New Jersey Geological Survey
Technical Memorandum 89-1

ANNUAL SUMMARY OF PHYTOPLANKTON BLOOMS AND RELATED CONDITIONS IN NEW JERSEY COASTAL WATERS, SUMMER OF 1988

New Jersey Department of Environmental Protection
Division of Water Resources

1989

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Division of Water Resources
Jorge H. Berkowitz, *Acting Director*

Geological Survey
Haig F. Kasabach, *State Geologist*

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by
Paul Olsen and Barbara Kurtz

New Jersey Department of Environmental Protection
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Geological Survey
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Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters, Summer of 1988

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Synopsis

Phytoplankton data and related water quality conditions are presented for the current NJDEP/USEPA cooperative New York Bight water-quality Survey. As in the few years previous to 1988, red tides in our northern shore area were confined principally to the Hudson/Raritan estuary; however, their intensity and duration were somewhat greater in 1988. In the coastal sector, although no extensive red tide blooms have occurred since 1985, cool water conditions and consequent diatom blooms were unusually persistent in summer of 1988. The diatom *Cerataulina* sp. bloomed initially in late May in Raritan Bay and subsequently over the entire New Jersey coast; resultant accumulations of brown foam were scattered over much of the NJ northern shore. At this time, neritic dinoflagellates, including *Ceratium* sp., were also abundant in samples taken off Ocean County. No other diatom blooms resulted in nuisance conditions. Phytoflagellate red tides dominated by *Olisthodiscus, Katodinium, Prorocentrum* and *Eutreptia* sp. occurred in the northern estuarine area in June and continued intermittently through early August; these were most intense along the Raritan - Sandy Hook Bay south shore in the Keansburg vicinity. Analysis for chlorophyll *a* (initiated by our laboratory this year) revealed a high maximum value of 277 mg/m^3 in these samples. Dead fish and shellfish, primarily demersal species (flounder, sea robins, crabs, etc.) were observed washing ashore downbay of Keansburg in late June and again in early August. Analysis of water samples collected by EPA indicated that hypoxia may have caused the fish kills. Helicopter surveillance for floatable debris (initiated by the NJDEP this year) revealed trash, wood and natural materials at scattered locations in Lower New York Bay, occasionally extending to adjacent New Jersey waters. Isolated red tide blooms were observed a few different times off Asbury Park, Atlantic City, and the Delaware Bay cape shore. The Delaware Bay location, newly established as a sampling site, had the highest mean chlorophyll *a* level (81 mg/m^3) of all stations regularly sampled. Brown water blooms, persisting again in Barnegat Bay (also recently established as a sampling area), were densest in southern reaches of the bay. The presence of the "brown tide" organism, *Aureococcus* sp., in New Jersey was confirmed, although *Nannochloris* sp. is still considered the dominant phytoplankter in this region. Along the NJ coast, southwesterly winds sustained onwellings resulting in unusually cool surf temperatures through most of July and August 1988. USEPA data revealed that nearshore bottom dissolved oxygen concentrations were generally above minimum levels (about 4.0 mg/l) necessary to support most marine life. Red tide blooms were minimal and several diatom species, including *Skeletonema* and *Thalassiosira* sp., dominated the phytoplankton throughout most of summer.

Introduction

Red tides caused by blooms of various phytoplankton (mostly dinoflagellate) species have recurred periodically in New Jersey estuarine and coastal waters. Recorded earliest in Delaware Bay in 1928 (Martin and Nelson, 1929) were localized blooms dominated by *Amphidinium fusiforme* and *Gymnodinium splendens*. Martin (1929) also mentioned dense blooms of *G. splendens* in Barnegat Bay. Records of events, however, have become more numerous during the past 30 years; events occurred primarily in the Hudson/Raritan estuary and adjacent New Jersey northern coastal waters at least as far south as Belmar (figure 1). Most of the blooms were dominated by *Olisthodiscus luteus* and *Katodinium rotundatum* (Mahoney and McLaughlin, 1977). Usually localized, these blooms have recurred annually since the early 1960's. Fortunately, none of the species were of the acutely toxic varieties, although there were occasional fishkills due to anoxia when blooms collapsed (Ogren and Chess, 1969; Young, 1974). *Gonyaulax tamarensis*, causative agent of paralytic shellfish poisoning (PSP) in the northeast U.S. and Canada, has been found in New Jersey but in very low concentrations (Cohn et al., 1988). A few blooms of *Prorocentrum micans*, however (most extensively in 1968), were associated with mild respiratory discomfort to bathers (Mahoney and McLaughlin, 1977). In response to the 1968 event, State and Federal agencies initiated an investigation of the problem. In 1969, the Interagency Committee on Marine Plankton Blooms was formed and has functioned to coordinate government response in the event of serious blooms (see USEPA, 1978-88 inclusive). In 1973 the New Jersey Department of Environmental Protection (DEP) and the National Marine Fisheries Service (NMFS), Sandy Hook Laboratory, cooperatively instituted an intensive phytoplankton study in the region most affected by the red tides (Olsen and Cohn, 1979).

Red tides observed in the region were generally estuarine in nature until 1976 when a massive bloom (of *Ceratium tripos*) occurred offshore in the New York Bight, resulting in widespread anoxia and consequent fishkills (Swanson and Sindermann, 1979). Another interagency group, the New York Bight Advisory Committee, was formed to respond to this and subsequent hypoxia problems, none of which became as serious as the 1976 event. In 1977, seasonal helicopter surveillance and sampling in the New Jersey northern coastal region was instituted by the USEPA, Region II, cooperatively with the NJDEP. In 1978 other major blooms occurred within the Bight and adjacent shelf waters. In the greater Atlantic City area, a milky brown discoloration caused by *Dinophysis acuta* (Figley, 1979) constituted the first recorded red tide in southern New Jersey coastal waters. Also in 1978, the diatom *Coscinodiscus walesii* caused clogging of fishermen's nets throughout an extensive area off Delaware Bay and southward (Mahoney and Steimle, 1980). The only other diatom causing similar nuisance conditions was *Cerataulina pelagica*, which bloomed more recently along much of the New Jersey coast (USEPA, 1987-88, inc.). In 1984-85 conspicuous "green tides" occurred along the south-central NJ coast; the causative species was identified as *Gyrodinium aureolum*, an unarmored dinophycean. An intensive study was initiated to investigate causes of these blooms (USEPA,

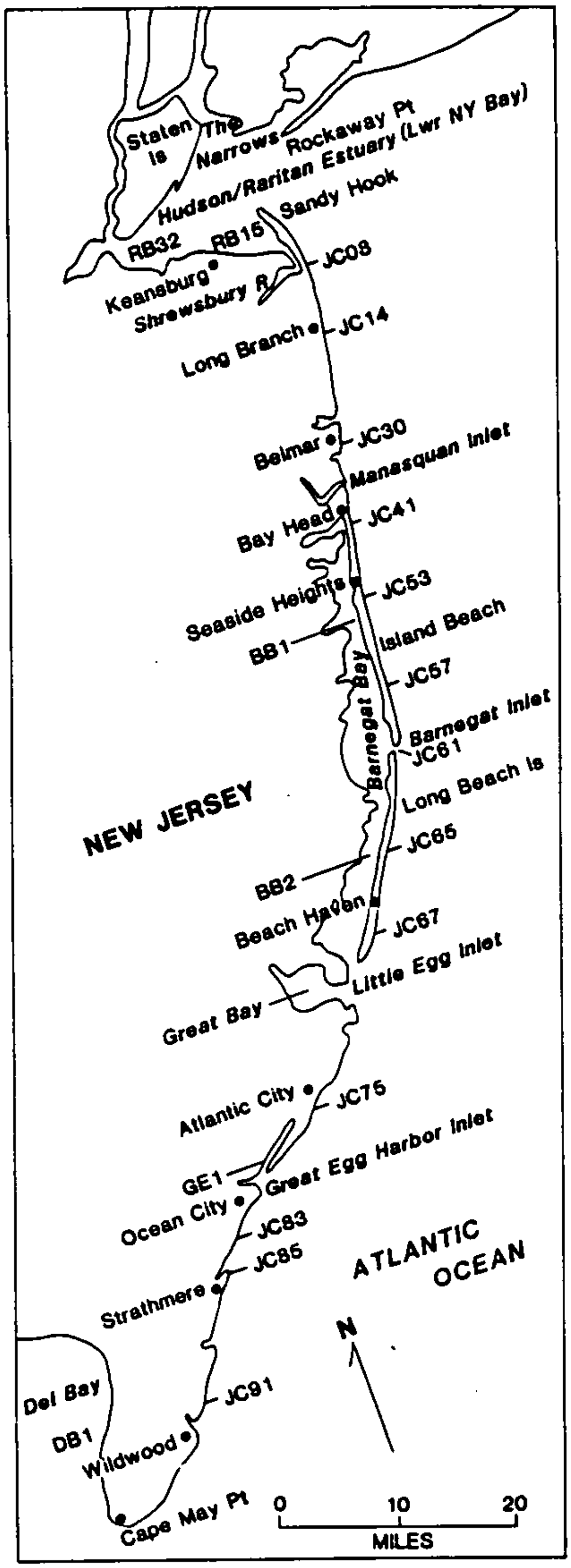

Figure 1. New Jersey coast station locations, Sandy Hook to Cape May.

1986a) and routine helicopter sampling was extended to include the coastal sector from Barnegat Inlet to Cape May (figure 1).

While the red tides in the region were composed mainly of phytoflagellates, considerably smaller (primarily chlorophycean) forms were found, as early as the 1950's, to be dominant and responsible for greenish water discoloration (Ryther, 1954; Patten, 1962); these were minute coccoid species identified initially as *Nannochloris atomus*. Although *N. atomus* was apparently most abundant in the Hudson/Raritan estuary and adjacent coastal areas, in 1985 extensive blooms of this species were observed offshore in the New York Bight and southward along the New Jersey coast, overlapping the area of the dinoflagellate green tides (USEPA, 1986). Also in 1985, brownish-water conditions due apparently to *N. atomus* were noted in coastal embayments, first in Barnegat Bay and subsequently southward at least to Great Egg Harbor. This coincided with the occurrence of the "brown tides" of a previously unidentified species (*Aureococcus anophagefferens*) which devastated eelgrass beds and economically important shellfisheries in Rhode Island and eastern Long Island, NY embayments (Cosper et al., 1987; Sieburth et al., 1988).

In the present report, phytoplankton data and related water conditions are presented for the New Jersey coastal region, summer of 1988. This year, sampling for chlorophyll *a* analysis was instituted and nutrient analyses were deleted from the routine schedule. Sampling stations were added in Barnegat Bay and Delaware Bay and a few coastal locations were changed from those previously sampled. Results are obtained cooperatively with the USEPA, Region II, and complement the physicochemical and bacteriological data also gathered during the annual New York Bight Water Quality Survey (USEPA, 1978-88, inc.). Other surveys gathering bacteriological data include the DEP Marine Water Classification (shellfish control) Program, and the Coastal Cooperative Monitoring (bathing water quality) Program of DEP and the shore county health agencies (NJDEP, 1988a and b). In 1988, additional helicopter surveillance of the Hudson/Raritan Estuary and New Jersey coastline for floatable debris was initiated by the NJDEP. Also, a cruise on the EPA ocean survey vessel, the P.M. Anderson, was undertaken to investigate another possible bight-wide *Ceratium* bloom.

Acknowledgements

Field collections were made primarily by personnel of the USEPA, Region II, helicopter surveillance unit. Analysis of samples for chlorophyll *a* was performed by John Kurtz.

Methods

The basic sampling scheme includes twelve sites selected from the New Jersey coast - Raritan estuary component of the EPA New York Bight sampling network (figure 1). In 1988 stations JC08, JC14, JC41, JC53 and JC91 were added and JC05, JC11, JC21, JC49 and JC93, from previous years, were deleted. To supplement the basic scheme, additional sites were introduced in the central and southern bays and estuaries; these included Barnegat Bay (BB1 and BB2), Delaware Bay (DB1) and Great Egg Harbor (GE1). Frequency of collection is weekly from May to September, when weather permits; exceptions occur when the helicopter is detained for maintenance or other reasons. Sampling is done by Kemmerer from helicopter. Because these waters are generally shallow and well-mixed, surface samples taken at a 1m depth are considered representative; coastal samples are taken just outside the surf zone. Clear plastic cubitainers holding approximately one liter are employed for chlorophyll *a* and phytoplankton analysis. These are refrigerated in a closed container and delivered to the DEP Biomonitoring Laboratory, usually within 24 hours. Field collections are made in accordance with DEP standard procedures (NJDEP, 1987). On occasion, special phytoflagellate samples taken for qualitative purposes are maintained at in-situ temperatures. Samples not examined within 24 hours of collection are preserved with Lugol's Solution at one drop per 100ml or more as necessary to maintain weak tea color. Analysis for chlorophyll *a* is performed by the in-vitro method as described in USEPA (1973) after Strickland and Parsons (1968). Water-column aliquots are first filtered through a 0.45μm membrane (Millipore apparatus), the chlorophyll is then extracted by grinding the filter in 90% acetone/$MgCO_3$ solution. Processed samples are refrigerated for at least two hours, then centrifuged (20 minutes at 1500 RPM, 500g) and their optical density measured in a Perkin-Elmer Lambda 3 spectrophotometer. Equations for conversion to chlorophyll *a* are taken from UNESCO (1966). Methods for phytoplankton community analysis are based on SCOR (1974); this essentially utilizes the Sedgewick-Rafter and Palmer-Maloney strip and random field techniques, counting cells as small as 2μm. A comprehensive reference list for phytoplankton identification is given in Olsen and Cohn (1979).

Results and Discussion

Chlorophyll *a* data are shown in table 1 (appendix); mean concentrations and seasonal changes are shown in figures 2 and 3. Estuarine concentrations were generally much higher than those in coastal waters. The highest value observed in routine sampling (220 mg/m^3) was at the Delaware Bay cape shore site (DB1); notably, this station also had the highest mean chlorophyll level (80 mg/m^3) of all stations regularly sampled. Mean chlorophyll levels in Raritan - Sandy Hook Bay (RB32 and RB15) and in Barnegat Bay (BB2) were generally between 20 and 30 mg/m^3. The highest single value observed (277 mg/m^3) occurred during a dense phytoflagellate red tide in Raritan Bay at a site not routinely sampled (table 1). Chlorophyll *a* levels in the Raritan - Sandy Hook estuary exceeded 40 mg/m^3 on several occasions at the routine stations during phytoflagellate and/or diatom blooms. In Barnegat Bay, where the blooms were dominated by picoplankton (minute cells about 1μm to 3μm is size, chlorophyll *a* levels remained between 20 and 40 in the southern section (BB2) and between 10 mg/m^3 and 20 mg/m^3 in the northern section (BB1). In coastal areas, more uniformity was exhibited with lower chlorophyll *a* values at the several stations, and peaks usually occurring simultaneously along the entire coastline (figure 3); this suggests neritic or offshore, rather than estuarine, influence, especially in the segment from JC30 to JC65 (figure 1). North and south of this segment, highest levels (between 20 and 30 mg/m^3) in coastal locations occurred during periods of diatom and phytoflagellate activity (along the northern shore as far south as JC14 (Long Branch) on June 22 and September 7 and at Atlantic City (JC75) on August 10 and 24). The tendency toward higher chlorophyll levels

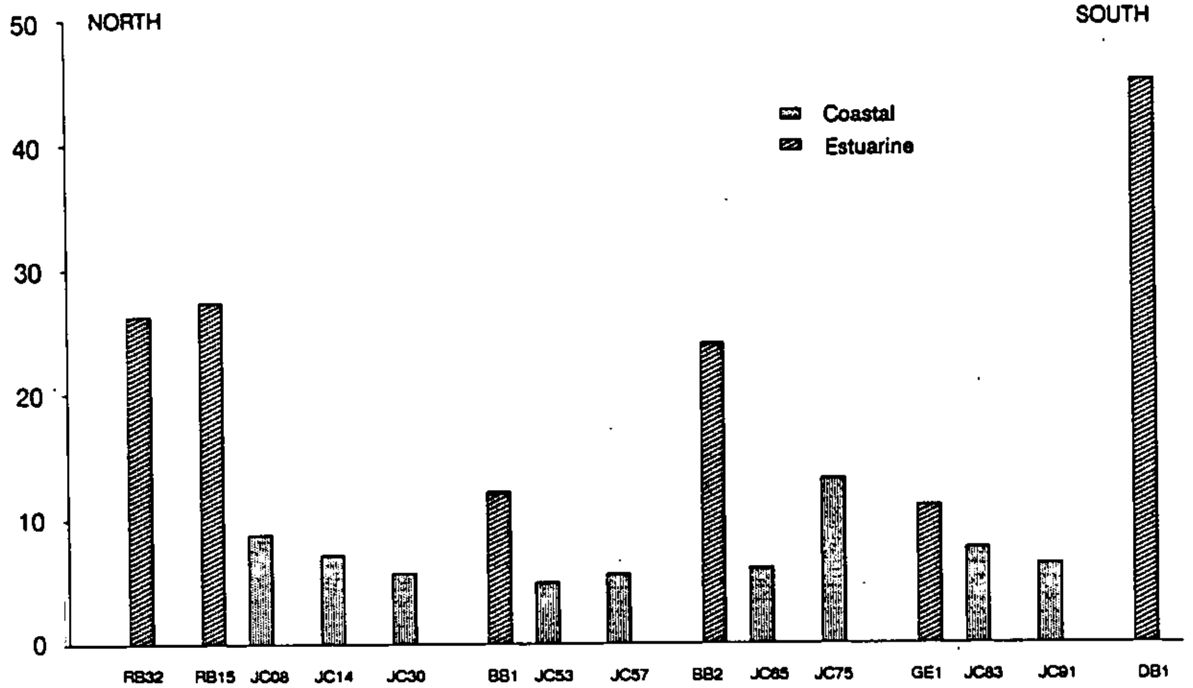

Figure 2. Mean chlorophyll *a* values for New Jersey coastal and estuarine stations, north to south, for the 1988 summer season.

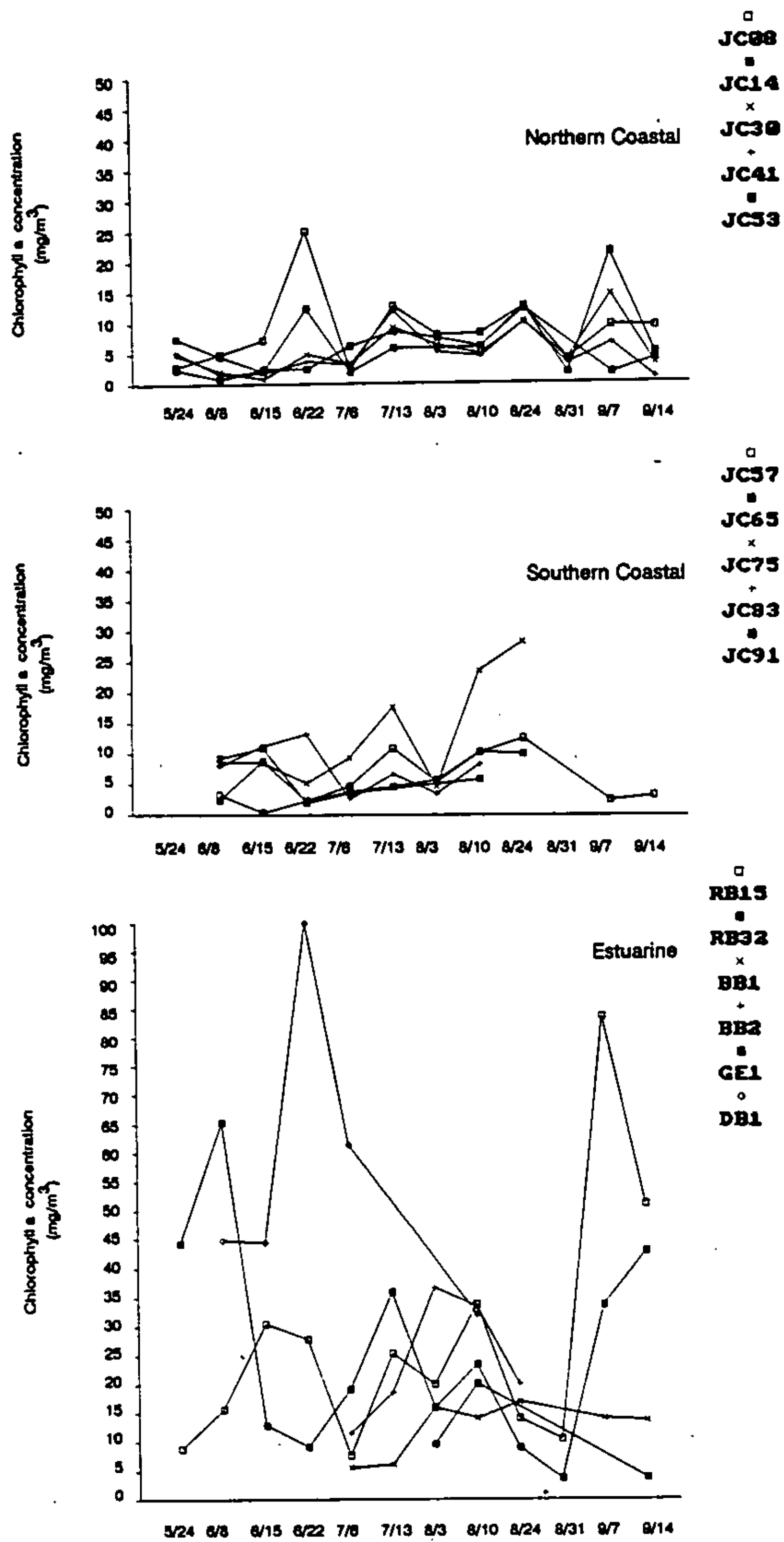

Figure 3. Seasonal changes in chlorophyll *a* concentrations at New Jersey northern coastal, southern coastal, and estuarine stations in the 1988 survey.

and bloom activity at these stations may reflect some estuarine influence in these areas.

Frequency of occurrence and succession of dominant species at routine stations is shown in tables 2 and 3 (appendix). The early spring period (May 24 - June 8) was characterized by the occurrence of a bloom of the diatom, *Cerataulina pelagica* in late May, initially at RB32 and subsequently at all coastal stations. Nuisance conditions of brown flocculent material (or foam) along much of the NJ shore (table 4) were associated with the *C. pelagica* bloom. During this period *Prorocentrum minimum* also bloomed in Raritan Bay and neritic dinoflagellates including *Ceratium* spp., *Dinophysis acuta*, and *Prorocentrum micans* were abundant in coastal samples taken off Ocean County. Phytoflagellate blooms of *Olisthodiscus luteus* occurred in early June from RB32 to JC14 causing red water in Raritan - Sandy Hook Bay. In late June, a red tide dominated by *O. luteus*, *Katodinium rotundatum*, and a euglenoid, *Eutreptia lanowii*, developed along the south shore in the vicinity of Keansburg (an area not routinely sampled). In late June many dead fish, primarily demersal species (sea robins, flounder, crabs, etc.) were observed downbay of Keansburg from the Earle Pier to Highlands (table 4). This incident was reported through the Monmouth County Health Department, the DEP Division of Fish, Game and Wildlife, and the NMFS, Sandy Hook Lab. The fish kill was attributed to localized hypoxia created by wind and tidal concentration of decomposing phytoplankton (from blooms) and other detrital material in the south-central portion of Sandy Hook Bay. During this period several diatom species primarily *Skeletonema costatum*, *Cyclotella* sp., *Thalassiosira nordenskioldii* and *Nitzschia* sp. bloomed in the eastern section of Sandy Hook Bay (RB15) (table 2); abundance of the euglenoid, *E. Lanowii* was also noted at RB15 while a bloom of this species occurred simultaneously off Ocean City (JC83). Through June, the diatom, *Cerataulina pelagica*, remained abundant at a few coastal locations. *Thalassionema nitzschioides* was abundant at southern coastal stations. At the Delaware Bay cape shore site (DB1), although sampling here ended in midsummer, a succession of many diatoms and flagellates was seen with several species abundant. This culminated in late June - early July with a red-water bloom of *Gyrodinium estuariale*; *Prorocentrum micans* was also abundant in that locale (tables 2 and 3).

In the midsummer period (July 6 - August 10), red tides of *P. minimum* and *E. lanowii* continued in Raritan - Sandy Hook Bay, while several diatom species, including *Leptocylindrus danicus*, *S. costatum*, and *Nitzschia* sp. (table 2) were abundant both in the estuary and in coastal waters. None of these coastal blooms produced noticeable water discoloration. Minute coccoid species in the "picoplankton" size range (to 3µm), primarily *Nannochloris atomus*, were abundant throughout the survey range with blooms at many locations. Coastal water temperatures were usually cool, e.g. < 70F° for most of July and < 60F° for most of August (figure 4), probably the result of persistent southwesterly winds. This likely precluded major phytoflagellate blooms and resulted in the dominance of diatoms throughout the summer. Late summer diatom blooms occurred at northern estuarine and coastal stations (table 2). Flagellate red tides continued in the Sandy Hook Bay south-shore area. Special samples collected at this time revealed the dominance in the blooms of *K. rotundatum*, *E. lanowii*, and *Prorocentrum triestinum (redfieldi)*. Reports of dead fish in the vicinity of Keansburg were received again in early August. Samples taken on August 4 by the EPA indicated that hypoxia caused the fish kills.

In Barnegat Bay the picoplankton bloom, responsible for brownish water discoloration during the previous three summers, was seen again in 1988. Bloom levels ($> 10^5$ cells ml^{-1}) were first observed in mid-July and continued through September. Cell concentrations were densest and most persistent in the southern section of the bay (BB2) where the salinity regime is generally higher than in the northern section (Chizmadia et al., 1984). The presence in Barnegat Bay of the "brown tide" species, newly identified as *Aureococcus anophagefferens* (Sieburth et al., 1988), was confirmed this year in samples sent to the Woods Hole Oceanographic Institution for analysis using a special immunofluorescent technique (D. Anderson, personal communication). This species constituted as much as 7.5% of the picoplankton in samples with total counts exceeding $10^6 ml^{-1}$ from lower Barnegat Bay. Although total cell densities were comparable to those that devastated the scallop fishery and eelgrass beds in Long Island, NY embayments (Cosper et al., 1987) the proportion of *Aureococcus* was considerably lower. Thus far, effects on

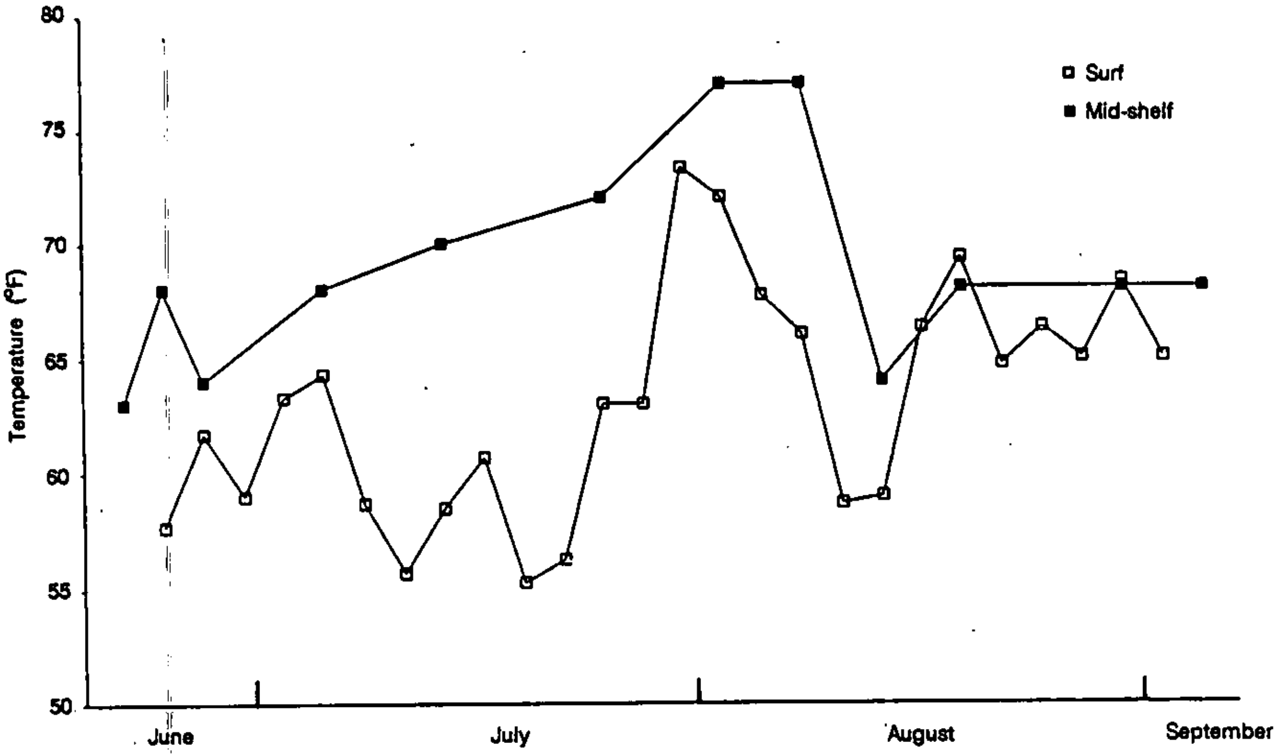

Figure 4. Seasonal changes in surf and offshore temperatures (°F). Surf temperatures at Island Beach State Park; mean temperatures for 3-day intervals from June 21 to September 5, 1988. Offshore mid-shelf surface isotherm at weekly intervals from NOAA satellite.

New Jersey's shellfish (primarily the hard clam) and other resources have not been documented. *Nannochloris atomus* is still considered the dominant species in this region. The only serious red tide recorded in Barnegat Bay occurred in 1964 (Mountford, 1965) dominated by a dinoflagellate, *Cochlodinium heterolabatum* (Silva, 1967).

Certain sampling locations, particularly estuarine stations RB15 and DB1 and coastal stations JC14 and JC75 (subject to considerable marine influence), exhibited more phytoflagellate activity than others (table 3). Mean chlorophyll *a* values also were higher at these stations (figure 2). The greater frequency and variety of these species (including some historically responsible for red tides) is due primarily to higher nutrient concentrations as well as the affinity of many phytoflagellates for lower salinity regimes. A late spring bloom of *Olisthodiscus luteus* produced red water at Raritan Bay station RB32 (tables 2, 4); the concurrent abundance of this species at station JC14 (Long Branch) reflects the influence of the Hudson/Raritan estuary along the New Jersey northern shore. Similarly, in the southern NJ. shore, although major red tides have appeared much less frequently than in the region of Hudson/Raritan influence, there was relatively high phytoflagellate incidence at JC75 (Atlantic City). Within a 25-mile stretch of coastline, with Atlantic City approximately in the center, there are four inlets (Little Egg to Great Egg Harbor, figure 1); discharge from local estuaries and embayments, is greater than in any equivalent length of the NJ coast. In Delaware Bay (DB1 vicinity) the recurrent blooms have apparently been localized and benign, providing sustenance for the valuable oyster fishery there (Pomeroy et al., 1956). From our 1988 samples, a rich and diverse phytoplankton flora is evident in this region. Conversely, at some coastal stations, especially off Ocean County (JC30 to JC65), the greater frequency and abundance of diatoms over flagellates (table 2) reflects neritic influence in the NJ central shore region. Larger dinoflagellates such as *Ceratium* and *Dinophysis* spp., representative of the nearshore ocean environment (Figley, 1979), were abundant during an apparent upwelling event which also carrried in remnants of the late spring diatom bloom of *Cerataulina pelagica* (tables 2 and 4). Extensive sampling of the New York Bight conducted on the June-28-to-July-1 Anderson cruise revealed substantial concentrations of *Ceratium* and *Dinophysis* spp. offshore in various areas and at certain depths (USEPA data, unpublished). These cell densities, however, were considerably lower than those observed during the 1976 event (Swanson and Sindermann, 1979), thus the 1988 data may reflect normal seasonal maxima.

In New Jersey coastal waters, red tide formation is strongly dependent on weather and nearshore circulation patterns (*in* USEPA, 1986a). Inorganic nutrients are usually present, especially in the northern estuarine and coastal region. Blooms often develop in sheltered situations such as the confines of bays and estuaries and, via tidal currents, may spread to adjacent coastal areas (USEPA, 1978-88, inc.). In open waters such as those of the New York Bight, however, weather conditions must be quiescent, as well as warm, with moderate onshore winds or converging water masses acting to concentrate the phytoplankton (Pomeroy et al., 1956). Upwelling, typically driven by southwesterly winds, is common along the New Jersey coastline (Ingham and Eberwine, 1984); this can carry in nutrient-rich water, but the accompanying drop in water temperatures may not be favorable for most phytoflagellates. This apparently was the case in 1988 when southwest winds prevailed through most of summer (table 5). While this apparently enhanced flagellate blooms in the major estuaries, diatoms dominated the coastal phytoplankton, and "seaweed" in the form of macroalgae (primarily *Ulva* sp.) was prevalent along the surfline (table 4). Nearshore bottom dissolved-oxygen concentrations were generally favorable for most marine life (4.0 mg/l or greater) during most of summer (R. Braun, USEPA, personal communication). Surf temperatures at Island Beach were below 60°F (16°C) during much of July and exceeded 70°F (22°C) for only one brief period from July 31 to August 3. The most prominent upwelling(s) occurred between August 4 and 16, with surf temperature again going below 60°F, including a drop of more than 18°F (10°C) within a six-day period (table 5). The previous year (1987) had seen very warm and clear, Gulfstream-like water adjacent to the NJ coast from July 10 through August 17 with surf temperatures at times exceeding 75°F. Although no red tides occurred, the presence of small invertebrates (salps, amphipods) characteristic of warm and/or pelagic waters was noted as creating a nuisance in several locales (USEPA, 1988). Conditions such as these were not observed in 1988.

The death of bottlenose dophins *(Tursiops truncatus)*, many of which washed ashore from New Jersey to Virginia in 1987 (USEPA, 1988), has been associated with phytoplankton-derived neurotoxin in fishes which the dolphins consumed (Geraci, 1989). Kills of menhaden, spanish mackerel, and other fishes due to toxic dinoflagellate blooms of *Ptychodiscus brevis* have occurred on Florida's Gulf coast (Ingle and deSilva, 1955). On rare occasion the blooms have been transported by the Gulfstream to the Atlantic side; thus in 1987 bloom(s) of *P. brevis* occurred as far north as the southern coast of North Carolina (Tester et al., 1988). Dolphin deaths occurred along the US eastern and Gulf coasts again in 1988 (Cassidy et al., 1988), but none were reported in New Jersey. On the Atlantic coast the dolphins' migratory route ranges far north of the bloom area. Although *P. brevis* occurred as close as North Carolina, the species has never been detected in our phytoplankton surveillance of New Jersey coastal waters.

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Appendix

Table 1. Chlorophyll a data (mg/m^3) for the 1988 New Jersey coastal phytoplankton survey

Station Location	5/24	6/8	6/15	6/22	7/6	7/13	8/3	8/4	8/10	8/24	8/31	9/7	9/14	Mean Chl a
Northern Coastal														
JC08-Sea Bright	2.85	4.88	7.15	24.98	2.36	12.60	7.92		8.18	12.44	3.91	9.36	9.23	8.82
JC14-Long Branch	7.48	4.51	2.02	12.31	1.87	5.76	5.77		5.90	12.44	1.71	21.28	4.92	7.16
JC30-Spring Lake	4.85	2.02	.83	4.85	3.24	9.11	6.10		4.78	9.96	4	14.37	3.09	5.68
JC41-Bay Head	5.27	1.62	1.90	3.65	3.09	11.88	5.04		4.38	9.94	3.20	6.47	.83	4.77
JC53-Seaside Heights	2.44	.82	2.46	2.41	6.11	8.44	7.34		5.91	12.17		1.64	3.92	4.88
JC57-Island Beach		3.27	.42	2.35	4.74	10.95	5.44		10.25	12.59		2.49	3.24	5.57
Southern Coastal														
JC65-Ship Bottom		2.41	8.78	2.38	3.87	4.67	5.76		10.29	9.98				6.02
JC75-Atlantic City		8.61	8.53	5.20	9.36	17.66	4.67		23.70	28.45				13.27
JC83-Ocean City		7.99	11.32	13.30	2.68	6.67	3.46		8.34					7.68
JC91-North Wildwood		9.29	10.98	2.02	3.69				5.90					6.38
Estuarine														
RB15-Sandy Hook Bay	8.84	15.66	30.50	27.83	7:59	25.34	19.94		33.82	13.99	10.29	83.52	50.99	27.36
RB32-Raritan Bay	44.19	65.28	12.80	9.11	19.12	35.86	15.93		23.44	8.86	3.62	33.67	42.82	26.23
BB1-Barnegat Bay N.					5.58	6.12	15.85		14.06	16.89		13.98	13.56	12.29
BB2-Barnegat Bay S.					11.43	18.63	36.60		33.42	20.04				24.02
GB1-Great Bay				14.14										14.14
GE1-Great Egg Harbor							9.53		20.12				3.73	11.13
DB1-Delaware Bay capeshore		44.71	44.30	220.82	61.38				32.07					80.66
Special Bloom Samples														
Raritan Bay														
RB1							34.66	22.49						28.58
RB2							61.53	81.41						71.47
RB3							124.49	43.93						84.21
RB4								25.14						
RB5								20.92						
RB6								17.42						
RB7								23.87						
RB8								33.31						
RB9								45.12						
RB10								28.10						
Keansburg				277.85										277.85
Bayshore				146.46										146.46

Table 2. Succession of dominant phytoplankton species found in the 1988 survey of New Jersey estuarine - coastal waters. Relative abundance is defined as follows: frequent (.) = concentrations of 100-1000 cells/ml; dominant (+) = cell counts exceeding 1000/ml. Blooms (*) occurred where counts approached or exceeded 10,000/ml, often imparting visible coloration to the water. No designation indicates that the species either was present in very low concentrations or was not observed. For Nannochloris, because of its minute size (<5 microns), the criterion is increased by a factor of ten (e.g. 10,000 for dominance, 100,000 for blooms). All species are listed under one of four taxonomic groups: (1) diatoms = Bacillariophyceae, (2) dinoflagellates = Dinophyceae; (3) other phytoflagellates = Chrysophyceae, Prasinophyceae, Euglenophyceae, Cryptophyceae, etc., (4) nonmotile coccoids = Chlorophyceae

	Sampling Location											
Species/Dates	RB32	RB15	JC14	JC30	JC41	JC57	JC65	JC75	JC83	JC91	BB1	DB1
Late spring (May 24 - June 8)												
1) Skeletonema costatum				+		+		+		+		
Cyclotella sp.	+	+										
Thalassiosira sp.									+			
Coscinodiscus sp.			.									+
Cerataulina pelagica	*		+	+	+	+	+	*	+	*		
Chaetoceros sp. (sociale)		+						+		+		
Thalassionema nitzschioides									+	*		
Phaeodactylum tricornutum												+
Nitzschia sp.												+
2) Prorocentrum minimum	*											
Gyrodinium pellucidum			.									+
Katodinium rotundatum	+	+										+
Heterocapsa triquetra								+				
3) Olisthodiscus luteus	*		+									
Bipedinomonas sp.												+
Pyramimonas sp. (grossii)	+	+										
Chroomonas sp. (amphioxiea, minuta)	+	+	+		*							+
4) Chlorella sp.				+					+			
Nannochloris atomus	*	+	+						+	+		
Early summer (June 15 - 22)												
1) Leptocylindrus sp.		+										
L. danicus			+		.					+		
Skeletonema costatum	.	*	.	.								+
Cyclotella sp.	.	*										
Thalassiosira sp.	+		.	.					.			
T. gravida		+										
T. nordenskioldii		*										+
Cerataulina pelagica	.		+	+					+			
Chaeotoceros sp.		+										
Thalassionema nitzschioides									+			+
Gyrosigma sp.												+
Phaeodactylum tricornutum		+										
Nitzschia sp.		*	.	+				.				.
2) Prorocentrum micans												+
Gymnodinium sp.		+										
Gyrodinium estuariale												*
3) Olisthodiscus luteus	.											
Eutreptia lanowii		+							*			
Euglena sp.												+
Cryptomonas sp.	+											
4) Chlorella sp.	.		+		.	.	.	.	.	.		
Nannochloris atomus	+	+			.	.						+

Table 2 (continued)

Species/Dates	RB32	RB15	JC14	JC30	JC41	JC57	JC65	JC75	JC83	JC91	BB1	DB1
	Sampling Location											
Mid-summer (July 6 - August 10)												
1) Leptocylindrus danicus		+	.		+	+				+		
Skeletonema costatum		+	.	+		+	+	+	+			+
Thalassiosira sp.	+	+	+	+	+	+			.			
T. rotula		.										
Cerataulina pelagica	.		+	.	+	+	.		.			
Chaetoceros sp. (sociale)		.						.				
Rhizosolenia sp.	+	+										
R. delicatula		+	+	.	+	+	+	.				
Thalassionema nitzschioides							+					
Nitzschia sp.		.	+	.				+			.	*
N. delicatissima			+									
N. seriata			.									
Cylindrotheca closterium		+									.	
2) Prorocentrum minimum	.	+										
P. redfieldi								+				
Gymnodinium sp.		.										
Gyrodinium estuariale												*
Katodinium rotundatum	.											
3) Olisthodiscus luteus		.										
Chrysochromulina sp.	+	.										
Eutreptia lanowii		+	+					+	.			
Euglena sp.												+
4) Chlorella sp.	+	+	+	+	+	+	+	+	+	.	+	
Nannochloris atomus	*	*	*	*	*	*	*	*	*	*	*	*
Late summer (August 24 - September 14)												
1) Leptocylindrus danicus		.	.			.						
L. minimus											+	
Skeletonema costatum	+	*	+	.		.	.	+				
Thalassiosira gravida	+	+	+									
T. nordenskioldii	+	+										
T. rotula		+										
Cerataulina pelagica	.		.									
Chaetoceros sp.		+						.				
C. decipiens			+									
Rhizosolenia delicatula	.	+	+	+	.	.	.					
Ditylum brightwelli		+	+									
Thalassionema nitzschioides							.					
Nitzschia sp.			.	.				+			*	
Nitzschia pungens			+									
Cylindrotheca closterium		.									+	
2) Prorocentrum minimum	.	.										
Gymnodinium sp.		.										
Katodinium rotundatum		.										
3) Olisthodiscus luteus	.											
Chrysochromulina sp.	.	+										
Pyramimonas sp.		.										
Eutreptia lanowii		.										
Chroomonas sp. (amphioxiea, minuta)		.									+	
4) Chlorella sp.		.										
C. marina											+	
Nannochloris atomus	*	*	*	*	*	*	*	*			*	

Table 3. Frequency of occurrence in samples of common phytoflagellate species at selected locations along the New Jersey coast and major estuaries for the period May 24 to September 14, 1988. Letters indicate times of dominance as follows: a = late spring (May 24 - June 8), b = early summer (June 15 - June 22), c = midsummer (July 6 - August 10), and d = late summer (August 24 - September 14)

	Sampling Location					
	RB15	JC14	JC30	JC57	JC75	DB1
CHRYSOPHYCEAE						
Ochromonas sp.	1					
O. variabilis				1c		
Calycomonas ovalis	1					
Apedinella radians						1
Ebria tripartita	3	2	2	1	1	
HAPTOPHYCEAE						
Chrysochromulina sp.	4d	1	1		1	
C. minor		1	1	1	1	
CHLOROPHYCEAE						
Chlamydomonas sp.	1d	1		1		
PRASINOPHYCEAE						
Bipedinonomas sp.						1
Pyramimonas sp.	1d		2	1		1
P. amylifera	1					
P. grossii	1					
P. micron	1					
Tetraselmis sp.	1					
EUGLENOPHYCEAE						
Eutreptia sp.	1		1			
E. lanowii[1]	5c	2c	1	2	2c	
Euglena sp.				2	2	1
E. proxima	1					
Trachelomonas sp.	2				1	
DINOPHYCEAE						
Prorocentrum micans[2]		2		1	2	1
P. minimum	5c	1	2	1	5	2
P. redfieldi[3] (triestinum)	1				1c	
P. scutellum			1			
Exuviella sp.		1				
E. marina			1			
Dinophysis acuta[4]		1	1	1		
Amphidinium sp.						1
Gymnodinium sp.	3				3	1
G. danicans	3		1	3	2	
Gyrodinium sp.	1					
G. estuariale[5]						1b
G. pellucidum						1a
Polykrikos sp.			1			
Katodinium sp.	1					1
K. rotundatum[1,2]	2a	3		1	2	2a
Heterocapsa triquetra		1			1	

Table 3 (continued)

	Sampling Location					
	RB15	JC14	JC30	JC57	JC75	DB1
Oblea rotunda		1			1	
Protoperidinium sp.	1	1	1	1	2	
P. achromaticum		2				
P. aciculiferum	1					
P. pallidum		1				
P. pellucidum		1	1			
Scripsiella trochoida (Peridinium trochoideum)	6		1		2	1
Ceratium sp.		1		1		
C. longipes			1	1		
C. minutum					1	
CRYPTOPHYCEAE						
Hemiselmis sp.					1	
Chroomonas sp.	1	1	1	1		
C. amphioxiea	1a					1
C. minuta	1	1a	1			1a
Cryptomonas sp.	2					
CHLOROMONADOPHYCEAE						
Olisthodiscus luteus[1,2]	5a	2a	1	1	1	2
Merotrichia capitata	1					
Total	60	27	22	21	32	19
Frequency Index[6]	4.62	2.08	1.69	1.91	3.56	3.17

Footnotes:
1. Dominant in red tides in Raritan - Sandy Hook Bay in 1988.
2. Caused previous red tides in Hudson - Raritan estuary and adjacent New Jersey coastal waters.
3. Caused red tides in Long Island Sound in 1987; dominant in red tides in Raritan - Sandy Hook Bay in 1988.
4. Caused milky-brown water in Atlantic City coastal area in 1978.
5. Caused red water in Delaware Bay capeshore in 1988.
6. Frequency Index = (total occurrences) divided by (number of times sampled).

Table 4. New Jersey coastal water conditions, summer of 1988 highlights and reported incidents*

Date	Locale	Observation/Condition
May 17 - 19	Brigantine (just north of Atlantic City) - 5 miles off	line of floating debris.
22 - 23	Sandy Hook	some trash (paper, plastics, etc.) and debris washing in.
	Manasquan	some floating debris one mile off.
	Island Beach to Atlantic City	scattered lines of floating trash and debris, brown water from diatom bloom (Cerataulina sp.) in patches along beach.
24 - 28	weather event	winds continuous from SSW; mean top speed 17 mph.
23 - 31	Lower New York Bay (Staten Island to Rockaway)	scattered lines of floating debris.
24	Lower Bay (at Narrows)	red water (phytoflagellate bloom).
	Raritan Bay (at Highlands)	reddish brown water along south shore (bloom of Cerataulina sp. plus dinoflagellates, Katodinium rotundatum and Prorocentrum minimum).
	first helicopter sampling	
	Island Beach to Long Beach Island	green water in surf and tide pools along beach.
24 - 31	entire coast of New Jersey	brown water and foam from widespread Cerataulina bloom in patches from beach to a few miles off.
	Ocean County (Manasquan to Long Beach Island)	the dinoflagellate, Ceratium sp., also abundant in coastal samples.
June 2 - 3	Raritan Bay at Perth Amboy (mouth of river)	some dead fish (menhaden), profuse garbage and vegetation (marsh grass) floating.
	Lower Bay, Arthurkill to Gravesend (Narrows - Rockaway) area	several floating slicks of marsh grass and trash.
7 - 8	Raritan Bay	red water phytoflagellate bloom of Olisthodiscus luteus.
	New Jersey Coast	brown water conditions lingering but beginning to clear.

* Observations of water discolorations and floating materials made primarily from NJDEP and USEPA helicopter surveillance flights

Table 4 (continued)

Date	Locale	Observation/Condition
June 7 - 8	Delaware Bay	water turbid (brown); phytoplankton very diverse, several (diatom and flagellate) species abundant in sample.
	first southern New Jersey helicopter sampling	
11	Barnegat Bay, BB2 to Barnegat Inlet	extensive seaweed (eelgrass) present.
13 - 17	Raritan - Sandy Hook Bay	red tide of *Olisthodiscus luteus*.
	Sandy Hook to JC65	brown algal foam in surf.
	Lower Bay (Staten Island, Gravesend area)	scattered floating debris (marsh grass and trash).
14 - 18	Atlantic City - 20 miles off	garbage and trash slicks, some bags full of garbage floating.
22 - 28	Raritan Bay south shore (Keansburg vicinity)	red to brown water; dense bloom dominated by *O. luteus*, *K. rotundatum* and *Eutreptia lanowii* (euglenoid).
	Sandy Hook Bay south shore (below RB15)	many dead fish of several species observed alongshore; hypoxia suspected as the cause.
24 - 28	Lower Bay and Narrows area	scattered garbage and brown foam.
	Sandy Hook to Long Beach Island	scattered streaks of greenish water observed off coast; seaweed in Ocean County surf.
	Brigantine	reddish-brown patch off coast.
July 2	Lower Bay (off Rockaway and Sandy Hook)	large slicks of floating marsh grass, timbers and plastics.
3 - 6	Raritan - Sandy Hook Bay	continued red to brown water bloom(s); sample dominated by *P. minimum*, *E. lanowii* and several diatom species.
5 - 8	Lower Bay (Staten Island to Gravesend)	scattered debris and foam on surface.
	Delaware Bay capeshore	red water dinoflagellate bloom of *Gyrodinium estuariale*.
	weather event	wind predominantly from SSW, mean top speed 21 mph; surf temperature drop from 65° to 54°F.

Table 4 (continued)

Date	Locale	Observation/Condition
July 11 - 14	Lower Bay (Staten Island, Narrows, and Ambrose Channel)	slicks of floating trash.
13	Raritan estuary, N.J. coast south to Atlantic City	widespread blooms of several diatom species.
	Barnegat Bay	brown water bloom dominated by the chlorophyte, <u>Nannochloris</u> <u>atomus</u> begins.
15 - 18	Raritan Bay	red tide continues.
	N.J. coast south to Long Beach Island	seaweed and brown foam along beaches.
13 - 29	Asbury Park vicinity	beaches closed intermittently due to high fecal coliform bacteria counts.
22	Sandy Hook bayshore	several thousand dead menhaden wash in; cause undetermined.
24 - 26	Deal to Asbury Park	patches of red to brown water to 1/4 mile off (partially due to sewage plant discharge plume); red tide unconfirmed.
August 1 - 2	Lower Bay at Staten Island, Ambrose Channel (bay entrance)	lots of debris; high tides washing it off shores into channels.
	New Jersey coast	varied floating slicks, algal foam and seaweed all along; surf temperature reaches season peak (80°F)
2	Sandy Hook Bay (south shore)	second fish kill with hypoxia event this summer; recurrent red tide dominated by <u>K.</u> <u>rotundatum</u>, <u>E.</u> <u>lanowii</u> and <u>Procentrum</u> <u>triestinum</u> <u>(redfieldi)</u>.
3 - 15	weather event	winds continuous from SSW, mean top speed 18 mph; surf temperature drop from upper 70's (80°) to 57°F.
7	New Jersey coast	seaweed all along.
7 - 10	southern N.J. coast	brown foam present (from diatom blooms).
9 - 11	Cape May	school of 30 dolphins sighted.
12	Asbury Park	seaweed and algae present; odor from sewage plant.
13	Lower Bay at Narrows	much debris present.
14	Sandy Hook to Long Branch	algae(?) present.

Table 4 (continued)

Date	Locale	Observation/Condition
August 21	Sandy Hook to Manasquan	algal foam present.
19 - 23	weather event	winds predominantly from NE, mean top speed 14-15 mph; > 2 inches rain; surf temperature increase to 69°F.
24	Atlantic City	reddish brown water (from algal bloom).
	last south Jersey helicopter sampling	
25	Sandy Hook	beach closed due to an apparent algal bloom.
25 - 26	Lower Bay (Narrows to Gravesend)	much trash and wood floating.
September 1 - 2	Manasquan to Ortley Beach	floating trash observed.
1 - 4	weather event	winds predominantly from SE, mean top speed 13 mph; > 1 inch rain; surf temperature relatively constant.
7 - 14	Raritan - Sandy Hook Bay	red - brown water caused by abundance of several diatom species.
8	Raritan Bay to adjacent N.J. coast	brown algal foam present.
12	Lower Bay at Ambrose Channel	scattered timbers present.
14	Barnegat Bay	brown water bloom continues; presence of Aureococcus sp. confirmed but Nannochloris sp. apparently still dominant.
	last helicopter sampling	

Table 5. Summary of 1988 ocean temperature data (°C) for EPA helicopter New Jersey coast perpendicular stations; NOAA* weather data (wind = fastest measured mile; ppt = cm of rainfall) and satellite offshore surface isotherms; surf temperatures from Island Beach State Park, N.J.

Date	WEATHER Wind	ppt	air °C	surf		TEMPERATURE JC14 1 mi./9 mi.	JC53 1 mi./9 mi.	JC69 1 mi./9 mi.	JC85 1 mi./9 mi.	NOAA Satellite mid-shelf
May										
24	SSW23	0.74	22.2							
25	SW18	0.69	13.9							
26	SSW16		13.9							
27	SSW16		17.3		Surface	17.0				
28	S12		18.3		Bottom	13.4 /10.5	11.7 /10.9			
29	W9		21.7							
30	SSW15		21.1							
31	NW17		26.8							
June 1	W23	0.51	23.3							
2	NE20	0.03	13.2							
3	NE22		12.8							
4	N14		12.2							
5	W23		18.9							
6	NW16		22.8		Surface	17.0 /16.7	16.7 /16.6			
7	NNW14		23.9		Bottom	13.2 /10.3	12.0 /11.9	15.2 /13.0	15.0 /14.0	
8	N12		17.8							
9	NNE17	2.72	14.5							
10	NNE14		13.2		Surface			16.6 /15.3	16.8 /15.8	
11	SSW12		16.1		Bottom			16.5 /14.5	15.8	
12	WNW16		23.3							
13	SSW14		25.0		Surface	18.8 /18.6	18.9 /18.4			
14	SW14		26.1		Bottom	14.5 /10.6	12.2 /13.0			
15	SSW15		25.0		Surface					17-18.0
16	SSW18		21.7		Surface	20.4 /19.7	15.7 /18.0	15.8 /12.4	18.4 /18.5	
17	SW21	0.46	20.5		Bottom	13.8 /10.2	11.7 /11.7	13.1 /17.4	16.7 /13.4	
18	ENE12		21.1							
19	S16		18.9							
20	SW24		21.1							
21	SW14		26.8	14.5	Surface					20-21.0
22	SW23		26.1	13.9						
23	SSW28	0.23	25.5	13.9						
24	NE21		18.9	17.3	Surface	19.3 /16.7	15.1 /16.9	16.6 /17.4	18.5 /18.5	
25	SSW23		18.9	17.8	Bottom	13.8 /9.5	10.7 /11.3	13.9 /12.0	16.7 /12.9	18-19.0
26	SW25		22.2	14.5						
27	NNW17		18.3	12.8	Surface	16.6 /16.3				
28	SSW21		20.5	16.1	Bottom	14.2 /9.4				
29	SSW16		22.2	16.1						
30	N20		19.5	17.8						
July 1	NW18		17.8	17.8						
2	NW18		20.5	16.8						
3	S21		21.7	17.8						
4	SSW21		21.7	18.3						
5	S16		21.7	17.8	Surface					20-21.0
6	SSW18		22.8	16.1						

Table 5 (continued)

Date	WEATHER					TEMPERATURE				
						JC14	JC53	JC69	JC85	NOAA Satellite
	Wind	ppt	air °C	surf		1 mi./9 mi.	1 mi./9 mi.	1 mi./9 mi.	1 mi./9 mi.	mid-shelf
7	SSW18	0.03	21.7	13.2						
8	SW18	0.05	21.7	15.0						
9	SSW25	0.97	25.0	12.2						
10	WSW14		26.1	13.2						
11	SSW13		22.2	13.2						
12	S18	0.69	22.2							
13	SW13		23.9	13.2	Surface					21.0
14	SSW18		23.3	16.1						
15	E12		27.8	12.2						
16	SSW18		23.9	17.8	Bottom	14.8 /12.8	12.3 /12.5			
17	N17		23.9	17.8						
18	N15		25.0	13.2						
19	S16		25.0	12.8						
20	SW17		25.5	12.8						
21	SSW23		22.2	15.6						
22	SW16	1.83	20.5	12.2						
23	S12	0.64	19.5	12.8						
24	SW14	0.10	22.2	13.9						
25	SW17		25.0	18.9						
26	NW12	1.40	21.7	18.9	Surface					22-24.0
27	WSW14	0.15	22.2	16.8						
28	S16		22.8	14.5						
29	SSW15		25.0	20.5						
30	SSW10		28.7	20.5						
31	SW12	1.42	26.8	21.7						
Aug. 1	SE10		25.5	27.0						
2	SSW14		25.0	26.8						
3	S12		26.8	21.1						
4	S15		26.8	21.1	Surface					25-26.0
5	SSW16		26.1	18.9						
6	SSE10		26.8	18.9						
7	SSW20		25.5	21.1						
8	SSW14		25.5	16.1						
9	SSW15		25.5	22.2						
10	SSW14	0.05	26.1	18.3	Surface					25-26.0
11	SSW20		24.5	15.0						
12	SSW21		23.9	15.0						
13	SW20		23.3	14.5	Bottom	17.0 /12.5	13.0 /11.0			
14	SSW23		22.8	16.8						
15	SSW22		23.3	13.9						
16	NW15		27.2	14.5						
17	SW20	2.79	23.9	20.5	Surface					18-23.0
18	N14		25.5	18.9						
19	NE14	0.31	19.5	17.8						
20	NE13	2.13	17.8	21.1						
21	N10	0.28	20.5	21.1	Bottom	14.0 /11.0	14.0			
22	NE20	2.39	18.3	20.0	Surface					20-23.0
23	SE15	0.05	20.5	20.5						
24	SSW17		22.8	13.9						

Table 5 (continued)

Date	WEATHER Wind	ppt	air °C	surf		TEMPERATURE JC14 1 mi./9 mi.	JC53 1 mi./9 mi.	JC69 1 mi./9 mi.	JC85 1 mi./9 mi.	NOAA Satellite mid-shelf
25	SSW15		22.8	20.0						
26	SSW14		22.8	18.3						
27	S14		22.8	20.0						
28	S15		23.3	18.9						
29	S21	1.45	21.7	17.8						
30	NE13	0.03	17.8	17.6						
31	N10		18.3	19.5						
Sept. 1	SE10		20.0	18.9	Surface					20-22.0
2	ESE10		20.6	20.0						
3	SSE12		20.6	20.7						
4	SSW18	2.96	20.5	17.5						
5	W15		20.0	16.8						
6	NNW14		17.3							
7	SSE10		16.1							
8	ENE13		17.8		Surface	19.8 /19.6	18.7 /18.9	19.6 /19.8	20.0 /19.4	20-21.0
9	SSW9	0.20	21.7		Bottom	18.7 /10.9	13.8 /13.1	19.1 /16.3	19.2 /15.4	
10	NW10	0.13	22.8							

* National Oceanic and Atmospheric Administration (NOAA) data from National Weather Service, Atlantic City; National Marine Fisheries Service, Sandy Hook, N.J.; Marine Climatological Investigation, Narragansett, R.I.

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