 | 1.7160 | 0 | 19 | 11 |
| 26 | JC63 | 1.0718 | 0 | 2 | 10 |
| 27 | JC65 | 1.3110 | 0 | 15 | 10 |
| 28 | JC67 | 2.5313 | 0 | 25 | 10 |
| 29 | JC69 | 1.5575 | 0 | 21 | 10 |
| 30 | JC73 | 1.7321 | 0 | 27 | 10 |
| 31 | JC74 | 1.5784 | 0 | 8 | 10 |
| 32 | JC75 | 1.4727 | 0 | 6 | 10 |
| 33 | JC77 | 1.4727 | 0 | 4 | 10 |
| 34 | JC79 | 1.6612 | 0 | 10 | 10 |
| 35 | JC81 | 1.3110 | 0 | 5 | 10 |
| 36 | JC83 | 1.1665 | 0 | 4 | 9 |
| 37 | JC85 | 1.5420 | 0 | 19 | 10 |
| 38 | JC87 | 2.1040 | 0 | 16 | 8 |
| 39 | JC89 | 1.6094 | 0 | 9 | 8 |
| 40 | JC91 | 1.4352 | 0 | 9 | 8 |
| 41 | JC92 | 1.2917 | 0 | 6 | 7 |
| 42 | JC93 | 4.8997 | 0 | 47 | 6 |
| 43 | JC95 | 1.6984 | 0 | 6 | 6 |
| 44 | JC96 | 4.2280 | 0 | 17 | 6 |
| 45 | JC97 | 3.5255 | 0 | 12 | 6 |
| 46 | JC99 | 1.4423 | 0 | 9 | 6 |

TABLE 5
ENTEROCOCCUS DENSITIES > 35 PER 100ML
NEW JERSEY COAST STATIONS
SUMMER 1990

| OBS | STATION | DATE | VALUE |
|---|---|---|---|
| 1 | JC14 | 071190 | 60 |
| 2 | JC30 | 071890 | 36 |
| 3 | JC35 | 090590 | 100 |
| 4 | JC36 | 053090 | 38 |
| 5 | JC36 | 092690 | 36 |
| 6 | JC55 | 090590 | 71 |
| 7 | JC93 | 090590 | 47 |

FIGURE 3

# GEOMETRIC MEANS OF ENTEROCOCCUS DENSITIES

## NEW JERSEY COAST STATIONS
## SUMMER 1990

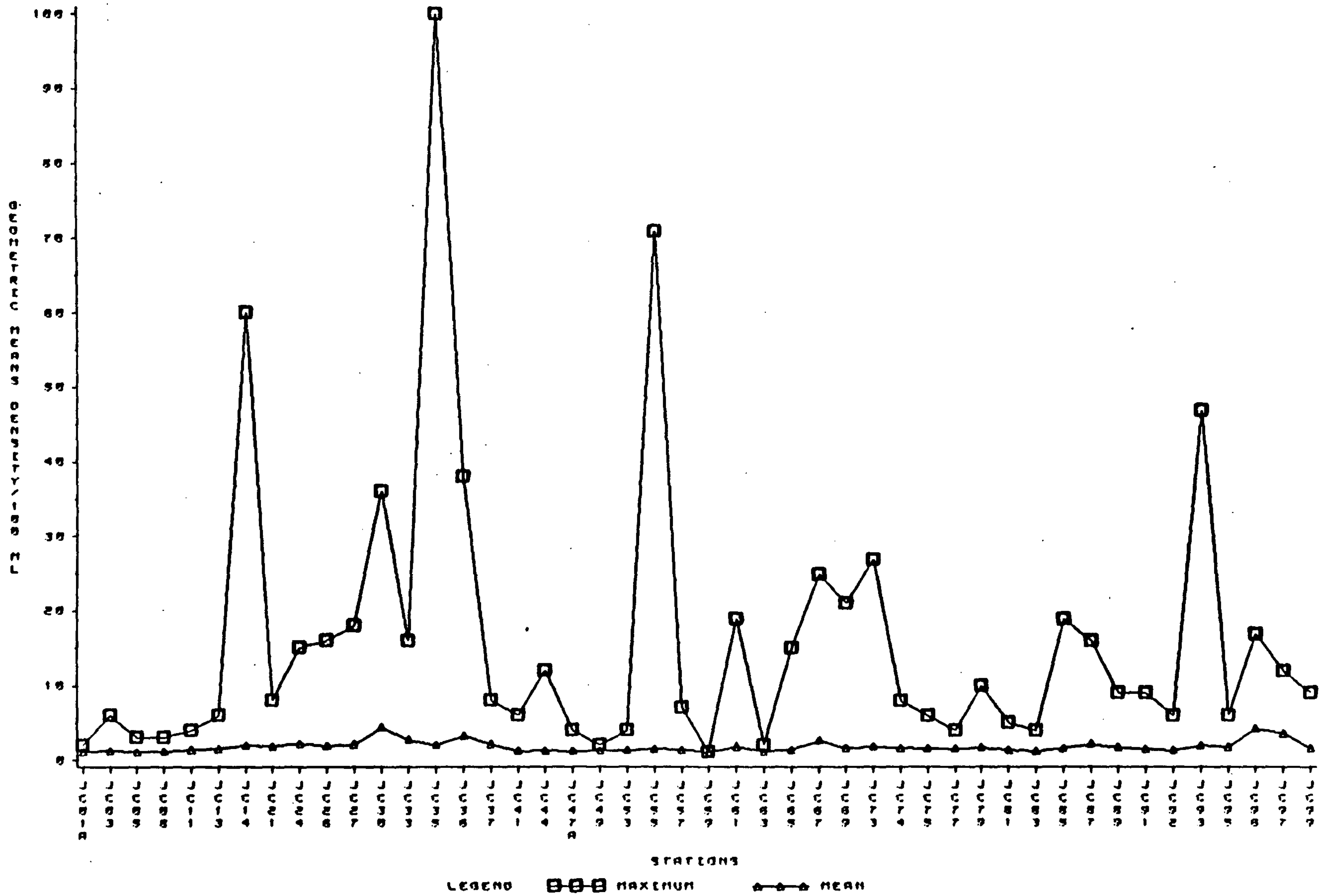

TABLE 6
GEOMETRIC MEANS OF ENTEROCOCCUS DENSITIES
LONG ISLAND COAST STATIONS
SUMMER 1990

| OBS | STATION | MEAN | MINIMUM | MAXIMUM | N |
|---|---|---|---|---|---|
| 1 | LIC01 | 1.4600 | 0 | 22 | 10 |
| 2 | LIC02 | 1.3110 | 0 | 5 | 10 |
| 3 | LIC03 | 1.8882 | 0 | 6 | 10 |
| 4 | LIC04 | 1.8661 | 0 | 4 | 10 |
| 5 | LIC05 | 1.6438 | 0 | 8 | 10 |
| 6 | LIC07 | 1.6438 | 0 | 6 | 10 |
| 7 | LIC08 | 2.0237 | 0 | 12 | 10 |
| 8 | LIC09 | 1.5060 | 0 | 5 | 10 |
| 9 | LIC10 | 2.2938 | 0 | 7 | 10 |
| 10 | LIC12 | 1.3741 | 0 | 4 | 10 |
| 11 | LIC13 | 1.6030 | 0 | 14 | 10 |
| 12 | LIC14 | 1.2589 | 0 | 5 | 10 |
| 13 | LIC15 | 1.5499 | 0 | 5 | 10 |
| 14 | LIC16 | 1.1962 | 0 | 3 | 10 |
| 15 | LIC17 | 1.3351 | 0 | 3 | 10 |
| 16 | LIC18 | 1.1487 | 0 | 4 | 10 |
| 17 | LIC19 | 1.2203 | 0 | 3 | 9 |
| 18 | LIC20 | 1.1665 | 0 | 2 | 9 |
| 19 | LIC21 | 1.8485 | 0 | 7 | 9 |
| 20 | LIC22 | 1.2203 | 0 | 3 | 9 |
| 21 | LIC23 | 1.1298 | 0 | 3 | 9 |
| 22 | LIC24 | 1.0801 | 0 | 2 | 9 |
| 23 | LIC25 | 1.2916 | 0 | 5 | 9 |
| 24 | LIC26 | 1.5761 | 0 | 6 | 9 |
| 25 | LIC27 | 1.0905 | 0 | 2 | 8 |
| 26 | LIC28 | 1.8888 | 0 | 18 | 8 |

FIGURE 4

# GEOMETRIC MEANS OF ENTEROCOCCUS DENSITIES

## LONG ISLAND COAST STATIONS
## SUMMER 1990

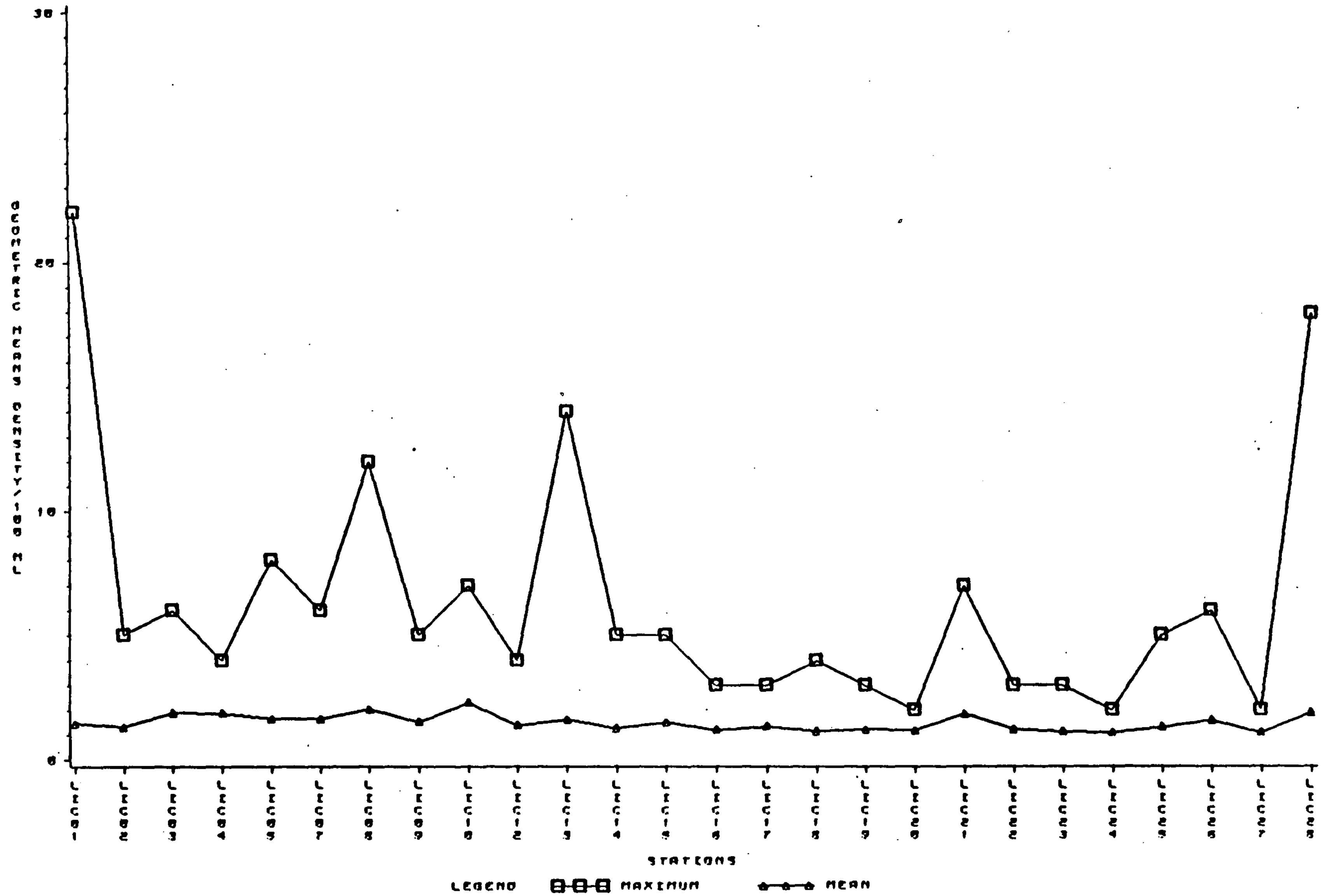

TABLE 7

PSEUDOMONAS AERUGINOSA DATA

Psuedomonas aeruginosa

| OBS | DATE | STATION | COUNTS/100 ml |
|---|---|---|---|
| 1 | 6/27/90 | JC-24 | 16 |
| 2 | | JC-26 | 0 |
| 3 | | JC-27 | 0 |
| 4 | | JC-30 | 4 |
| 5 | | JC-33 | 4 |
| 6 | | JC-35 | 4 |
| 7 | | JC-36 | 8 |
| 8 | | JC-37 | 12 |
| 9 | | JC-41 | 8 |
| 10 | | JC-44 | 8 |
| 11 | | JC-47A | 0 |
| 12 | | JC-49 | 8 |
| 13 | | JC-53 | 0 |
| 14 | | JC-74 | 12 |
| 15 | | JC-75 | 0 |
| 16 | | JC-79 | 0 |
| 17 | | JC-81 | 0 |
| 18 | | JC-85 | 0 |

TABLE 8

PSEUDOMONAS AERUGINOSA DATA

| OBS | DATE | STATION | PSEUDOMONAS AERUGINOISA COUNTS/100 ml |
|---|---|---|---|
| 1 | 6/26/90 | LIC-01 | 3 |
| 2 | | LIC-02 | 1 |
| 3 | | LIC-03 | 3 |
| 4 | | LIC-04 | 6 |
| 5 | | LIC-05 | 1 |
| 6 | | LIC-07 | 8 |
| 7 | | LIC-08 | 5 |
| 8 | | LIC-09 | 2 |
| 9 | | LIC-10 | 5 |
| 10 | | LIC-12 | 3 |
| 11 | | LIC-13 | 18 |
| 12 | | LIC-14 | 7 |
| 13 | | LIC-15 | 0 |
| 14 | | LIC-16 | 0 |
| 15 | | LIC-17 | 17 |
| 16 | | LIC-18 | 2 |
| 17 | | LIC-19 | 9 |
| 18 | | LIC-20 | 3 |
| 19 | | LIC-21 | 1 |
| 20 | | LIC-22 | 2 |
| 21 | | LIC-23 | 1 |
| 22 | | LIC-24 | 0 |
| 23 | | LIC-25 | 4 |
| 24 | | LIC-26 | 0 |
| 25 | | LIC-27 | 3 |
| 26 | | LIC-28 | 12 |

# APPENDIX B

Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters

Summer 1990

# ANNUAL SUMMARY OF PHYTOPLANKTON BLOOMS
# AND RELATED CONDITIONS
# IN NEW JERSEY COASTAL WATERS
# SUMMER OF 1990

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER RESOURCES
NEW JERSEY GEOLOGICAL SURVEY
BUREAU OF MONITORING MANAGEMENT
BIOMONITORING UNIT

# ANNUAL SUMMARY OF PHYTOPLANKTON BLOOMS AND RELATED CONDITIONS IN NEW JERSEY COASTAL WATERS SUMMER OF 1990

## INTRODUCTION

To help protect its valuable recreational and fishery resources, the New Jersey Department of Environmental Protection, in cooperation with the United States Environmental Protection Agency and the shore county health agencies, each summer monitors coastal water quality conditions. For the past few years, emphasis has been placed on aerial observation and beach cleanup operations for floatable debris as well as intensive bacteriological sampling for safe bathing. The phytoplankton program dates back considerably further. Annual occurrences of "red tides" caused by blooms of several flagellate species have been documented in the Hudson-Raritan estuary and along the adjacent New Jersey oceanfront at least since 1960, although adverse effects were usually only aesthetic in nature (Mahoney and McLaughlin, 1977). Monitoring began in the early 1970's after serious blooms of a dinoflagellate, _Prorocentrum micans_, were associated with complaints of respiratory discomfort by bathers along the Monmouth County coast. Initial studies of the affected estuarine and coastal region were conducted by the NJDEP cooperatively with the National Marine Fisheries Service, Sandy Hook Laboratory. As a result, the red tides were associated with eutrophic conditions; standardized methods for phytoplankton analysis and a comprehensive list of species indigenous to the region were developed (Mahoney and McLaughlin, 1977; Olsen and Cohn, 1979).

In 1977, monitoring was expanded offshore into the New York Bight following a massive offshore bloom in this region, that of _Ceratium tripos_, which resulted in widespread anoxia and consequent kills of benthic fauna (Swanson and Sindermann, 1979). Routine phytoplankton sampling was instituted cooperatively with the USEPA, Region II helicopter surveillance unit, as part of their ongoing New York Bight water quality monitoring program. This program included sampling for dissolved oxygen on transects perpendicular to the coast as well as for coliform bacteria in the surf zone. Phytoplankton samples were taken initially at stations from Raritan Bay southward to Island Beach. In 1986, following the occurrence of extensive "green tides" of a dinoflagellate identified as _Gyrodinium aureolum_ (Mahoney _et al_, 1990), routine sampling was expanded again, this time to include the New Jersey beaches from Long Beach Island southward (see Figure 1). Probable factors contributing to the development of these blooms were investigated (USEPA, 1986).

Since 1985, major red tide blooms attributed to phytoflagellates have been confined primarily to estuarine waters, i.e. Raritan-Sandyhook Bay and, to a lesser extent, Delaware Bay (see USEPA, 1978-1990 inclusive). A notable exception to this occurred in late October of 1989 with a bloom dominated by species normally abundant in the estuary (including Katodinium routundatum and Eutreptia lanowii). This red tide extended linearly for over 25 miles along the N.J. coast from northern Monmouth County to Barnegat Inlet and offshore to five miles. It took place, fortunately, after the summer bathing season but during an abnormally warm period preceded by heavy stormwater runoff. Blooms dominated by K. rotundatum have continued to occur in Raritan-Sandy Hook Bay, primarily in early summer. For the past few years, extensive and persistent diatoms blooms dominated by several species (especially Skeletonema costatum) have occurred in mid to late summer in the major estuaries and along most of the New Jersey coast. As indicated by weather records, this may be partially due to atypical conditions, because diatoms normally constitute the dominant flora during the cooler months. In Barnegat Bay, the dense, summer-long chlorophyte bloom of Nannochloris atomus, once most conspicuous in Raritan Bay, has recurred annually at least since 1985.

## METHODS

The current survey encompasses the entire New Jersey coastal region, including the major estuaries at the northern and southern extremes. At least twelve sites, among those in the USEPA New York Bight network, were sampled for phytoplankton and chlorophyll a (see Figure 1). In 1990, several locations were changed from those sampled the previous year(s), including the following: Raritan Bay - RB24 and 32 deleted, RB1 added; Monmouth County coast - JC30 deleted, JC33 added; Ocean County Coast - JC41 deleted; Barnegat Bay - DEP station SM substituted for BB2; Atlantic County-GE1 and JC75 deleted, JC77 added; Delaware Bay - DB2 added (2 mi W of DB1). Another cooperative NJDEP/USEPA study conducted in 1989-90 encompassed the area between sites RB1 and 15 in the Hudson-Raritan estuary subject to dense red tides and occasional fish kills; these results will be reported separately. Chlorophyll a data from station 51A in that study are included in the present report. The Barnegat Bay area also was included as part of a special study by NJDEP (stations NM, HP, WT and SM); results of chlorophyll a analysis for these sites are included in the present report.

For the routine survey, field collections via helicopter were made as in previous years by members of the USEPA, Region II Monitoring and Surveillance Branch (Edison, N.J.). Sampling frequency was weekly from late May through early September, weather and logistics permitting. Samples were taken at a one-meter depth using a Kemmerer sampler. Coastal stations were sampled just outside the surf zone. Water aliquots for species composition and phytoplankton chlorophyll a were retained in clear plastic, one-liter cubitainers and stored in an ice chest. If analyses could not be accomplished within 24 hours of collection, samples for phytoplankton identification and cell counts were preserved with Lugol's solution; those for chlorophyll a remained iced, to be analyzed within 48 hours of collection. These procedures were in accordance with DEP standard field methods (NJDEP, 1987). Species composition by the Sedgewick-Rafter method and chlorophyll a by spectrophotometry were performed according to Standard Operating Procedures of the DEP Division of Water Resources, Biomonitoring Laboratory.

## RESULTS AND DISCUSSION

### 1990 Highlights

### Hudson-Raritan Estuary

The Summer of 1990 was highlighted, as in the past few years, by an intense bloom of the dinoflagellate Katodinium rotundatum in the Hudson-Raritan estuary. As in 1989, the red water persisted only about a week (June 26-29), but it extended throughout Raritan and Sandy Hook Bay or roughly the southern half of the Hudson-Raritan estuary. In 1988, the red tide continued intermittently through summer in the southern portion of the estuary. Again in 1990, the euglenoid Eutreptia lanowii was subdominant in the blooms and other phytoflagellates formerly dominant (e.g. Olisthodiscus luteus and Prorocentrum spp.) appeared less abundant. A bloom of O. luteus in Sandy Hook Bay preceded the red tide of K. rotundatum. The appearance of Protoperidinium trochoideum, Gymnodinium danicans and Euglena sp. in the estuary was also noted. Localized blooms in the area both preceded and followed the major K. rotundatum bloom which apparently collapsed prior to July 4, possibly due to the onset of stormy conditions as indicated by weather records. Small flagellates (Pyramimonas micron and Chroomonas minuta) later became generally abundant along the Monmouth County coast from Raritan Bay to Manasquan inlet. Only one fish kill attributable to hypoxia from decomposing algae was recorded in 1990; this was a localized event which occurred in a tributary of the Shrewsbury River about June 18 and was reported to us by personnel of the Monmouth County Health Department. Except for Barnegat Bay where the summer chlorophyte bloom continued, diatoms predominated throughout the sampling range for the balance of the season.

### Coastwide Diatom Abundance

At the start of routine sampling in May, normally-occurring spring diatom blooms (flowerings) were in progress; these persisted into June until the phytoflatellates (i.e. K. rotundum, etc.) gained prominence. In Raritan-Sandy Hook Bay, Skeletonema costatum attained bloom status; Rhizosolenia fragilissima, Chaetoceros sp. and Leptocylindrus minimus were also abundant. A localized bloom of the diatom Cyclotella sp. accompanied the flagellate bloom of O. luteus observed in Sandy Hook Bay in mid-June. In coastal waters from Sandy Hook to Cape May, the abundance of R. fragilissima and delicatula, Leptocylindrus danicus and Cerataulina pelagica was noted during this period. Nuisance conditions attributable to diatom blooms (especially C. pelagica) were not reported in 1990 as they had been in previous years.

As in the previous few years, following flagellate red tides, diatoms regained dominance for the remainder of the season. In 1990 several species became abundant the latter part of July throughout the survey region. From Raritan Bay to Sandy Hook, these included Thalassiosira subtilis, S. costatum, L. danicus, and Cylindrotheca closterium; along the N.J. coast from Monmouth to Cape May County, S. costatum, Cyclotella sp. , T. subtilis and Chaetoceros sp. Until mid-August, S. costatum, and T. subtilis remained dominant in Raritan - Sandy Hook Bay and adjacent New Jersey coastal waters south to northern Ocean County. During August, Hemiaulus sinensis also became abundant throughout the same area, while S. costatum and Chaetoceros sp. bloomed in the estuary.

Between July 18 and August 29, because of helicopter logistics, no sampling was done south of Island Beach. In late August, S. costatum became abundant throughout the survey region with blooms at northern and southern extremes (Sandy Hook Bay, Cape May - Delaware Bay). From late August into September, Thalassiosira rotula and T. gravida appeared in abundance in northern locales, especially in the estuary; Eucampia zoodiacus appeared at sites southward to Island Beach. In Sandy Hook Bay Cyclotella sp. appeared again, with a flagellate Calycomonas ovalis. Along the N.J. coast south of Island Beach, S. costatum and Chaetoceros sp. remained into September. At the final sampling on Sept. 29, phytoplankton densities were considerably diminished except in Sandy Hook Bay.

## Delaware Bay

The profusion of diatoms in Delaware Bay (capeshore area), where we began sampling in 1988, is noteworthy; in 1990 at least eight species were predominant throughout the season. Those abundant spring through summer included S. costatum, Thalassiosira spp., Asterionella glacialis and Nitzschia sp. Also abundant in spring were L. minimus, Thalassiosira nordenskioldii and, in summer, Thalassiosira rotula, Phaeodactylum tricornutum and Cylindrotheca closterium. Blooms of P. tricornutum and C. closterium occurred in late July; these two species have been common also in Sandy Hook Bay. A dinoflagellate, Gyrodinium spp., was abundant for a period in late summer. Localized phytoflagellate blooms have recurred periodically in Delaware Bay, particularly in the northeastern section just west of the New Jersey capeshore.

## Barnegat Bay

In Barnegat Bay the summer-long, brown-water blooms of the chlorophyte, Nannochloris atomus, recurrent at least since 1985, persisted again in 1990. Highest concentrations were again found in the area south of Barnegat Inlet (Site BB2) where the salinity regime has normally been higher than in northern Barnegat Bay (Olsen, 1989). Peak chlorophyll a levels (>20mg/l) occurred in mid-July and again in late August (Table 2, Figure 2). N. atomus has been dominant throughout the New York-New Jersey region especially in the other major estuaries, and often in association with phytoflagellate or diatom species; in 1990 its blooms in the Sandy Hook and Cape May areas coincided with late summer diatom blooms (Table 1). In Barnegat Bay, however, its densities (> 1,000,000 cells/ml) have well exceeded those in the other areas, at times to the virtual exclusion of other species. Several factors have possibly contributed to this apparent eutrophication of the Barnegat system; e.g. it is shallow and not well flushed, there is considerable freshwater influx, and its shoreline is extensively developed.

## Localized Blooms

In addition to those detected by routine sampling, localized red tides were observed along the Sandy Hook Bay shore and in the Shrewsbury River; these were reported primarily by personnel of the Monmouth County Health Department. At Atlantic Highlands Yacht Harbor on June 18 a bloom dominated by Katodinium rotundatum suggested this as a possible seed area for the bay-wide bloom of that species seen a week later. Concurrently, green water in the upper Shrewsbury River at Branchport Creek, caused by a bloom of the diatom Cyclotella sp. with a few other species abundant, was coincident with an apparent kill of small fish. In mid-July, red water in the Branchport Creek vicinity was caused primarily by K. rotundatum, with a cell density of 80,000/ml exceeding those in the preceding bay-wide bloom of that species. In early August, brown water conditions were observed from the Sandy Hook Bay southwestern shore (Keansburg vicinity) through the Shrewsbury River to Branchport Creek; these were caused by blooms of diatoms, especially Skeletonema costatum and Thalassiosira nordenskioldii, with several other species abundant.

## General Species Composition

A comprehensive list of common or abundant phytoplankton species at representative locations, showing seasonal succession, is presented in Table 1. Species considered dominant occurred often in cell concentrations greater than 1000/ml; blooms occurred with densities greater than 10,000/ml. Concentrations of this magnitude tend to impart visible coloration to the water, i.e. cause "red tide". During the major bloom in the Hudson-Raritan estuary, maximum counts of Katodinium rotundatum, the dominant species, approached 40,000/ml. For Nannochloris, because of its minute cell size (<5um), the criterion is increased by a factor of ten, i.e. 100,000/ml for blooms. Notably, of a total of 49 species in Table 1, 25 (slightly more than 50%) were diatoms. Some of the stations represented in Table 1, especially southern locations, were sampled less frequently than others. Based on the total number of occurrences/number of times sampled, RB15 (Sandy Hook Bay) and DB1 (Delaware Bay) had the greatest frequency or diversity of species, although DB1 was sampled only six times.

## Chlorophyll a Distribution

Results of chlorophyll analysis are given in Table 2, Figures 2 and 3. Seasonal variations, as shown in Figure 2, were greatest in the major estuaries at northern and southern extremes of the New Jersey coast. The highest value (120 ug/l) was derived from the dinoflagellate red tide bloom in Raritan-Sandy Hook Bay (station 51A) in late June, while values of almost 100 ug/l were seen from the diatom blooms, especially late summer, in both estuaries. Tidal patterns may be partially responsible for the extreme fluctuations seen in these estuaries. Coastal areas are much lower overall, with their higher values in a range similar to lower levels in the estuaries (10-40 ug/l). Coastal chlorophyll a levels were most elevated during the periods of general diatom abundance. Barnegat Bay chlorophyll a levels displayed the least variation while remaining relatively high (15-25 ug/l). This is attributed partially to its lack of flushing and to the consistent abundance of Nannochloris which, due to its minute cell size (<5.0 mm), probably represents less biomass than the dominant species in the other estuaries. Mean chlorophyll a levels per station for the entire season are shown in Figure 3. Again, the major estuaries exhibited the highest values (>50 ug/l), while central to southern coastal locations were much lower (<10 ug/l). The lowest mean value, at station JC57 (Island Beach State Park), reflects its geographical position, i.e. farthest removed from inputs of the major estuaries and coastal inlets.

## Environmental Factors

Seasonal temperatures variations are shown in Figure 4. In Raritan-Sandy Hook Bays, surface temperature peaked at about 74° (23°C) the last few days of June, concurrenly with the red tide of K. rotundatum. USEPA data shows that corresponding bottom temperatures were somewhat lower (to 69°F or 20.5°c), thus there was slight stratification at the time of the blooms. Nearshore ocean temperatures remained well below 70°F through this period. Bay temperatures fell somewhat in early July as the bloom rapidly declined; weather records show that precipitation occurred in the region from June 29 to July 2. Following this, both bay and ocean temperatures rose again to peaks in mid-August (Figure 4). Overall, the mid-July to mid-August warming trend coincided with the general increase in diatom abundance. Variation in surf and nearshore bottom temperatures through August indicate a slight upwelling-downwelling trend; this is supported by weather records which show a shift from a southwesterly to a northeasterly flow during the period. This would tend to promote mixing in the nearshore zone as reflected in surface and bottom temperatures becoming more equalized in late August (Figure 4). Weather and circulation patterns thus may have contributed to the lack of phytoflaellate blooms and abundance of diatoms in New Jersey coastal waters (see USEPA, 1986).

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Table 1. List of common or abundant phytoplankton species at representative locations in the 1990 survey of New Jersey coastal and estuarine waters.

Numbers under each location denote the amount of samples each species appeared in. Letters denote times of abundance as follows: Aa - late spring (May 23 - June 13), Bb - early summer (June 20 - July 11), Cc - midsummer (July 18 - August 15), Dd - late summer/early autumn (August 29 - September 26). A capital letter indicates dominance (i.e. >1000 cells/ml); an asterisk (*) following a capital letter indicates a bloom (>10,000 cells/ml).

| | North | | Location | | | | South |
|---|---|---|---|---|---|---|---|
| Species | RB1 | RB15 | JC14 | JC33 | JC57 | JC77 | DB1 |
| diatoms | | | | | | | |
| *Leptocylindrus danicus* | 5bcd | 5BC | 6abcd | 8abc | 4Abd | 4abc | |
| *L. minimus* | 4Abd | 4ab | 1d | | 1a | 4Bc | 3Ac |
| **Skeletonema costatum*[1] | 6AC*D | 9A*CD* | 4CD | 8aCD | 4CD | 4BCD | 6ABCD* |
| **Cyclotella* sp.[2] | 4ab | 5A*bD | 2ac | 2Cd | 1b | 3aC | 3abC |
| *Thalassiosira* sp. | 2a | 1a | 1D | | | | 2bd |
| *T. gravida* | | 1D | 1a | 2ad | | 1d | |
| *T. nordenskioldii* | 2b | 2ac | | 1c | | | 3Ab |
| *T. rotula* | 4aD | 1aD | 2ad | 4ad | 2ad | 1c | 2ad |
| *T. subtilis* | 4CD | 10aCD | 4aCd | 3ac | 4abc | 2aC | 3aBC |
| *Coscinodiscus* sp. | 4bcd | 2d | 1b | | | 2ac | 1d |
| *Eucampia zoodiacus* | 1D | | 2D | | 2D | | 1d |
| *Hemiaulus sinensis* | 4bCd | 6bcd | 3CD | 3CD | 2D | 1d | |
| *Cerataulina pelagica* | 5abcd | 6abcd | 4abcd | 2cd | 2Ad | 2ad | 1c |
| **Chaetoceros* sp. | 3C*D | 7AbC*D | 4CD | 3Cd | 5acD | 4BCD | 3AB |
| *C. sociale* | | 1a | | 1D | | | |
| *Rhizosolenia alata* | | 1c | 1d | 2c | 1c | | |
| *R. delicatula* | 3acd | | 3A | 3A | 2ac | | |
| *R. fragilissima* | 4aB | 6abd | 3Ab | 5Ab | 4Ab | 5AB | |
| *Ditylum brightwelli* | 2d | 1d | 2d | | | 1d | |
| *Asterionella glacialis* | 1a | 1a | 2ad | 2ac | | 1d | 5ABD |
| *Thalassionema nitzschioides* | | | | | | 2ad | 3aD |
| *Navicula* sp. | 2ab | 1a | 1a | 2ad | | 1c | 3abd |
| *Nitzschia* sp. | 2ab | 4abc | 3bd | 2cd | 1b | 4ac | 5aBD |
| **Phaeodactylum tricornutum* | | 2bd | | | | | 3C*D |
| **Cylindrotheca closterium* | 1d | 2Cd | 1C | 2ac | 1c | 2d | 3*CD |
| dinoflagellates | | | | | | | |
| *Prorocentrum micans* | 2ab | 2ac | 1d | | | 1b | |
| *P. minimum* | 3ab | 7Abc | 2ac | 4acd | 2a | 2b | 1d |
| *P. triestinum (redfieldi)* | 1d | 2d | 1d | 1d | 1d | 1d | |
| *Gymnodinium* sp. | 1b | 3ac | 1c | 3cd | 1a | | 1a |
| *G. danicans* | 3abd | 6Abcd | | 1c | 1c | 2bc | 1a |
| *Gyrodinium* sp. | 2b | 1c | 1c | | 1c | | 1D |
| **Katodinium rotundatum*[3] | 1B* | 5AB*c | 2bc | 1b | 4bc | 1c | 1a |
| *Oblea rotunda* | 3bd | 3bcd | | 1c | | | |
| *Protoperidinium* sp. | 3d | | 1d | 1c | | | 2cd |
| *P. trochoideum* | 3Bd | 4acd | | 1d | 3cd | | |
| other phytoflagellates | | | | | | | |
| **Olisthodiscus luteus*[4] | 3ab | 5A*Bc | | | 1b | | |
| *Calycomonas ovalis* | | 1D | | | | 1d | |

Table 1. (continued)

| Species | North RB1 | RB15 | Location JC14 | JC33 | JC57 | JC77 | South DB1 |
|---|---|---|---|---|---|---|---|
| *Ebria tripartita* | 2a | 3abd | 1a | 1a | | | |
| *Pyramimonas micron* | 8abd | 8abcd | 4aBd | | 3bcd | 2ab | 3Abd |
| *Tetraselmis gracilis* | 2ab | 5ac | 3cd | | 2bc | | |
| *Chlamydomonas* sp. | 4ab | 4ab | 3ad | 2ab | 2ab | | 1a |
| *Eutreptia lanowii* | 4aB | 9ABc | 3cd | | 4bc | 3abc | 1b |
| *Chroomonas amphioxiea* | 3ac | 1c | 2c | 4abc | | 1c | 1d |
| *C. minuta* | 5Bcd | 3a | 1B | 3Bc | 2b | 2bd | 1b |
| *Cryptomonas* sp. | 1b | 1a | 1d | | | 2ab | 2ab |
| nonmotile chlorophytes | | | | | | | |
| *Chlorella* sp. | | | 7a | 2bc | | 1d | 2ad |
| *C. marina* | 7Ab | 8Abcd | 3bcd | 5abc | 5acd | 5abc | 2ab |
| *Ankistrodesmus* sp. | 5ab | 3a | | 1a | | | 3Ab |
| *Nannochloris atomus*[5] | 13aBC*D | 13AB*C*D* | 12aBCD | 10aBCD | 11ABCD | 10ABCD | 6A*BC*D |
| total occurrences | 142 | 175 | 100 | 96 | 79 | 78 | 79 |
| total samples | 13 | 13 | 13 | 12 | 11 | 10 | 6 |
| frequency index[#] | 10.92 | 13.46 | 7.69 | 8.00 | 7.18 | 7.80 | 13.17 |

footnotes: [#] = number of occurrences/number of samples

[1] - common most of season throughout the survey region; early season abundance in Sandy Hook Bay (bloom) and Delaware Bay; late season abundance throughout with blooms in both estuaries; in early August partially responsible for localized red tides in Shrewsbury River and Sandy Hook Bay vicinity.

[2] - co-dominant with *O. luteus* in early - season red tide in Sandy Hook Bay; partially responsible for localized green water, coincident with fish kill in Branchport Creek tributary to Shrewsbury River (June), localized red tide in Sandy Hook Bay and Shrewsbury River (early August).

[3] - caused widespread and locally dense red tide in late June in the lower Hudson - Raritan estuary, localized and very dense red tide in Branchport Creek (July).

[4] - responsible for red tide in Sandy Hook Bay in mid-June.

[5] - ubiquitous throughout the survey region, bloom(s) all summer in Barnegat Bay, mid to late season abundance throughout with bloom(s) in Raritan - Sandy Hook Bay and Cape May - Delaware Bay coincident with diatom blooms. Because of its minute cell size ($<5\mu m$) the criterion for abundance is increased by a factor of ten (i.e. $10^4 ml^{-1}$ for dominance, $10^5$ for blooms).

Table 2. Chlorophyll a data (mg/m³ = µg/L) for the 1990 New Jersey coastal and estuarine phytoplankton survey.

| Location* | 5/30 | 6/7 | 6/13 | 6/20 | 6/26 | 7/11 | 7/18 | 8/8 | 8/15 | 8/29 | 9/12 | 9/26 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H/RE | | | | | | | | | | | | | |
| RB1 | 8.1 | 20.9 | 6.9 | 34.5 | 86.5 | 9.7 | 20.3 | 14.8 | 80 | 34.2 | | 2.4 | 28.9 |
| RB51A | 7.5 | | | | 119.2 | 11.5 | | | 95 | 66.5 | | | 59.9 |
| RB15 | 15.9 | 29.9 | 46.5 | 23.6 | 29.2 | 36.2 | 72.2 | 44.4 | 42.8 | 75 | | 12.7 | 38.9 |
| MCC | | | | | | | | | | | | | |
| JC08 | 5.6 | 2.4 | 7.9 | 10.6 | 3.6 | 15.9 | 14.9 | 21.6 | 39.7 | 35.9 | | 2.1 | 14.6 |
| JC14 | 9.6 | 1.7 | 7.9 | 2.5 | 2.6 | 15.9 | 3.1 | 18.6 | 37.2 | 36.7 | | 2.1 | 12.5 |
| JC33 | 13.1 | 2.4 | 10.2 | 2.1 | 2.9 | 7.0 | 5.0 | 9.7 | 13.2 | 21.0 | | .9 | 7.9 |
| OCC | | | | | | | | | | | | | |
| JC57 | 12.6 | 1.6 | 13.0 | 3.1 | 1.3 | 2.2 | 2.8 | 2.4 | 1.7 | 6.3 | | 1.8 | 4.4 |
| JC65 | 9.9 | 5.3 | 9.7 | 3.5 | 5.3 | 2.8 | 4.0 | | | 7.7 | | 5.7 | 6 |
| BB | | | | | | | | | | | | | |
| NM | | | 11.1 | | 8.6 | 12.5 | 17.7 | 15.7 | | 5.6 | 9.5 | 11.7 | 11.6 |
| HP | | | 13.5 | | 14.7 | 14.0 | 16.8 | 14.3 | | 17.0 | 12.1 | 9.4 | 14 |
| WT | | | 13.3 | | 15.1 | 17.3 | 13.6 | 11.3 | | 14.3 | 8.9 | 7.3 | 12.6 |
| SM | | | 15.7 | | 21.8 | 21.5 | 24.3 | 15.1 | | 24.1 | 13.0 | 14.4 | 18.7 |
| A/CMC | | | | | | | | | | | | | |
| JC77 | 19.6 | 4.1 | 3.6 | 1.9 | 3.3 | 6.5 | 3.5 | | | 10.0 | | 2.3 | 6.1 |
| JC83 | 9.6 | 4.8 | 2.4 | 6.0 | 2.0 | 8.3 | 2.5 | | | 6.9 | | 3.5 | 5.1 |
| JC91 | 17.1 | 2.6 | 1.6 | 2.2 | | | 2.8 | | | 17.8 | | 7.5 | 7.4 |
| DB | | | | | | | | | | | | | |
| DB1 | | 84.0 | 25.9 | 34.5 | | | 41.3 | | | 99.1 | | | 57 |
| DB2 | | 56.7 | 12.9 | 26.5 | | | 40.6 | | | 33.5 | | | 34 |
| MEAN | | | | | | | | | | | | | |
| H/RE | 10.5 | 25.4 | 26.7 | 29.1 | 78.3 | 19.1 | 46.3 | 29.6 | 72.6 | 58.6 | | 7.6 | 36.7 |
| MCC | 9.5 | 2.2 | 8.7 | 5 | 3 | 12.9 | 7.7 | 16.6 | 30 | 31.2 | | 1.7 | 11.7 |
| OCC | 11.3 | 3.5 | 11.3 | 3.3 | 3.3 | 2.5 | 3.4 | 2.4 | 1.7 | 7 | | 3.8 | 4.9 |
| BB | | | 13.4 | | 15 | 16.3 | 18.1 | 14.1 | | 15.3 | 10.9 | 10.7 | 14.2 |
| A/CMC | 15.4 | 3.8 | 2.5 | 3.4 | 2.6 | 7.4 | 2.9 | | | 11.5 | | 4.5 | 6 |
| DB | | 70.4 | 19.4 | 30.5 | | | 41 | | | 66.3 | | | 45.5 |

* H/RE - Hudson/Raritan Estuary
MCC - Monmouth County Coast
OCC - Ocean County Coast
A/CMC - Atlantic/Cape May Counties
BB - Barnegat Bay
  NM - Mantoloking
  HP - Holly Park
  WT - Waretown
  SM - Manahawkin
DB - Delaware Bay

Table 3. Temporal and spatial occurrence of dominant species, bloom incidence and associated conditions in New Jersey estuarine and coastal waters during the 1990 season.

| Date | Locale | Observation/Condition |
|---|---|---|
| May | | routine sampling begins; spring diatom flowering(s): |
| 23 | Raritan - Sandy Hook Bay (RB1,15) | Skeletonema costatum abundant (>1000 cells/ml); |
| 30 | NJ coast, Long Branch (JC14) to Wildwood (JC91) | several species abundant including Rhizosolenia delicatula, R. fragillisima, Cerataulina pelagica and Leptocylindrus danicus; |
| Jun. 6 | Raritan Bay (RB1) and Sandy Hook Bay (RB15) | S. costatum, Leptocylindrus minimus abundant, S. costatum bloom (>10,000 cells/ml); |
| 6-20 | Delaware Bay capeshore area (DB1,2) | several diatom species abundant including S. costatum (dominant all season), Thalassiosira spp., Chaetoceros sp. and Asterionella glacialis; |
| 13 | Barnegat Bay | start of annual chlorophyte bloom of Nannochloris atomus (>100,000 cells/ml), N. atomus also abundant in the other estuaries; |
| | Sandy Hook Bay | first observed phytoflagellate bloom of the season, Olisthodiscus luteus (>$10^4$ cells/ml) accompanied by a bloom of Cyclotella sp. (diatom) with abundance of Eutreptia lanowii (euglenoid), chlorophytes N. atomus and Chlorella sp.; |
| 13-20 | Raritan Bay | abundance of the diatom Rhizosolenia fragillisima and the dinoflagellate Protoperidinium trochoideum; |
| | NJ coast, Sandy Hook to Wildwood (JC08-91) | abundance of R. fragillisima throughout, abundance of E. lanowii in Ocean City locale (JC83); |
| 18 | Branchport Creek (tributary to the Shrewsbury River) | green water caused by bloom(s) of Cyclotella sp. and N. atomus, many small fish seen dead coincident with bloom; |
| 18-28 | Sandy Hook Bay at Atlantic Highlands | red tide dominated by Katodinium rotundatum with several other flagellates abundant including Euglena/Eutreptia spp., O. luteus and diatoms C. pelagica and Cyclotella sp.; |
| 26-29 | Raritan - Sandy Hook Bay north to Staten Island | red tide bloom of the dinoflagellate Katodinium rotundatum throughout southern half of the Hudson - Raritan Estuary; |

Table 3. (continued)

| Date | Locale | Observation/Condition |
|---|---|---|
| Jul. 11 | Raritan - Sandy Hook Bay | red tide in estuary virtually gone possibly due to changes in weather, *N. atomus* remaining abundant; |
| | Monmouth County coast (RB1-33) | small flagellates *Pyramimonas micron* and *Chroomonas minuta* abundant; |
| 18 | | start of summer diatom flowerings: |
| | Raritan - Sandy Hook Bay and northern Monmouth County coast (JC08) | abundance of *S. costatum*, *L. danicus*, *Thalassiosira subtilis* and *Cylindrotheca closterium*; |
| | NJ coast, Manasquan and Atlantic City locales (JC33,77) | abundance of *Cyclotella sp.*; |
| | southern NJ coast (JC65-91) | abundance of *S. costatum*, *T. subtilis* and *Chaetoceros sp.*; |
| | Delaware Bay capeshore | abundance of *S. costatum*, *T. subtilis*, *Nitzschia sp.*, blooms of *C. closterium*, *Phaeodactylum tricornutum* and chlorophyte *N. atomus*; |
| | Barnegat Bay | *N. atomus* bloom peak (chlorophyll *a* $>24 \mu g l^{-1}$); |
| Aug. 2 | Sandy Hook Bay at Ideal Beach (E. of Keansburg), Shrewsbury River at Sea Bright and Branchport Creek | brown water caused by blooms of several diatoms (especially *S. costatum* and *Thalassiosira nordenskioldii*) and *N. atomus*; |
| 8-15 | Raritan - Sandy Hook Bay, Monmouth County coast | abundance of *S. costatum*, *T. subtilis*, *Hemiaulus sinensis* and *Chaetoceros sp.*; |
| 15-29 | Raritan - Sandy Hook Bay | bloom and continued dominance of *Chaetoceros sp.* and *S. costatum*; *L. danicus* and *H. sinensis* abundant; |
| | Monmouth County coast (JC08-33) | abundance of *S. costatum* and *H. sinensis*; |
| 29 | Sandy Hook Bay at Atlantic Highlands | brown water caused by an abundance of several diatom species; |
| | Belmar at 20th Avenue (Monmouth County coast) | localized patch of discolored water caused by an abundance of many species, mostly phytoflagellates; |
| | entire NJ coast, Sandy Hook to Cape May and Delaware Bay | *S. costatum* and *N. atomus* abundant throughout with blooms at northern and southern extremes (RB15, JC91, DB1,2); |
| | Barnegat Bay | second *N. atomus* bloom peak (chlorophyll *a* $>24 \mu g l^{-1}$); |

Table 3. (continued)

| Date | Locale | Observation/Condition |
|---|---|---|
| Aug. 29 - Sept. 5 | Raritan - Sandy Hook Bay | abundance of Thalassiosira rotula, T. subtilis and T. gravida; Calycomonas ovalis (flagellate) in Sandy Hook Bay; |
| | NJ coast, south to Island Beach | abundance of the diatom Eucampia zoodiacus; |
| | Delaware Bay | continued dominance of diatoms including A. glacialis, Thalassionema nitzschioides, P. tricornutum, Nitzschia sp., C. closterium and the flagellate Gyrodinium sp.; |
| 26 | entire NJ coast | phytoplankton (chlorophyll) levels generally diminished throughout; |
| | Sandy Hook Bay | a few diatom species and N. atomus remaining abundant; |
| | | end of regular sampling |

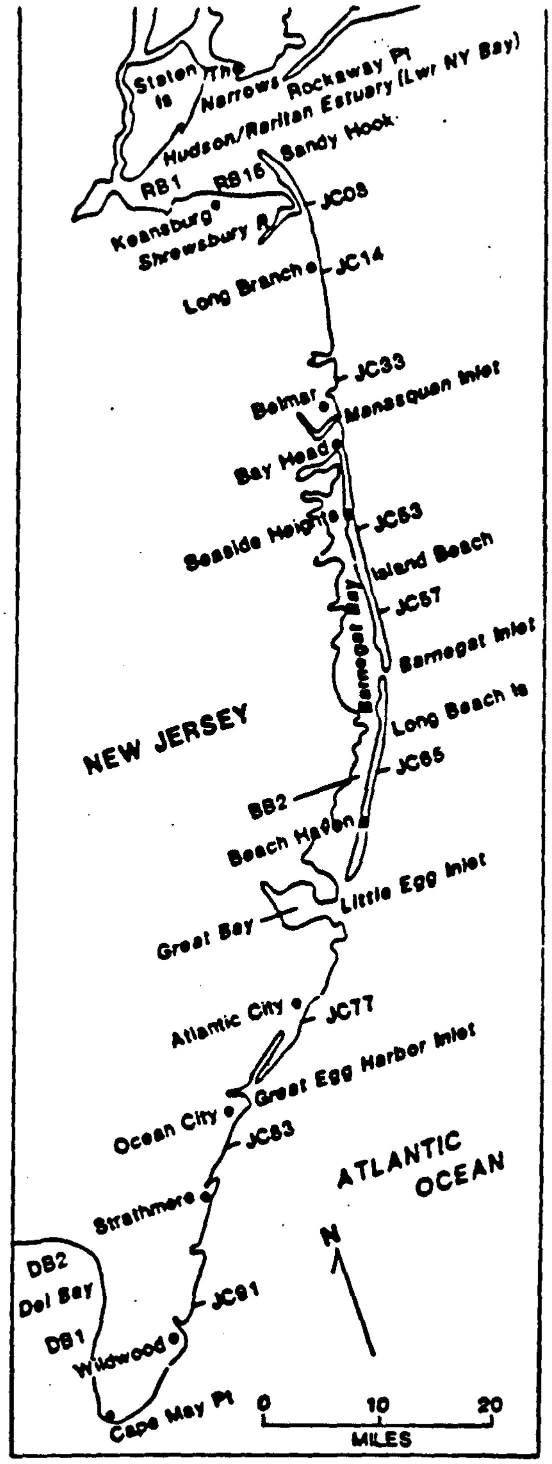
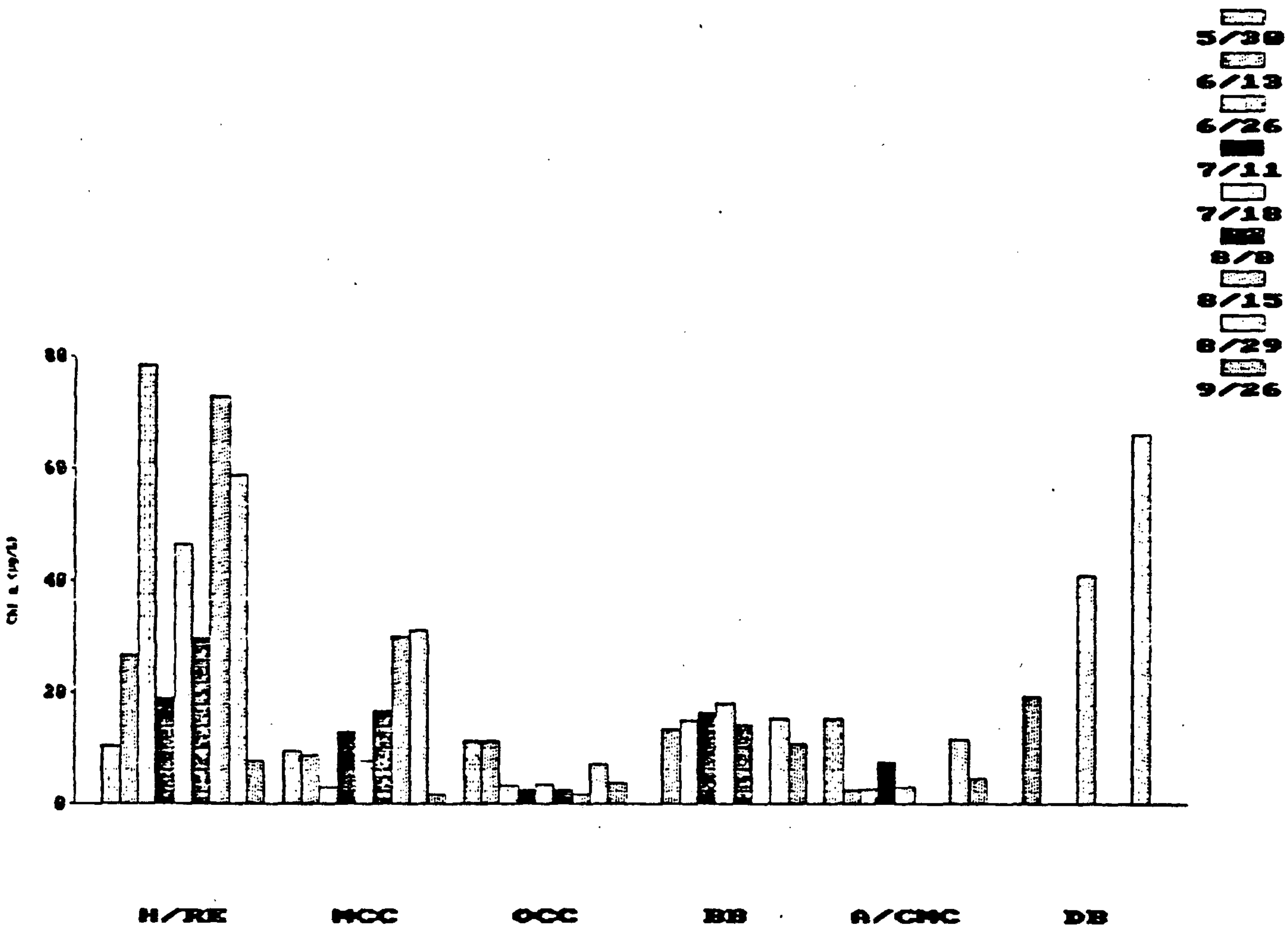


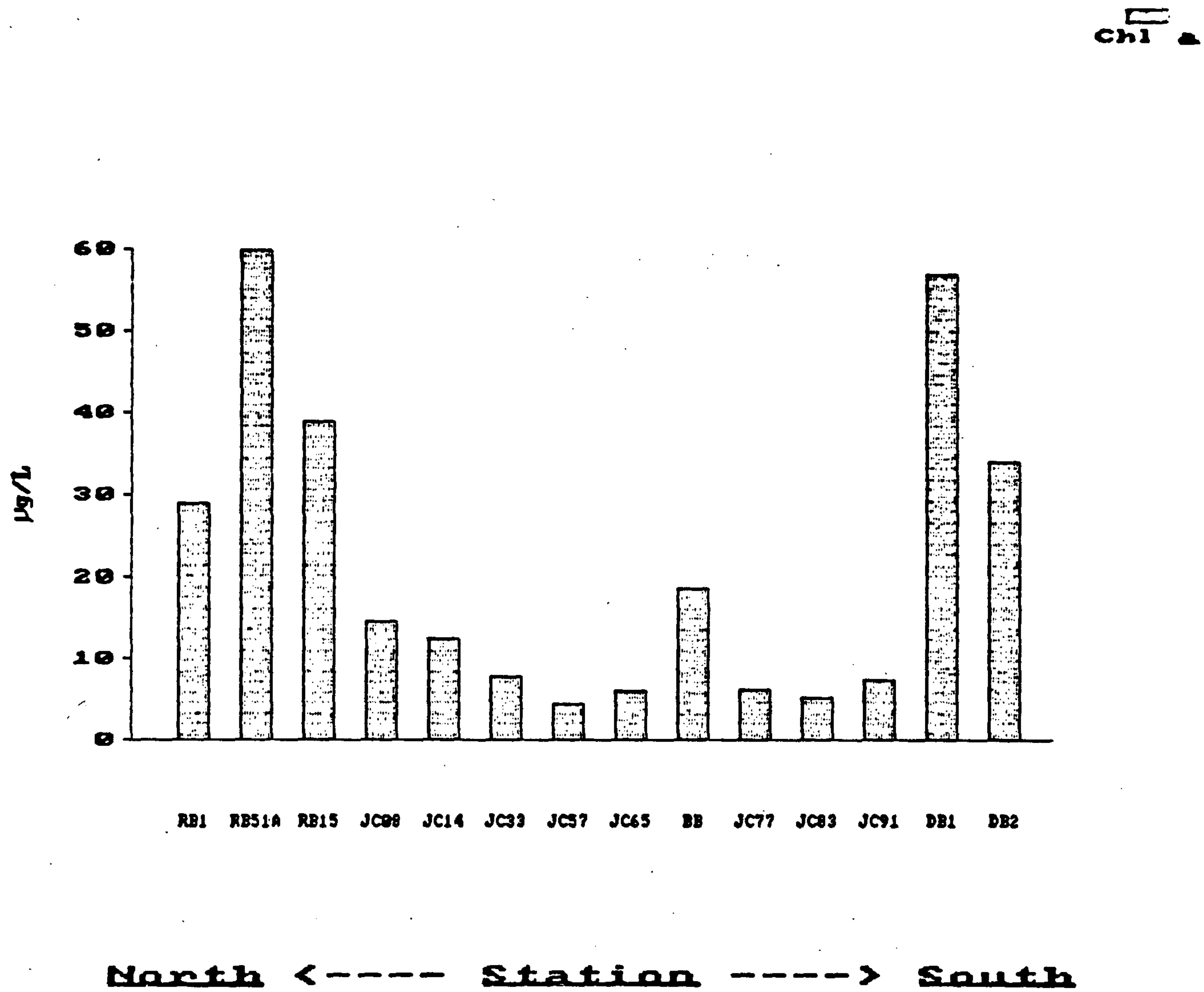

Figure 1. New Jersey coast station locations, Sandy Hook to Cape May.

Figure 2. Seasonal changes in chlorophyll a concentrations (µg/L) for the 1990 New Jersey coastal and estuarine phytoplankton survey. Bars represent composite values for the major segments of the survey region.




H/RE - Hudson/Raritan Estuary (RB1, RB15, RB51A)
MCC - Monmouth County Coast (JC08, JC14, JC 33)
OCC - Ocean County Coast (JC57, JC65)
BB - Barnegat Bay (Mantoloking, Holly Park, Waretown, Manahawkin)
A/CMC - Atlantic/Cape May County Coast (JC77, JC83, JC91)
DB - Delaware Bay (DB1, DB2)

Figure 3. Mean chlorophyll a values for New Jersey coastal and estuarine stations, north to south, for the 1990 summer season.




| condition* | chl a (µg/L) |
|---|---|
| oligotrophic | 0 - 3.3 |
| mesotrophic | 3.4 - 6.6 |
| eutrophic | 6.7 - 10 |
| hypertrophic | >10 |

* Criteria are based on levels normally found in coastal and offshore waters.

Figure 4. Changes in New Jersey coastal and estuarine water temperature (°F) for summer of 1990. USEPA station 51A in Raritan - Sandy Hook Bay, surface; Island Beach State Park, surf; USEPA transect off Seaside Heights, JC53E (1 mile offshore) bottom, JC53M (nine miles offshore) surface and bottom.