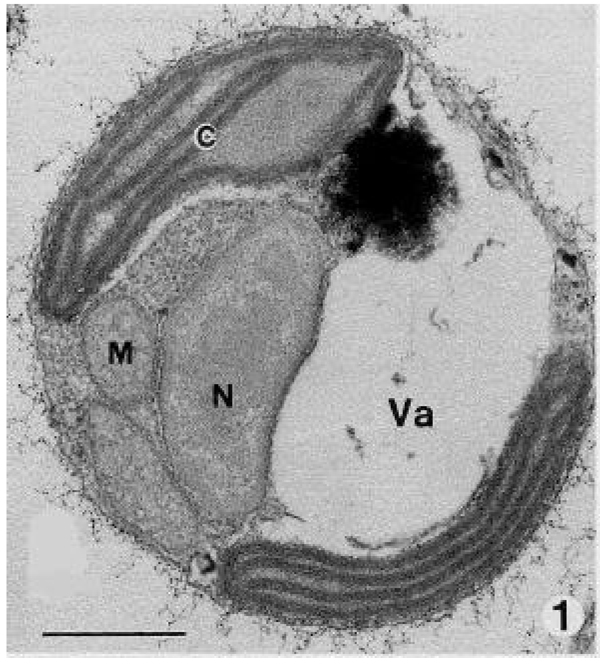

Brown Tide Alga, *Aureococcus anophagefferens*

HARMFUL ALGAL BLOOMS IN COASTAL WATERS OF NEW JERSEY

BY

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May, 2000

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Acknowledgements: The following people are gratefully acknowledged for their review and input to this report: Paul Olsen for his expertise and information on the NJ Phytoplankton Network and his comprehensive reviews, Eric Feerst, Bob Connell, Bill Eisele, Jim Mumman, Tom Atherholt and to Alan Stern, Dr.P.H. for their support.

Executive Summary

Harmful algal blooms are an increasing phenomenon throughout the coastal waters of the world. There have been recurring algal blooms in the coastal waters of New Jersey documented over the last twenty years. Harmful algal blooms (HABs) include species of microscopic, usually single celled eukaryotic plants that live in estuarine and marine waters.

The purpose of this issue paper is to inform managers and scientists about the severity and extent of harmful algal blooms in New Jersey coastal/estuarine waters, both from a historic and current perspective, and to recommend research and information needs to better understand the phenomena in order to develop appropriate management actions. A review of available documents on this subject is also provided.

When a given species of algae blooms and imparts a particular color to the water, due to the pigments they contain, they are known as "red tides", "green tides", or "brown tides". These algal blooms can cause numerous ecological and/or human health problems due to the toxins produced by the species and/or their potential bioaccumulation in the food web, or due to the degradation of blooms which may cause hypoxic (low levels of dissolved oxygen in water) conditions.

There have been chronic red tide blooms of various species in the Hudson-Raritan Estuary and New Jersey coastal waters for over three decades. Harmful algal blooms may contribute to hypoxia or other negative ecological impacts, but it is important to point out that there are few cases on record of acute human toxicity from phytoplankton in New Jersey waters with some exceptions of moderate bather discomfort and/or illness reported from specific blooms. In 1999, there was an extensive and severe brown tide bloom in Barnegat Bay which has the potential, if it chronically reoccurs, to cause extensive ecological damage.

It is important to continue spatial and temporal monitoring of harmful algal blooms and to conduct research that will assist in the management of these blooms including:

- Assessment of potential biological and environmental factors that may influence the initiation and sustenance of algal blooms including the contribution of the specific species of nutrients from specific sources (nonpoint source, atmospheric deposition, etc.) and the rates of nutrient loading;
- Determination of the physical characteristics of local circulation patterns and long periods of low water flow, water column stratification, and reduced mixing – conditions that are often associated with long residence times for water (e.g., reduced exchange with outside water sources such as ocean or rivers) in some shallow estuarine systems.
- Research related to the life cycles of harmful algal species, and what factors control transitions between life stages, should be conducted (e.g., resting spores of algal

species produced as ambient conditions change), including in-situ measurements of species-specific rates of growth, photosynthesis, nutrient uptake, and physiological measurements at different times and locations to understand HAB population dynamics and their harmful effects.

- Nutritional studies on important shellfish resources (e.g., hard clams) are a priority because Barnegat Bay and Raritan Bay had historical oyster and bay scallop fisheries which have disappeared and the hard clam fishery may suffer a similar fate if not specifically protected. Research on multiple stressors, including HABs (e.g. brown tide blooms), on other important natural resources, such as eelgrass beds, are needed in the Barnegat Bay.

A more complete and detailed set of research recommendations are found on pgs. 20-25 of the issue paper. Some of these recommendations will be incorporated into the Coastal Research Agenda being drafted by the Division.

FOREWORD

Harmful algal blooms are an increasing phenomenon throughout the coastal waters of the world. There have been recurring algal blooms in the coastal waters of New Jersey documented over the last twenty years. In 1999, there was an extensive and severe brown tide bloom in Barnegat Bay. Harmful algal blooms may be associated with various human health, ecological, and aesthetic impacts or use impairments. The purpose of this issue paper is to inform managers and scientists about the severity and extent of harmful algal blooms in New Jersey coastal/estuarine waters, both from a historic and current perspective, and to recommend research and information needs to better understand the phenomena in order to develop appropriate management actions. A review of available documents on this subject is also provided.

I. Background

What are harmful algal blooms?
Algae are photosynthetic organisms that can range in size from minute picoplankton (e.g. < 10 micrometers in diameter) to giant marine kelps, which may reach 60 meters long. They have no roots, stems, leaves or flowers as do higher plants. While algae may inhabit terrestrial systems, harmful algal blooms are associated with aquatic ecosystems. Harmful algal blooms (HABs) may produce toxins that can kill other marine organisms directly or which can be transferred through the food chain. Some seaweeds (macroalgae) are harmful, but not toxic, because their uncontrolled growth may alter habitat, displace indigenous species, or deplete oxygen levels.

Harmful algal blooms (HABs) include species of microscopic, usually single celled eukaryotic plants that live in estuarine and marine waters. A "bloom" occurs when algae grow very quickly or "bloom" and accumulate into dense visible patches near the surface of the water (National Office for Marine Biotoxins and Harmful Algal Blooms, 1999). Only a few of the many thousands of species of algae are associated regularly with toxic or harmful algal blooms (National Office for Marine Biotoxins and Harmful Algal Blooms, 1999).

When a given species of algae blooms and imparts a particular color to the water, due to the pigments they contain, they are known as "red tides", "green tides", or "brown tides". These algal blooms can also cause numerous ecological and/or human health problems due to the toxins produced by the species and their potential bioaccumulation in the food web, or due to the degradation of blooms which may cause hypoxic (low levels of dissolved oxygen in water) conditions. Red and green tides are caused mainly by dinoflagellates while the "brown tide" is caused by a minute golden brown alga (*Aureococcus anophagefferens*). Shellfish poisoning syndromes include paralytic (PSP), diarrhetic (DSP), neurotoxic (NSP), and amnesic (ASP) based on human symptoms. Amnesic Shellfish Poisoning is produced by diatoms while other symptoms are caused by dinoflagellate species. The harmful algal blooms in coastal waters of New Jersey include red tides, green tides, brown tides and other harmful species as listed in Appendix I.

II. National Assessment of Harmful Algal Blooms (HABs)

A. National Assessment of HABs
Harmful algal blooms (HABs) are an increasing phenomena throughout the world which may have been responsible for an estimated one billion dollars in economic loses during the last decade (U.S. Environmental Protection Agency, 1999, Public Law, P.L., 105-383). HABs can be responsible for fish kills, deaths of marine mammals, beach and shellfish bed closures, various human health effects and public avoidance of seafood (U.S. Environmental Protection Agency, Public Law. 105-383).

Recently, the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) was signed into law on November 13, 1998 becoming Public Law 105-383. The Act recognizes that many of the coastal areas throughout the world are suffering from harmful algal blooms and hypoxia each year, threatening coastal ecosystems and endangering human health. The Act recognizes that occurrence of HABs includes red tides in the Gulf of Mexico and Southeast, brown tides in New York, Texas (and now New Jersey), Ciguatera fish poisoning in Hawaii, Florida, Puerto Rico, and the U.S. Virgin Islands, and shellfish poisonings in the Gulf of Maine, the Pacific Northwest and the Gulf of Alaska (Title VI – Harmful Algal Blooms and Hypoxia). The Act calls for the following:

- The establishment of an inter-agency task force on Harmful Algal blooms (HABs) and hypoxia
- A national assessment on harmful algal blooms – draft available June 1999
- A national assessment on hypoxia
- An assessment and Plan for hypoxia in the Gulf of Mexico

Drafts of two National Assessments are available on the NOAA's National Center for Coastal Ocean Science (NCCOS) HABHRCA website as well as other information on these activities (HABHRCA website: http://www.habhrca.noaa.gov/habdraft.html) .

B. National Perspective on the Causes of HABs

There is a widely held supposition that algal blooms are a result of nutrient loadings. However, a recent national assessment of harmful algal blooms (draft, HABHRCA 1999) concludes that, except for a few cases where there is some evidence to support this, **the majority of U.S. HABs cannot be tied to anthropogenic nutrient loading, but to a combination of regional circulation patterns coupled to life histories of the species.** While there seems to be no universal relationships between nutrient enrichment and the occurrence of HABs, at least three specific algal species may bloom as a result of nutrient inputs: *Pfiesteria piscicida* (a dinoflagellate toxic to humans and fish), *Pseudonitzschia* (several toxic species of diatoms associated with Amnesic Shellfish Poisoning), and *Heterosigma sp. (*confused with *Olisthodiscus sp.)* which is a raphidophycean alga associated with mortalities at fish pen aquaculture operations. More commonly associated with the development of HABs are local circulation patterns, long periods of low water flow, water column stratification, and reduced mixing – conditions that are often associated with low flushing rates and long residence times for water. Such conditions are found as in the shallow Peconic estuaries in Eastern Long Island (HABHRCA, 1999) and possibly, Barnegat Bay in New Jersey.

III. Sources of Current and Historical Data on HABs in New Jersey

A. Sources of Historical Data

The 1989 study by Olsen documents all major historical harmful algal blooms and species occurring in New Jersey waters from 1968 through 1988. A map of the historical perspective of major phytoplankton blooms causing red tides and green tides in the New York Bight and adjacent New Jersey coastal region is found in Figure 1 (Olsen, 1989).

Reports of various phytoplankton blooms and/or their environmental impacts in coastal areas of New Jersey as early as the mid-1960s have been documented and blooms occurring since 1978 have been summarized in the NJ summary reports (listed below) and in numerous studies (Cohn et al. 1988; Draxler et al. 1984; Mahoney 1979; Mahoney and McLaughlin, 1977, 1979; Mahoney and Steimle 1979, 1980; Mahoney et al 1990; Malone 1978; Olsen 1989; Olsen and Cohn, 1979; Olsen and Mulcahy 1989). An historical survey taken from 1975-1978 at estuarine and coastal waters along the New Jersey northern shore and Lower New York Bay identified 332 species (9 classes) of algae.

B. Sources of Current Information

The following reports on monitoring of phytoplankton occurrence and abundance, including harmful algal blooms in New Jersey, are available from the respective agencies.

- **New Jersey Department of Environmental Protection: Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters (1978-1988).**

  The New Jersey Department of Environmental Protection (NJDEP) publishes an annual report on the results of the Phytoplankton Survey (monitoring results of phytoplankton blooms and related conditions encompassing the entire New Jersey coastal region including major estuaries). These summaries were prepared by Paul Olsen, with input from other staff from 1978 to 1998, in the Division of Watershed Management's Water Monitoring Management (WMM) program. As of 2000, this report will be prepared by the WMM's Bureau of Marine Water Monitoring. These reports provide a consistent long-term dataset and documented record that can be used to assess management and/or scientific issues that may be related to chronic or recurring algal blooms. Each annual report summarizes the monitoring effort in specific geographic areas including species occurrence and abundance.

  The WWM's Bureau of Marine Water Monitoring conducts the Phytoplankton Survey including monitoring phytoplankton assemblages and red tide blooms in coastal waters and major estuaries each summer. Figure 2 is a map of **New Jersey's Coastal Phytoplankton Monitoring Network,** included in the phytoplankton survey, which summarizes the intensity and frequency of red tides, occurrence of chronic blooms (brown tides), coastal phytoplankton and green tides (December 1997). These data are used to evaluate algal blooms for the potential presence of toxin-producing organisms that may impact shellfish, as required by the National Shellfish Sanitation Program. Potential effects of algal blooms on bathers are also evaluated. This monitoring has been conducted since the well-known catastrophic *Ceratium tripos* bloom of 1976 (first reported by the U.S. Environmental Protection Agency in 1977 as part of the New York Bight Water Quality helicopter survey).

  Currently, twelve stations are sampled in New Jersey twice a month from May through September for phytoplankton including six stations in the USEPA New York Bight/NJ Beach network (see Fig. 2) (includes three sites in the Hudson/Raritan estuary, two in Barnegat Bay and one in Delaware Bay). Bacteriological sampling is also conducted by the USEPA, concurrently at the beach stations, and by the

WMM's Bureau of Marine Water Monitoring for bay sites. In response to the 1995 appearance of the brown tide blooms**,** caused by *Aureococcus anophagefferens,* two additional stations were added in the Barnegat Bay, one in the central portion and one in Little Egg Harbor Bay (adjacent to lower Barnegat Bay). Supplemental sampling in Little Egg Harbor at Tuckerton and in Great Bay has also been conducted.

- **New Jersey Department of Environmental Protection: Algal Conditions Report**
  In addition to the annual phytoplankton report above, the Algal Conditions Report is prepared biweekly by the Bureau of Marine Water Monitoring after each summer's sampling event. In addition to the twelve stations above, water samples are collected by the USEPA helicopter crews and analyzed by the Bureau of Marine Water Monitoring at the Leeds Point Laboratory. The Monmouth County Health Department performs supplemental analyses but not for the brown tide (Cosgrove, pers. comm.).

  The Algal Conditions Report contains the results of the data measurements collected by the Data Sondes and information on the presence of algal blooms in the coastal areas such as Raritan/Sandy Hook Bay area, northern coast, Barnegat Bay area, and southern coastlines. Data Sondes are devices positioned in the water column that continuously measure water quality data on an hourly basis for parameters such as temperature, dissolved oxygen, salinity, pH, depth, and turbidity. Chlorophyll a measurements are taken separately but not continuously. Chlorophyll a is a pigment found in all algae and provides a relative measure of the amount of suspended plant material present in the water. The Sondes were deployed at a variety of estuarine monitoring locations over the past year to provide water quality information through the diurnal and tidal cycles.

  The biweekly algal conditions reports are general in nature and not as comprehensive as the Annual Reports of the phytoplankton network assessments. Because the focus of the weekly reports are on **human health** impacts, they do not include all species of phytoplankton present in the waters, nor do they fully characterize phytoplankton composition, assemblages and blooms that may contribute to **ecological** impacts.

- **New Jersey Department of Environmental Protection - Daily Shore Reports**
  The Daily Shore Reports are produced as part of the Cooperative Coastal Monitoring Program (CCMP) in the Division of Watershed Management and a description of the program as it relates to monitoring algal blooms in coastal waters is included below. Because the information is collected by a fly-over, the Daily Shore Reports identify only suspected algal blooms by the discoloration of the water. Follow-up water samples may be analyzed for species identification.

  Since 1974, the NJDEP has administered the Cooperative Coastal Monitoring Program (CCMP) with the participation of local environmental health agencies. The CCMP assesses nearshore coastal water quality and investigates sources of water pollution. The information collected under the CCMP assists the DEP in developing coastal zone management strategies such as land use planning to control pollution from nonpoint sources. The CCMP also enables local health agencies to respond to immediate public health concerns arising from contamination in coastal recreational areas. The NJDEP's Division of Watershed Management performs aerial surveillance of nearshore coastal waters. The aerial surveillance enables the routine evaluation of coastal water quality and the assessment of the nature and extent of public reports of ocean pollution. There are six flights per week including overflights of Raritan Bay, the Lower New York Bay, and the Atlantic coast from Sandy Hook to Barnegat Inlet. Flights two days per week are extended to include the area from Barnegat Inlet to Cape May Point for additional coastal coverage.

- **U.S. Environmental Protection Agency (USEPA) New York Bight Water Quality Reports**
  The U.S. EPA conducts water column sampling from May 15 to Sept. 6, and includes the collection of samples for phytoplankton enumeration from the New York Bight, New Jersey coast including Barnegat Bay and Great Egg Harbor. The list of species identified and counted by the NJDEP's Water Monitoring Management program, is included in the USEPA annual reports from 1977-1996.

- **National Oceanic Atmospheric Administration (NOAA)/National Marine Fisheries Service (NMFS): James J. Howard Laboratory at Highlands, NJ**
  While there are no routine reports, NMFS conducts weekly water quality monitoring for conventional parameters and the enumeration of the brown tide algae, *Aureococcus anophagefferens.* Data availability is variable.

- **NJ Sea Grant Extension Program**
  The NJ Sea Grant Extension Program, in cooperation with U.S. Department of Commerce, NOAA Sea Grant College Program, National Marine Fisheries Service, and the NJDEP, funded by NJ Sea Grant and the NOAA Office of Sea Grant and Extramural Programs, U.S. Department of Commerce, prepares a series of bulletins on a variety of topics. The most recent, Brown Tide Bulletin (Sea Note Series No. 14) in July 1999, addressed the brown tide issue in New Jersey including a listing of information on brown tides and harmful algal blooms.

- **Reports/Research: Brown Tide websites**

Woods Hole Oceanographic Institute: http://www.whoi.ed/science/(search: Brown Tides
NOAA: http://research.nwfsc.noaa.gov/ec/tox/introduction_page.htm
NOAA: http://www.cop.noaa.gov/projects.HAB.htm

IV. HEALTH AND ECOLOGICAL IMPLICATIONS FOR NEW JERSEY

A. Human Health Impacts

There have been chronic red tide blooms of various species in the Hudson-Raritan Estuary and New Jersey coastal waters for over three decades (NJ Annual Phytoplankton Report, 1998). These blooms include the dinoflagellate species in New Jersey coastal waters (e.g., *Ceratium tripos, Prorocentrum spp. Ceratium tripos, Cochlodinium heterolobatum, Masartia (=Katodinium) rotundatum, , Prorocentrum micans (P. redfieldi, P. lima)* and a raphidophycean species *(Olisthodiscus luteus).* Harmful algal blooms may contribute to hypoxia or other negative ecological impacts, but it is important to point out that there are few cases on record of acute human toxicity from phytoplankton in New Jersey waters with some exceptions of moderate bather discomfort and/or illness reported from specific blooms (NJDEP Annual Summary, 1998). It is also important to keep in mind that many incidents of human health complaints (e.g., bather complaints) are not reported and there are few systematic cause/effect studies conducted to assess the ecological consequences of algal blooms.

While some harmful algal blooms in other areas of the nation have resulted in severe human illness, there are no reports of such algal blooms occurring in New Jersey with the exception of moderate illness and/or bather discomfort caused by the green tide organism, *Gyrodinium cf aureolum* (and red tide species of *Prorocentrum, Massartia, and Olisthodiscus* sp.*)*. The green tide appeared as a greenish discoloration of the nearshore coastal waters from Ocean City to Atlantic City during the summers of 1984-85. There were reports from swimmers of skin reactions, respiratory problems, nausea, sore throat, eye irritation, fatigue, dizziness, fever and lung congestion as a result of exposure to the bloom (U.S. Environmental Protection Agency Region 2, October 1986).

Phytoflagellate blooms caused by the dinoflagellate species, *Massartia rotundata (=Katodinium)* and *Prorocentrum micans* and the raphidophycean alga, *dluteus*, were dominant blooms from 1962-1976 in New Jersey coastal waters (including Raritan Bay) from June to September (Mahoney and McLaughlin, 1977). These species were presumed benign, but there were reports of adverse effects on biological and recreational uses in the area, including respiratory discomfort among bathers (as reported in Mahoney and McLaughlin, 1977).

Human illness from consumption of toxic shellfish are caused by different species of toxic algae which occur in coastal waters of the US and other areas of the world and include: Paralytic Shellfish Poisoning (PSP) (*Alexandrium spp., Gymnodinium catenatum, Pyrodinium bahamense)* (National Office for Marine Biotoxins and Harmful Algal Blooms, 1999), Amnesic Shellfish Poisoning (ASP) (*Pseudonitzschia* sp.), Ciguatera fish poisoning (*Gambierdiscus toxicus, Prorocentrum* spp., *Ostreopsis* spp., *Coolia monotis, Thecadinium* spp. and *Amphidinium carterae),* Diarrhetic Shellfish Poisoning (*Dinophysis* sp.), and Neurotoxic Shellfish Poisoning (*Gymnodinium breve*) (Cohn et al. 1988; NJDEP Annual Summary 1998; Woods hole Oceanographic Institute 1999). While *Pseudonitzschia* spp. (closely associated with Amnesic Shellfish Poisoning in humans) has been abundant in NJ coastal waters and nearshore waters, especially during the fall and winter months, there are no reported cases of ASP in New Jersey (NJDEP Annual Phytoplankton Reports, 1998).

There are no reported occurrences of the dinoflagellate *Gymnodinium breve* in NJ coastal waters, but it is associated with Ciguatera fish poisoning and Neurotoxic Shellfish Poisoning in tropical/subtropical waters (NJ Annual Phytoplankton Reports, 1998). While the dinoflagellates, *Scripsiella trochoidea* and *P. brevipes*, have been abundant in NJ coastal waters, they have not been related to toxicity in NJ waters (NJ Phytoplankton Reports, 1998).

Recently, another harmful algal bloom species occurred along the North Atlantic Bight and, while the toxicity of the species has not yet been confirmed in New Jersey waters, it may pose a substantial threat. The troublesome non-photosynthetic predatory dinoflagellate, *Pfiesteria piscicida*, is known as the “cell from hell” because of its devastating effects on fish and human health effects on researchers and fishermen who have been exposed to its toxins. This organism has well-documented human health effects and associated neurocognitive disorders in researchers working on the organism in close proximity and high concentrations proximity (Bay Journal Archive, 1997; Congressional Research Service Report, 1999). *Pfiesteria* has been linked to effects on laboratory workers exposed to water or aerosols from cultures in the toxic stage. Effects include epidermal lesions, respiratory distress, stomach cramping, disorientation, rages, paranoia, erratic heart beat, short-term memory loss, severe cognitive impairment, and compromised immune systems (NJDEP, 1999). Commercial fishermen working in areas of Maryland have exhibited many of the above symptoms linked to *Pfiesteria* exposure in the laboratory environment (NJDEP, 1999). Thirteen researchers and ten fisherman who have been exposed to water containing the organism have reported symptoms ranging from mild to serious adverse health impacts (Burkholder and Glasgow, 1995a; Fox, 1998; North Carolina Aquatic Botany Laboratory *Pfiesteria piscicida* Homepage, 1997). However, there have been no reports of illness as a result of consumption of seafood from the Chesapeake Bay; people are advised to eat healthy fish and not eat fish with lesions (U.S. Environmental Protection Agency, 1997). Because of the potential human health and ecological threat, the NJDEP has developed a draft NJ *Pfiesteria* Contingency Plan (New Jersey Department of Environmental Protection and NJ Department of Health, 1999) and conducted sampling to determine the presence of the organism. Preliminary sampling results are discussed below.

B. Ecological Impacts

Descriptive and qualitative summaries of the status of algal bloom occurrence and ecological impacts have been included in the NJDEP Annual Phytoplankton Summary

Reports. While there have been reports of phytoplankton blooms, mainly red tides, in New Jersey in the Delaware Bay since 1928, none of the red tide blooms, originating in New Jersey waters, were acutely toxic to aquatic life (Olsen, 1989). Occasional fish kills were presumably due to anoxia when various blooms collapsed and periodic hypoxic conditions may have been the result of different algal bloom species (Olsen & Mulcahy, 1991; USEPA, Annual *Reports*, NY Bight Water Quality summer of 1977-1987, incl.).

Various dinoflagellate red tide species (e.g., *Ceratium tripos)* have caused oxygen deficiency off the coast of NJ in 1976 due to decomposition of algae (Malone, 1978; Mahoney, 1989; Mahoney & Steimle, 1979; NJDEP Annual Phytoplankton Summary Reports, 1978, 1998; U.S. EPA Annual Reports). The *C. tripos* bloom was associated with hypoxia and consequent widespread fish kills (NJDEP annual summary of phytoplankton blooms and related conditions in NJ coastal waters, 1998).

Other red tide dinoflagellates have had ecological impacts. The red tide dinoflagellate species C*ochlodinium heterolobatum (*formerly *Polykrikos barnegatensis)* was observed in upper Barnegat Bay in 1964 and caused distress and mortality to several species of small fish and shellfish and concomitant pungent odor (Mountford, 1965; NJDEP Annual Phytoplankton Reports, 1998; Olsen, 1989). While *Gymnodinium breve (= Ptychodiscus breve, a southern species*) was associated with the deaths of hundreds of bottlenose dolphins that washed ashore in NJ (associated with bioaccumulation of brevetoxin accumulated in fish that are eaten by dolphins, esp. menhaden and Spanish mackerel) (Cassidy et al, 1988; Geraci, 1989), there were no observations of this organism in NJ.

Several dinoflagellate *Prorocentrum* species have been implicated in ecological impacts. *P. lima* is an abundant species in Barnegat Bay and was associated with a blueclaw crab kill west of Barnegat Inlet in 1987 (NJDEP Annual Summary 1998). *P. micans* is associated with anoxia/hypoxia-related mortality of marine fauna including a fish kill associated with prolonged bloom off NJ in 1968 *(*summarized in Mahoney, 1989*;* Ogren and Chess, 1969). Other *Prorocentrum* species responsible for Ciguatera fish poisoning have not been observed in NJ (Mahoney, 1989). The dinoflagellates, *Scripsiella trochoidea (=Protoperidinium trochoideum),* and *P. brevipes*, a common species throughout New Jersey's coastal waters, have not been directly implicated in toxicity, but toxicity from these organisms has been found in other regions (NJDEP Annual Summary, 1998).

Phytoflagellate blooms caused by the dinoflagellate species, *Massartia rotundata (=Katodinium)* and *Prorocentrum micans* and the raphidophycean alga, *Olisthodiscus luteus,* dominated the blooms from 1962-1976 in New Jersey coastal waters (including Raritan Bay) from June to September (Mahoney & McLaughlin, 1977). These species were assumed to be benign but there were reports of adverse effects on biological and recreational uses in the area, including a potential role in fish mortality and a diminished aesthetic value of the beaches (as reported in Mahoney & McLaughlin, 1977). In the Hudson-Raritan Estuary, summer red tide blooms of the raphidophycean alga, *Olisthodiscus luteus* and two dinoflagellate species, *Prorocentrum spp.* and *Katodinium (=Massartia) rotundatum* apparently contributed to hypoxia in the estuary (Olsen &

Mulcahy, 1991). Other red tide dinoflagellates, such as *Katodinium (=Massartia) rotundatum*, were implicated in hypoxia and consequences of fish kills. (Olsen & Mulcahy, 1991; Mahoney & Mclaughlin 1977; Olsen & Mulcahy 1991).

The green tide dinoflagellate, *Gyrodinium cf. aureolum* (green tide) is detrimental to marine biota and bloomed along the NJ coast in 1984-85 (U.S. Environmental Protection Agency. 1986). Associated kills of the blue mussel, *Mytilus edulis*, and lady crab, *Ovalipes ocellatus*, were coincident with these occurrences (summarized in Mahoney, 1989; Mahoney et al. 1990). While increases in residence times of water masses in the nearshore southern area of the state may have resulted in the accumulation of nutrients, that may have contributed to the blooms, wind driven transport patterns over the southern New Jersey coast may also have been an important causal factor in the development of the green tide bloom in New Jersey (USEPA, 1986).

Brown tides have chronically occurred in Long Island Bays over the past decade with varying intensity, duration and geographic area since 1985 (Cosper et al., 1989a; Bricelj & Lonsdale, 1997). The brown tide blooms, caused by a newly described minute alga, *Aureococcus. anophagefferens* (c. 3 μm) were first observed in the summer of 1985 in Narragansett Bay, RI and bays in Long Island, New York. In Long Island bays, brown tide cell densities exceeded 2.5 X 10^{6} cells ml –1 (Nuzzi & Waters, 1989, 1996; Cosper, 1991), but immunofluorescent identification of the alga was not available until mid-1990. *A. anophagefferens* ("…golden brown sphere causing the lack of feeding…") is a golden-brown alga (Pelagophyceae) (Sieburth et al., 1988) which caused major impacts on the macrobenthos. The brown tide contributed to detrimental effects on the eelgrass (submerged aquatic vegetation, SAVs), *Zostera marina*, (Dennison et al., 1989; Cosper et al., 1987) and caused mass mortality of the bay scallop, *Argopecten irradians*, virtually eliminating the scallop industry in Long Island between 1985-86 through starvation (Cosper et al., 1987; Bricelj & Lonsdale, 1997; Bricelj & Kuenster, 1989; Bricelj et al., 1987; Bricelj & Lonsdale, 1997). There was significant growth reduction and high mortalities of bay scallop (*A. irradians)* larvae and the mass mortalities of bivalves, including the demise of bivalve mollusk populations in the mid-1980s in Long Island bays (Tracey, 1988; Bricelj et al., 1987; Bricelj & Lonsdale, 1997). The bloom reduced the growth of clams in Great South Bay, NY. The brown tide also bloomed in Narragansett Bay, RI in 1985 and caused mortalities of the blue mussel, *Mytilus edulis,* in Narragansett Bay, Rhode Island (Tracey, 1988).

In Long Island bays, there was damage to other shellfish including scallops, oysters, blue mussel, and anchovy (*Anchoa mitchilli*) fecundity (Mahoney, 1989; Smayda & Fofonoff, 1989). Brown tide blooms coincided with spawning, planktonic larval development and juvenile growth of important bivalves in mid-Atlantic estuaries (e.g. mussels, scallops) and caused adverse effects on adult and larval stages of suspension-feeding bivalves (e.g., bay scallops, *Argopecten irradians*, mussel, *Mytilus edulis)*.

Brown tide blooms in Long Island bays in 1985-86 coincided with the growth season of eelgrass beds, *Zostera marina,* and caused severe light attenuation due to high density and enhanced light-scattering properties of minute algal cells, that lead to a reduction in eelgrass and kelp (*Laminaria saccharina* and *L. digitata)* coverage (Dennison et al., 1980). Eelgrass beds provide nursery habitat for finfish and shellfish and loss of eelgrass beds in Long Island bays may have contributed to poor recruitment of juvenile bay scallops (Pohle et al., 1991; Tettlebach & Wenczel 1993). Extended algal blooms (> 1.5 months) resulted in severe shading on growing eelgrass beds (McLain & McHale, 1996; Dennison et al., 1989).

Brown tides in Long Island bays also impacted plankton. Higher densities of brown tide blooms (>5 X 10^6 cells per ml $^{-1}$) in Long Island bays were attributed to detrimental effects on protozoa (Caron et al., 1989). In addition, declines in ciliated protozoa were recorded in 1995 in West Neck Bay, NY (Mehran, 1996) and tintinnid protozoans were more severely affected by brown tide blooms than aloricate ciliates (Bricelj & Lonsdale 1997).

The ecological effects of brown tide have been well documented in Long Island bays. Because of the similarities of the Long Island bays to Barnegat Bay, the chronic effects of brown tide occurrence in New Jersey bays should be assessed. Barnegat Bay has many of the characteristics of the Long Island bays in that it is shallow, has elevated salinities during the brown tide blooms and a long flushing time (c. 50 days). *A. anophagefferens* has been reported to adversely affect filter-feeding molluscan shellfish (NJDEP Report of Algal Conditions in New Jersey Coastal Waters, May 27, 1999). In New Jersey, the 1995 brown tide bloom in Barnegat Bay was associated with reduced juvenile hard clam, *Mercenaria mercenaria*, growth as reported by the commercial aquaculture facility for hard clams (e.g., Biosphere, Inc.) in Tuckerton (Nuzzi et al. 1996).

Another harmful algal bloom, due to the toxic dinoflagellate, *Pfiesteria piscicida,* was associated with large fish kills in the nutrient-enriched estuaries along coastal waters of North Carolina, Maryland (Chesapeake Bay) and Virginia. *Pfiesteria* is polymorphic having 24 different forms and shifts from one form to another: from non-toxic to a toxic form including a non-toxic benthic cyst, a flagellate that swims to its prey and releases a toxin that stuns fish by releasing toxin, and an ameboid fish-killing/eating stage (Burkholder et al. 1995a,b; Gong, 1999; Fox, 1998). *Pfiesteria* has been associated with several massive fish kills along coastal North Carolina's Albemarle-Pamlico estuary, beginning in the early 1990's and recent fish kills in the Pocomoke and Chicamacomico Rivers and King's Creek tributaries to the Chesapeake, on Maryland's east shore (NJDEP, 1999; Bay Journal, 1997). *P. piscicida* was lethal to at least 19 species of native and exotic finfish and shellfish bioassays in culture (Burkholder et al., 1995b). This organism also preys on other estuarine microorganisms (e.g. bacteria, algae, and ciliates) (NJDEP, 1999).

A fish kill in the Tuckahoe River at Corbin City, NJ in September 1999 had the outward appearance of a *Pfiesteria*-related fish kill. No toxic *Pfiesteria* complex organisms were observed in a water sample collected during the fish kill, but other lines of evidence suggested that *Pfiesteria* piscicida may have been involved in the event (Atherholt and Ruppel, 2000). *Pfiesteria piscicida*-specific DNA was detected in 1 of 3 water samples and 3 of 3 sediment samples collected by the NJDEP's Division of Science, Research and

Technology in October 1999, in the Tuckahoe River near Corbin City, NJ approximately three weeks after the above fish kill event. The test used can reveal the presence of the DNA of *Pfiesteria piscicida*, but it cannot tell if live organisms were present, how many organisms are present or whether or not the organisms are (or were) toxic. To date, 38 water samples and 18 sediment samples from 16 different estuaries in the state have been tested for the presence of *Pfiesteria*-specific DNA but the presence of this DNA has only been detected at one of the locations – in the Tuckahoe River near Corbin City, NJ. However, the geographic distribution of this organism in NJ or elsewhere has not been adequately characterized. Additional sampling is anticipated for the summer of 2000. The NJ *Pfiesteria* Contingency Plan is nearing completion and is expected to be finalized prior to the start of the summer, 2000 (Atherholt, pers.comm).

C. Aesthetic/Economic Impacts

There are harmful algae that have deleterious aesthetic/economic impacts. The dinoflagellate green tide organism, *Gyrodinium* cf. *aureolum* Hulburt, caused a greenish water discoloration and odors along the southern New Jersey coast during the summers of 1984-85. This bloom diminished the aesthetic enjoyment of the affected New Jersey beaches in addition to some reports of mild sickness as noted above (Mahoney et al., 1990). Other algal species caused reddish or reddish-orange discoloration of the water and the presence of flocculent material, including the dinoflagellate species, *Prorocentrum micans, P. minimum,* and *P. triestinum* (= *P. redfieldi), (*NJDEP Annual Phytoplankton Reports), *Katodinium rotundatum (*NJDEP Annual Phytoplankton Reports), the raphidophycean alga *Olisthodiscus luteus* (confused with *Heterosigma akashiwo*) in Narragansett waters (Thomas, 1977) and in NJ waters (NJDEP Annual Phytoplankton Reports). Bloom-forming algae that caused the water to have a brown or yellow-brown discoloration of the water**,** including the presence of a flocculent material, included the diatoms (Bacillariophyceae) *Skeletonema costatum, Thalassiosira spp.* and *Cerataulina pelagica*, the green alga (Chlorophyceae) *Nannochloris atomus,* (Olsen, 1996) and the brown tide (Golden brown algae/Pelagophyceae) *Aureococcus anophagefferens* in Barnegat Bay and Little Egg Harbor (NJDEP Annual Phytoplankton Summary Reports, 1978-1998).

Appendix I summarizes harmful algal bloom species responsible for human health, ecological, and aesthetic/economic impacts.

V. Extent, Severity And Duration Of HABs In New Jersey

A. Summary Of Historic and Recent HABs In New Jersey

The following summary of the major harmful algal blooms in the last few decades in coastal waters of New Jersey is excerpted from the 1998 NJDEP Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters.

> Beginning in 1973, the NJDEP and the National Marine Fisheries Service (NMFS) James J. Howard Laboratory (Fort Hancock, NJ) conducted an intensive phytoplankton survey of the state's northern estuarine and coastal waters. This

survey identified late spring and summer red tides caused by several species of phytoflagellates including *Olisthodiscus luteus, Katodinium rotundatum* and *Prorocentrum* spp. – species that have been observed since the 1960's. The blooms extended to the New Jersey shore areas and were associated with hypereutrophication in the region.

In recent years, major phytoflagellate red tides have been confined primarily to the Hudson-Raritan estuary [e.g., Raritan-Sandy Hook Bays]…as well as several localized blooms in other New Jersey waters… but diatoms (e.g., *Skeletonema costatum and Thalassiosira* spp.), abundant during the cooler months, have dominated from mid to late summer. From 1996 to1998, flagellate red tides were overshadowed by dense summer blooms of several diatom species in the estuary and, to a lesser degree along the adjacent New Jersey northern coastline.

Between 1984-85, the "green tides", caused by the dinoflagellate *Gyrodinium aureolum*, bloomed along the southern New Jersey coast. The green tide, *G. cf aureolum*, reappeared in our coastal waters in 1996 and 1997, but to a lesser extent than previously, being most concentrated in the Atlantic City-Ocean City area. The green tide was not observed in 1998. . In Barnegat Bay, yellowish-brown water, caused by the minute chlorophyte, *Nannochloris atomus,* was first noted in 1985 and has recurred each summer with diminished aesthetic water quality.

In 1995, the minute "brown tide**"** alga, *Aureococcus anophagefferens*, associated with damage to shellfish crops in eastern Long Island (NY) embayments, was documented in bloom proportions for the first time in New Jersey, in lower Barnegat Bay and adjacent Little Egg Harbor Bay (Nuzzi et al., 1996). Adverse effects were seen on the growth of juvenile clams. In 1996 and 1998, *A. anophagefferens,* was detected here only in low numbers, but the species bloomed again in 1997.

While the brown tide was suspected in 1985 in Barnegat Bay, from mid-June to mid-October, because of a yellow-brown water discoloration (Olsen, 1989), it was not confirmed because immunofluorescent identification techniques were not developed until 1988 to enumerate the brown tide organism (Anderson et al., 1989). Due to its minute size (c. 3 µm), *A.. anophagefferens* cannot be identified using routine light microscopy. In addition, there could have been other minute picoplanktonic alga (e.g., the chlorophyte, *Nanochloris atomus)*, which may have imparted a yellowish-brown discoloration to the waters of Barnegat Bay, and which may have accompanied the brown tide and which can be indistinguishable from the brown tide organism (Olsen, 1996; Olsen, pers. comm.).

A recent assessment of algal blooms, including HABs, but not including the brown tide species, *Aureococcus anophagefferens,* in the New York Harbor/Bight and New Jersey coastal waters, concluded there is no evidence of an increase in bloom impacts or severity over the time frame from 1957-1995 (Cosper & Cerami, 1995). This assessment of four databases: 1) New York City Harbor Survey; 2) NJDEP; 3) EPA, and; 4) Gateway National Park, National Park Service used statistical correlations and factor analysis to correlate occurrences of algal blooms to physical-chemical parameters. The assessment characterized normal and excessive phytoplankton blooms and conditions to determine the location, extent, impacts, and factors contributing to the blooms in these waters. An algal bloom index was developed by Cosper and Cerami (1995) that ranked and quantified algal blooms for severity, extent, and impact from 1957-1995. The index included impacts and severity of green tides (Chlorophytes and Dinoflagellates), red tides of various species, diatom blooms (Bacillariophyceae), and blue-green algal blooms (Cyanobacteria).

Data from the geographic sites of the various database programs were combined into regional entities and plotted over two decades from 1975 to1995, on a monthly basis, with the long-term means. Table 1 includes a listing of documented algal blooms from 1957-1995 in New York and New Jersey and identifies species, maximum cell density, area of occurrence, time frame of occurrence, codes of severity, extent and impact, and literature references for the documentation (Cosper & Cerami, 1995). Table 1 contains sites in New York including Western Long Island Sound (WLIS), Upper East River (ER-U), Lower East River (ER-L), Upper North River (NR-U), lower North River (NR-L), Upper Harbor (UG), Upper Jamaica Bay (JB-U, Lower Jamaica Bay (JB-L), and Lower Bay (LB), and substantial data from New Jersey coastal waters, including the Kill Van Kull (KVK), Raritan Bay (RB), Sandy Hook Bay (SHB), North Jersey Coast (JC-N), Mid Jersey Coast (JC-M) and the South Jersey Coast (JC-S).

The results of the assessment indicated that there were no evident shifts from one bloom species to another in this geographic area excepting some shifts to the diatom blooms during the late 1980s and early 1990s (Cosper & Cerami, 1995). In addition, there *were greater bloom impacts and severity in coastal waters in comparison to the inner bays.* While this finding suggests that there is a need to continue to monitor the ocean-side of coastal waters, it is not contradictive of the recommendation to better characterize algal species that are emerging problems in inner bays (e.g., brown tide in Barnegat Bay).

Because the Cosper-Cerami algal bloom index did not include any brown tide blooms caused by *A. anophagefferens,* mainly because the methods of using immunofluorescent techniques were not available until the mid-1990s and the brown tide blooms were not reported as prominent in New Jersey waters over the last decade as they were in Long Island Bays, the index can be modified for an overall assessment of the brown tide blooms in Barnegat Bay. The current method of enumerating field samples of the brown tide organism relies on epifluorescence microscopy and the application of a polyclonal antibody (Anderson et al., 1989). A new method of enumeration has been developed using a monoclonal antibody using tissue culture pans, with results read on an automated plate reader (David Caron, pers. comm.). The monoclonal method uses fresh brown tide cultures and a standard curve is developed for each sample set. The enumeration results of the monoclonal method appear to be approximately four times greater than the polyclonal method and take only a couple of days for results as compared to the labor-intensive polyclonal method that can take weeks (David Caron, pers. comm.).

B. Summary of the 1999 Harmful Algal Blooms in the New Jersey Coastal waters

Because the 1999 Annual Summary was not available, a preliminary summary of the harmful algal blooms conditions along the New Jersey coastal areas during the summer of 1999 is provided below. Information was extracted from the weekly NJDEP Algal Conditions Report. This issue paper does not include all the information that will be included in the 1999 Annual Summary of Phytoplankton Blooms and Related Conditions in New Jersey Coastal Waters.

Raritan/Sandy Hook Bay Area:
During early June, 1999, there were moderate diatom blooms ongoing throughout the area (*Rhizosolenia*, *Asterionella and Skeletonema spp.)* as opposed to flagellates, or "red tide"-associated species; total cell counts were in the range of 15,000 to 20,000 per mL with some resultant brownish water (Algal Conditions Report, 6/7/99). Moderate blooms are approximately 10^5 cells per mL while a high bloom is greater than 10^6 cells per mL. Coastal conditions were clear, with sparse algal concentrations, except in the northernmost sector (Sandy Hook to Long Branch) where brownish water was reported, which was likely to be an extension of the bloom in Sandy Hook Bay (Shore Reports, 6/7 and 6/18). During mid-June, in addition to the dominant diatom species above, other diatom species (*Thalassiosira* sp.) occurred along with a few flagellates and red tide-associated species (Algal Conditions Report, June 16).

In early July, the daily shore report found heavy algae patches around the tip of Sandy Hook (Shore Report, 7/9). During the week of July 28, moderate algae blooms continued with a mixture of diatoms, chlorophytes and flagellate species, including *Katodinium and Prorocentrum* sp. that are associated with the "red tide" (red water), but none are acutely toxic varieties. It was conjectured that the warmer water temperature at the end of July might have promoted further development of the bloom and "red water" (Algal Conditions Report, week of July 28).

By mid-August, phytoplankton concentrations were diminished somewhat since the previous sampling on July 29. Dispersion from high winds prior to and during sampling on Aug. 11 was suggested as a potential cause. Several species were present in moderate numbers and water temperatures remained warm. It was suggested that red-water blooms could resume when conditions allow (Algal Conditions Report, week of Aug. 11). At the end of August (Shore Report, 8/25), phytoplankton levels were moderate and, while some red tide species were present, they were at low levels with no toxic species were reported.

New Jersey Coastal Area:
During early and mid-June, the Daily Shore Report noted that coastal conditions were clear, with sparse algal concentrations except in the northernmost sector (Sandy Hook to Long Branch) where brownish water was reported. This discoloration of the water was likely to be an extension of the bloom in Sandy Hook Bay (Daily Shore Report, 6/7 and 6/18).

In July, the Algal Conditions Report noted numerous species of phytoplankton are present including the diatom *Pseudonitzschia seriata* identified near Sandy Hook, but the concentrations were not sufficient to pose a human health impact (the species is considered toxic and is indigenous to most coastal and estuarine waters on the Atlantic coast)(Algal Conditions Report, week of July 14). The June (6/22) Daily Shore Report noted the occurrence of "brown algae" (but this did not refer to the brown tide alga *A. anophagefferens)* approximately 50 yds offshore from Ship Bottom south to Sea Isle City. During the week of July 28, moderate algal concentrations with scattered red water patches were reported along Monmouth Co. beaches. Species composition was similar to that in the estuary, although in lesser concentration. Persistence of southwesterly winds had caused recent upwellings of cooler water along the Ocean Co. coast, that may have resulted in low algae diversity (Algal Conditions Report, 7/28).

By August, algal concentrations were at moderate levels. Toxic species such as the diatom, *P. seriata*, and the dinoflagellate, *Prorocentrum micans*, were at low levels (Algal Conditions Report, week of 8/25).

The Daily Shore Report indicated that in early July, green algae were observed approximately 200 yards offshore of Surf City, approximately 50 yds offshore of Ocean City, 50 yds offshore of Sea Isle City, and approximately 25 yds offshore of Island Beach State Park. Heavy patches of green algae were observed in early August, approximately 200 yards offshore of Surf City and approx. 50 yds offshore of Ocean City and offshore of Sea Isle City. Heavy patches of decomposing algae were observed 200 yds of the south end of Pt. Pleasant and in the surf to 50 yds off the north end of Pt. Pleasant and again 50 yds off the north end of Sea Girt. Brown algae (not brown tide algae) were observed in the surf at Barnegat Light, Harvey Cedars, Brant Beach, Beach Haven Borough to the southern tip of Long Beach Island, Brigantine, Ventnor, Ocean City, Strathmere, Avalon, Stone Harbor and North Wildwood. Brown water was observed off of Mantoloking north to Pt. Pleasant, Normandy Beach north to Pt. Pleasant, Belmar and Sea Bright north to the tip of Sandy Hook and in the surf at Asbury Park, Barnegat Light, Harvey Cedars, Brant Beach, Beach Haven Borough to the southern tip of Long Beach Island, Brigantine, Ventnor, Ocean City, Spring Lake, Strathmere, Avalon, Stone Harbor and north Wildwood. Heavy patches of brown algae (not brown tide) were visible around the jetties from Avon and at the north end of Belmar to Long Branch. In mid July (7/13), brown water was observed off the Mantoloking north to Pt. Pleasant, Belmar and Sea Bright north to the tip of Sandy Hook.

Along the southern NJ coast during the week of July 28, waters were generally clear with moderate algal concentrations. *P. seriata*, a normally occurring diatom species has been associated with cases of human illness in Maine and southeastern Canada but at levels too low to produce toxicity (Algal Conditions Report, week of July 28). Algal densities were elevated but with the diverse species assemblage normally found in these waters.

By August, there were patches of decomposing algae approximately 100 yards offshore the south end of Sea Bright, 500 yards off of Long Branch and Deal and along the beach from Asbury Park south to Belmar. Again, brown algae, but not the brown tide alga, *A. anophagefferens,* occurred at different times in August off the south end of Manasquan and from the south end of Island Beach State Park to Ship Bottom.

Delaware Bay/Capeshore Area:
During the week of June 16, phytoplankton concentrations were moderate with species of diatoms dominant. High levels of detritus and suspended material were present. Historically, the condition is normal for the area (Algal Conditions Report, week of 6/16). In July, moderate diatom blooms were identified, but overall phytoplankton concentrations were moderate, with a normal diverse assemblage. Nuisance conditions from algal blooms have rarely occurred in these waters (Algal Conditions Report, week of July 14). By mid-August, a few "red tide" species were observed in Delaware Bay but they were moderate in numbers. There were no reports of any acutely toxic algal species in samples taken from NJ coast and estuarine waters (Algal Conditions Report week of Aug. 11).

Barnegat Bay
A significant "brown tide" bloom occurred in Barnegat Bay in the summer of 1999 was presumed to be caused by *A. anophagefferens.* This bloom began in May, continued through June, and abated in July but with continuing brownish water discoloration throughout the summer in specific locations. During the week of May 27, 1999, moderate blooms of the "brown tide" organism, *A. anophagefferens*, were observed in lower Barnegat Bay and adjacent Little Egg Harbor accompanied by reports of golden brown water discoloration in the area (NJDEP Report of Algal Conditions in New Jersey Coastal Waters, May 27, 1999). A summary of the brown tide conditions in Barnegat Bay is condensed below from the NJDEP weekly report of algal conditions.

During early and mid-June, the algal condition reports (6/7/ and 7/18) documented moderate bloom concentrations of the "brown tide" algae *Aureococcus* sp. in lower Barnegat Bay and adjacent Little Egg Harbor with brown water discoloration reported in this area. In the area north of Barnegat Inlet, the water was generally clear but brown water (likely of algal origin) was reported. At this time, concentrations of the brown tide alga (*Aureococcus)* had increased since the last sampling on May 27th. The NJDEP's Cooperative Coastal Monitoring Program's Daily Shore Report also noted brown colored water due to the brown tide (6/14).

During the week of June 16, the highest densities (over two million cells per mL) of *A. anophagefferens* were reported in the lower bay, between Surf City and Manahawkin, and into Little Egg Harbor (Algal Conditions Report). The bloom extended southward into Great Bay, and northward possibly as far as Forked River. The report indicated that there might have been adverse effects on hard clams and eelgrass in the affected area.

During the week of July 14, the brown tide bloom diminished in Barnegat Bay, but the bloom persisted throughout the area. During the week of July 28, the brown tide occurred at low levels, and *Nannochloris* sp., approached peak concentrations. This chlorophyte was responsible for the persistence of greenish brown water discoloration through the bay in recent summers, but no toxic effects are known from this species.

Around Aug. 14, the typical summer species assemblages, responsible for greenish or yellowish-brown water discoloration, continued at near peak concentrations and the brown tide remained at low levels. By the end of August (Algal Conditions Report, 8/27), the brown tide remained at low levels and the normal summer species assemblage responsible for the greenish-brown water discoloration continued but not at peak levels.

Public Response to the Brown Tide Blooms in Barnegat Bay in 1999

There were numerous public and press inquiries concerning the brown tide bloom during the summer of 1999. In addition to the weekly newspaper articles chronicling the occurrence and progression of the brown tide in Barnegat Bay (e.g., Asbury Park Press, NY Times, Atlantic City Press, Camden Courier Post, Associated Press, Trentonian, Trenton Times, and Middlesex County Home Tribune), the NJDEP received calls from the public reporting conditions relating to the brown tide blooms or raised concerns about the blooms including:

- human health impacts including the consumption of shellfish/fish (particularly hard clams) and primary/secondary recreational uses (e.g., swimming) in waters where brown tide blooms are occurring
- reports of the discoloration of clam meat which prompted questions of human health and ecological health of clams;
- reports of a temporary reduction in the growth of juvenile hard clams
- reports of hard clams being found deeper into the sediment;
- reports of reduced numbers of fish catches in areas of brown tide;
- report of the disappearance of waterfowl in local areas (e.g., Barnegat) (may be due to waterfowl feeding elsewhere because the inability to locate food in densely colored brown tide water);
- observations of large patches of floating and/or detached seagrasses (e.g., eelgrass) in the waters or in the marina areas where brown tide is blooming;
- concern about the unappealing discoloration of the water which interferes with the aesthetic quality of the bay;
- inquiries and concern over the causes of the blooms including the severity, extent, frequency, and duration of the brown tide;
- inquiries as to whether to purchase real estate in towns along the Barnegat Bay because of the brown tide blooms.

The NJDEP has a toll-free number to report environmental complaints, abuses and emergencies including the occurrence of harmful algal blooms (e.g., brown tide) at **1-877-WARNDEP (1-877-927-6337).** All public inquiries are referred to the press office at (609) 984-1795.

VI. Research and Indicator Development

There are numerous hypotheses to identify environmental factors important to the development and sustenance of harmful algal blooms. Slobodkin's "Null Case of the Paradox of the Plankton" (1989) expertly and elegantly hypothesizes that the management of algal blooms needs to be considered within the context of ecology:

> *"…In short, essentially any body of water that meets the criterion of relatively constant conditions and a low mixing rate will tend towards a monoculture bloom, while which species will bloom depends on regional history of cyst accumulation and subtleties of chemistry, temperature and light…."*

Slobodkin identifies two exceptions to this hypothesis: 1) the possibility of a highly infectious disease, such as **viral infection**, which would wipe out the bloom species and 2) more remote is the possibility of specific trace element removal (e.g. availability of iron). The role of viral infection in harmful algal blooms, such as the brown tide organism, is currently under study (Gastrich et al., 2000, submitted for publication) and is discussed below.

A. General Research and Indicator Development: Harmful Algal Blooms

The NJDEP is committed to monitoring harmful algal blooms in coastal waters. One of the major goals of the NJDEP's Strategic Plan is "Healthy ecosystems" and a sub-goal of the National Environmental Partnership System (NEPPS) Performance Partnership Agreement (PPA), between NJDEP and the USEPA, is "…to maintain surface water quality aquatic life designated use.…" One of the indicators (S9) identified to address these goals is "…**to determine status/trends in phytoplankton blooms in assessed tidal waters and extent of assessment…."** The NJDEP's Bureau of Marine Water Monitoring conducts the Phytoplankton Survey, mentioned earlier, that monitors harmful algal blooms for the presence of toxin-producing organism that may impact shellfish, as required by the National Shellfish Sanitation Program. This monitoring addresses mainly harmful algal blooms having human health effects. In addition, the NJDEP's Division of Science, Research and Technology conducts research and risk assessments on harmful algal blooms and develops indicators of their substantial ecological impacts.

Specific research/informational needs relating to harmful algal species:

- In response to the findings of the recent assessment of harmful algal blooms (draft, HABHRCA, 1999), it would be useful for research and studies in New Jersey to determine the characteristics of local circulation patterns and long periods of low water flow, water column stratification, and reduced mixing – conditions that are often associated with long residence times for water (e.g., reduced exchange with outside water sources such as ocean or rivers) in some shallow estuarine systems.

- In general, NJDEP reports have recommended continued spatial and temporal monitoring of harmful algal blooms.
- Additional taxonomic identification, using immunofluorescent microscopy and electron microscopy on water samples and algal isolates from Barnegat Bay, as well as Raritan Bay and other locales, to definitively characterize the composition of picoplankton communities and, to clarify distinctions among the picoplanktonic algae during different stages of the life cycle. Different stages of one species may resemble different stages of another species (Olsen, 1996; NJDEP Annual Phytoplankton Report, 1998);
- Taxonomic work on harmful algal blooms should be conducted concurrently with environmental indicators (e.g., water quality parameters, nutrient cycling) of year-round physical conditions of watershed and circulation patterns, hydrogeography, and meteorology, salinity regimes, groundwater contributions, and the identification of specific nutritional and physiological requirements of harmful algal blooms in the state (Olsen, 1996).
- Assessments of previous and future hypoxic events, due to algal decomposition, that are associated with consequent fish kills and potential toxicity to biota, should be conducted (Olsen, 1996).
- Research related to the life cycles of harmful algal species, and what factors control transitions between life stages, should be conducted as appropriate (e.g., resting spores of algal species produced as ambient conditions change) and studies at the cellular level are necessary to understand HAB population dynamics and their harmful effects (HABHRCA, 1999).
- In-situ measurements of species-specific rates of growth, photosynthesis, nutrient uptake, and physiological measurements at different times and locations (HABHRCA, 1999).
- Methods need to be developed to rapidly identify and enumerate HAB species from mixed phytoplankton assemblages (HACHRCA, 1999)
- Determine whether the mechanism in the case of fish kills and/or bather complaints, due to harmful algal blooms, is direct contact with microorganisms, or their irritants, or toxics (NJDEP Annual Phytoplankton Report, 1998).
- Appropriate study of potential environmental factors that may influence the initiation and sustenance of algal blooms including: the contribution of the specific species of nutrients from specific sources (nonpoint source, atmospheric deposition, etc.) and the rates of nutrient loading;
- Studies of predator-prey interactions and other biological processes that may influence the species of algae that dominate blooms and influence their maintenance and/or demise.
- Nutritional studies on important shellfish resources (e.g., hard clams) is a priority because Barnegat Bay and Raritan Bay had historical oyster and bay scallop fisheries which have disappeared and the hard clam fishery may suffer a similar fate if not specifically protected Kennish et al. 1984; Olsen, 1996) (related studies have been conducted for the Long Island bay brown tide blooms).

While nutrient enrichment is often cited as a cause for increasing occurrence of HABs, it is difficult to determine what role specific nutrients have played because of the lack of historic data on nutrients and abundances of HAB organisms (HABHRCA, 1999). In addition, it has been documented that some HABs are circulation-driven blooms and that physical factors (e.g., stratified water columns, subject to long periods of low flow and low mixing) may be associated with HABs occurrences (HABHRCA, 1999). In addition, environmental impacts (e.g., physical and ecological processes controlling partition of nutrients in a given systems, or specific physiochemical regimes associated with HAB events) of HABs population dynamics need to be addressed (HABHRCA, 1999). Some ecosystems may be more vulnerable to HABs and those unique characteristics should be identified in order to help predict future HAB occurrences. In addition, there are major research needs to identify the interaction of food webs and community interactions in the dynamics of algal blooms (HACHRCA, 1999). Finally, the interaction of HABs and their impacts on natural resources and wildlife should be a focus of research efforts (HABHRCA, 1999).

B. Specific Brown Tide Bloom Research Needs

Currently, the only harmful algal blooms that are monitored by the NJDEP are those having human health risks. Therefore, the brown tide blooms are not routinely monitored by the Department because they do not represent a human health risk at this time. However, because of the potential for ecological impairments in Barnegat Bay and other shallow estuary bays, there are specific research needs for the brown tide blooms.

The development of brown tides in the mid-Atlantic has been confined to shallow, relatively unstratified estuaries, with reduced flushing rates, elevated salinities (>25-30 ppt), and winter and spring droughts followed by below average rainfall levels and drought conditions (Bricelj and Lonsdale 1997; Cosper et al. 1987). It is hypothesized that higher salinities in Long Island bays during summers with reduced rainfall, may have been conducive to blooms in the mid-1980s (Cosper et al. 1989a,b). Drought conditions were associated with the 1985 brown tide bloom in Long Island bays (Bricelj & Lonsdale, 1997). Elevated salinities were also considered a factor (from 25-30 ppt) in the brown tide bloom in Narragansett Bays in 1985 (Bricelj & Lonsdale, 1997). Numerous environmental variables have been considered to contribute to brown tide blooms in Long Island including elevated salinities (>28 parts per thousand) due to drought conditions, lower temperatures, pulses of rainfall delivering organic and/or micronutrients to bay waters, reduced grazing and reduced flushing rates of bays (Cosper et al., 1989b; Bricelj & Lonsdale, 1997).

Areas in Barnegat Bay where brown tide occurred in the summer of 1999 have similar characteristics to Long Island bays (e.g., elevated salinities). The bay is shallow in depth (average depth = 1.3 m)(Guo et al. 1995; 1999, in press) with a long flushing time (the time interval in which the total amount of the existing bay water will be replaced by "new" water or in which the entire existing bay water will leave the bay), of about 50 days (Guo et al.,1996; 1999 in press).

- Therefore, an assessment is needed of factors related to the dry spring and drought-related summer of 1999 that may have contributed to the significant brown tide bloom in Barnegat Bay. Ecosystem impacts on resources (e.g. shellfish and seagrasses) has been documented in Long Island (Bricelj & Lonsdale, 1997) and similar impacts, due to brown tide blooms, need to be assessed in Barnegat Bay and Little Egg Harbor.

While salinity data from the Data Sonde stations in Barnegat Bay during the years 1993-97 were not significantly different from 1999 data, there were events that may have elevated salinities, compared to previous years, which may have been favorable to brown tide growth in recent years. In addition to the drought conditions, documented in New Jersey during the 1999 spring and summer season (NJDEP, 1999), which may have sustained elevated salinities in specific locations in Barnegat Bay (> 28 ppt), two other events since 1992 may have caused increases in salinity in Barnegat Bay. There was an increase in the tidal range, which probably caused increases in salinity in Barnegat Bay, due to the new south jetty modifications at the Barnegat Inlet in 1992 (Guo, pers. comm.; Seabergh et al., in preparation). More recently, coastal ocean upwellings offshore of Little Egg Inlet and Barnegat beginning on May 25 and continuing through June 12, and again from June 26 to July 6, brought cooler waters with higher salinity into the Bay Inlet (Michael Crowley, pers.comm., Coastal Ocean Observation Laboratory, Institute of Marine & Coastal Sciences, Rutgers University, pers. comm.).

Another area of research relates to the extent of the eelgrass beds in Barnegat Bay. Over 70% of the state's eelgrass beds are located in Barnegat Bay (Lathrop, 1999). Eelgrass beds are marine habitats of great ecological and economic value (Thayer et al. 1984; Short et al. 1993; Pohle et al. 1991; Burdick and Short 1999). While eelgrass beds in Barnegat Bay appeared healthy in the late 1960s and early 1970s, a recent report indicated that the beds are no longer healthy due to various interactive factors such as "wasting disease", algal blooms, uprooting of seagrasses and other deleterious effects from boating activity, docks, and wood structures (Burdick & Short, 1999; McLain & McHale, 1996; Short et al., 1993; Woods Hole Oceanographic Institute, 1998; Burdick & Short, 1999). Algal blooms of extended duration (> 1.5 months) have resulted in severe shading on growing eelgrass beds in Long Island bays (McLain & McHale, 1996; Dennison et al., 1989).

Barnegat Bay is a shallow bay, containing eelgrass beds, especially in the southern part of the Bay, with similar characteristics to some of the Long Island bays experiencing brown tide problems. With the apparent recurring brown tide blooms in Barnegat Bay, the eelgrass beds are subjected to an additional stressor and may be susceptible to damage during future prolonged brown tide blooms.

- Therefore, assessments are needed of the relationship of the brown tide blooms to various environmental quality indicators (e.g., salinity, temperature, nutrients, etc.) as well as to the presence of hard clam populations and status and trends of the eelgrass populations in specific locations in Barnegat Bay.

In Barnegat Bay, the declining quality of hard clams in Little Egg Harbor Bay has been documented (Kraeuter et al., 1996).

- Therefore, surveys of the status and trends in abundance and distribution of hard clams in Barnegat Bay are needed.

While the brown tide has often been characterized as an “ecosystem” problem, with multi-faceted degradation of whole ecosystems, recent research may point to explanations that are more specific. An early hypothesis focused on the timing of the brown tide blooms in juxtaposition with decreased grazing pressure due to the population dynamics of two copepod populations (e.g., *Acartia* sp.) (Duguay et al., 1989). Recently, it has been hypothesized that the reduction in the abundance of filter-feeding macrobenthos, specifically the hard clam, *Mercenaria mercenaria,* occurring in shallow bays (similar to Barnegat Bay), may result in a shift in the pelagic microbial community from filter-feeding benthic species to pelagic microbial consumers (Caron & Lonsdale, 1999). Conversely, the reintroduction or invasion of hard clams in Long Island waters has shifted the major grazing impact of phytoplankton (Caron & Lonsdale, 1999). Once the shift to the pelagic grazing community occurs, there appears to be “grazing selectivity” in the pelagic phytoplankton community which *could* allow the brown tide organism to dominate. While there is evidence that some species of protozoa consume the brown tide organism, *A. anophagefferens,* many other microbial consumers select against this species and choose other prey.

A secondary hypothesis to this idea of predatory grazing pressure is that the *rate* of nutrient loading to the bay, not the particular type of nutrient loading, may affect the timing of dominance of the brown tide bloom (Caron & Lonsdale, 1999;Caron et al., pers. comm.).

- Therefore, an assessment of the brown tide blooms in Barnegat Bay may need to address the *rates of loadings* of nutrients, not just the particular nutrient.

In addition, the role of viral infection, as referred to in the Slobodkin hypothesis, in sustaining or controlling brown tide blooms needs to be assessed in conjunction with other environmental variables. A recent study indicated there was a consistent viral infection throughout the 1999 brown tide bloom period in lower Barnegat Bay and Little Egg Harbor (Gastrich et al. 2000 in press). The viruses were similar in shape and size to those observed previously in inoculated (with the isolated BtV virus) in laboratory cultures (Gastrich et al.,1998; Cosper et al., 1996) and similar to the viruses observed in natural populations of *A. anophagefferens* during the 1985 bloom in Narragansett Bay (Sieburth et al., 1989).

- Therefore, abundances of the brown tide organism, *A. anophagefferens,* and the extent of viral infection needs to be analyzed throughout the viral infection cycle throughout the year in Barnegat Bay, Little Egg Harbor and other locations where brown tide is likely to occur.

To date, there has been no documentation of the possibly profound effects of the brown tide blooms in Barnegat Bay (Olsen, 1989). Therefore, additional recommendations for research/information needs for brown tide blooms are included below:

- Recommended research includes an assessment of how regional climatic and hydrographic changes may influence conditions that promote brown tide growth in local shallow bays such as Barnegat Bay;
- It has been recommended that high priority be given to the study of brown tide occurrence and impacts in relation to various physical and chemical parameters and to undertake this in cooperation with scientists working on the issue in the region (Mahoney et al., 1996; Olsen, 1989).
- It has been further recommended that cultures of *A. anophagefferens* be established to facilitate studies comparing their nutritional requirements, relative tolerance to contaminants, and relative toxicity (Mahoney et al., 1996).
- Studies are needed to identify various physico-chemical differences in areas where brown tide blooms occur and to correlate these characteristics with the blooms (Mahoney et al., 1996).
- Future studies should address the extent and intensity of brown tide blooms and their impacts in Barnegat Bay because of its important natural and recreational resources.

In conclusion, continued monitoring and studies of the dynamics of harmful algal blooms throughout the year, especially *A. anophagefferens*, will provide more information on the status and trends of these blooms in coastal and estuarine waters. Surveys of natural resources (e.g., eelgrass, hard clams and other bivalves) need to conducted in order to assess potential negative impacts due to harmful algal blooms of extended duration (> one month). Additional assessments are needed that lead to the development of tools to predict areas at high ecological risk for harmful algal blooms. The coincident variables (e.g., meteorological and hydrographic conditions) found in other occurrences of harmful algal blooms elsewhere need to be related to harmful algal blooms in New Jersey coastal waters.

The research and information needs identified in this issue paper will be incorporated into the Coastal Research Agenda that is being drafted by the Division.

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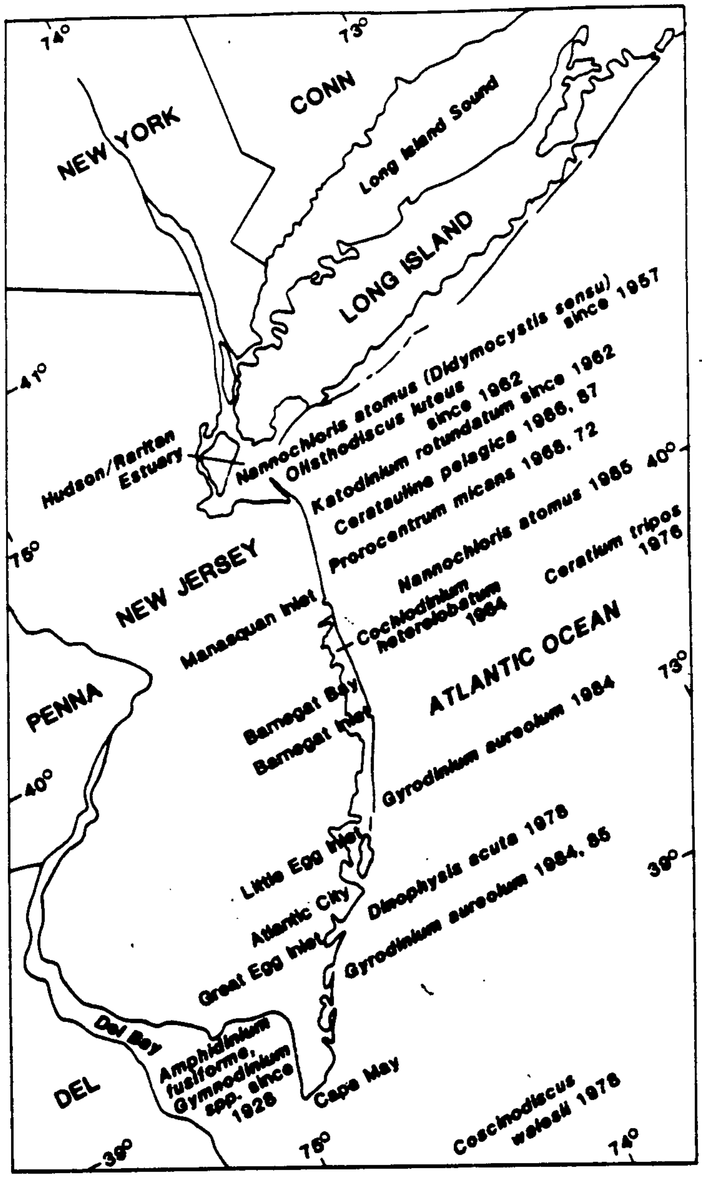

Figure 1. Historical perspective of major phytoplankton blooms causing red tides in the New York Bight and adjacent New Jersey coastal region.

(Olsen, 1989)

New Jersey's Coastal Phytoplankton Monitoring Network

Water Monitoring Management
James E. Mumman, Administrator

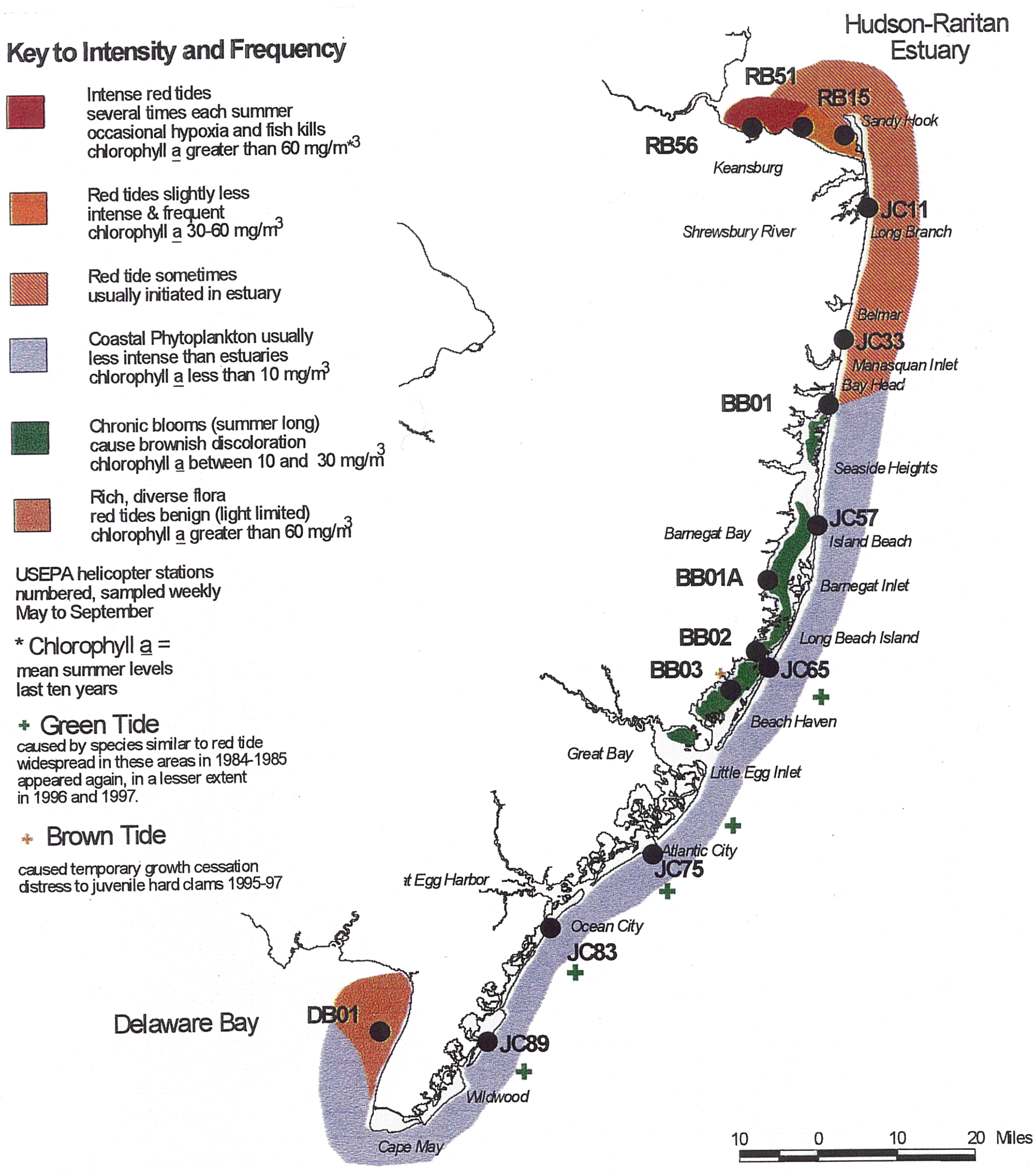

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Table 1. Listing of documented algae blooms from 1957-1995 in the New York Harbor and New York Bight (Cosper and Cerami, 1996)

Year	Species	Max Density	Area	Time Frame	Severity	Extent	Impact	References
1957	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1958	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1959	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1959	K. rotundatum		RB					Smayda, 1973
1960	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1961	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1962	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1962	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1962	Diatoms; S. costatum	2.00E+06	JCN	June	1	1	1	Kawamura, 1966
1963	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1963	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1964	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1964	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1965	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1965	Chlorophytes; N. atomus, D. sensu	5.00E+08	RB	June - Oct	1	2	2	McCarthy, 1965; Patten, 1962; Jeffries, 1962
1966	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1967	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1968	P. micans	4.00E+08	JCN, ROCKAWAY	July - Oct	4	3	12	Ogren & Chess, 1969; ISSC 1968; Mahoney & McLaughlin, 1977
1968	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1969	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1970	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1971	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1972	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1973	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1974	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1975	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1976	Phytoflagellates; K. rotundatum, O. luteus, P. micans		LB, RB	June - Aug	4	2	8	Mahoney & McLaughlin, 1977
1976	C. tripos	2.40E+05	JCN	April - July	3	3	9	Mahoney & Steimle, 1978
1977	D. acuta, Ceratia	3.00E+06	JCS	June	2	3	6	Figley, 1979
1978	N. atomus	3.00E+08	RB, JC	July - Aug	1	3	3	Takas, 1978
1978	O. luteus	6.00E+07	SHB, JCN	June	1	2	2	Takas, 1978
1978	D. acuta, Ceratia	9.60E+06	JCS	June, July	1	2	2	Takas, 1978
1979	K. rotundatum	4.00E+07	SHB, JCM	June - July	1	3	3	Olsen, NJDEP
1979	N. atomus	1.25E+08	SHB, JCN, JCM	June - July	1	3	3	Olsen, NJDEP
1979	O. luteus	1.30E+07	JCM	July	1	2	2	Olsen, NJDEP
1980	N. atomus	1.80E+08	SHB, JCN	June - July	1	2	2	Olsen, NJDEP
1980	O. luteus	1.10E+08	SHB, JCN	July	1	2	2	Olsen, NJDEP
1980	Chroomonas	7.30E+07	SHB	May	1	1	1	Olsen, NJDEP
1981	N. atomus	1.00E+08	SHB, JCN	June - July	1	2	2	Olsen, NJDEP
1981	O. luteus	2.00E+07	JCN	June	1	1	1	Olsen, NJDEP
1981	K. rotundatum	1.40E+07	SHB	July	1	1	1	Olsen, NJDEP
1982	Skeletonema, Chaetoceros	4.00E+07	SHB, JCN	August	1	2	2	Olsen, NJDEP
1982	O. luteus	2.00E+07	RB, JCN	June - July	1	2	2	Olsen, NJDEP
1982	N. atomus	8.00E+07	RB, JCN	June	1	1	1	Olsen, NJDEP
1983	P. micans	1.30E+07	JCN, JCM	July	4	2	8	Olsen, NJDEP
1983	O. luteus	1.00E+08	SHB,JCN	June	1	2	2	Olsen, NJDEP
1984	G. aureolum	3.00E+07	JCS	Aug - Sept	4	3	12	Olsen, 1989; USEPA, 1986 - 1986
1984	Diatoms	5.00E+07	JCN, JCM	August	1	2	2	Olsen, NJDEP
1984	N. atomus	1.00E+08	SHB	July	1	1	1	Olsen, NJDEP
1985	G. aureolum	3.00E+07	JCS	July - Aug	4	3	12	NJDEP
1985	Diatoms	1.00E+07	SHB	May	3	2	6	Olsen, NJDEP
1985	N. atomus	5.00E+08	JCS, NYB	July - Sept	1	3	3	Olsen, 1989

Table 1. Listing of documented algae blooms from 1957-1995 in the New York Harbor and New York Bight (Cosper and Cerami, 1996)

Year	Species	Max Density	Area	Time Frame	Severity	Extent	Impact	References
1985	Dinoflagellates; others	1.00E+07	RB, SHB, JCN	June	1	2	2	Olsen, NJDEP
1986	K. rotundatum	1.00E+07	RB, SHB, JCN	June - July	3	3	9	Olsen, NJDEP
1986	N. atomus	5.00E+08	JC	July - Sept	1	3	3	Olsen, NJDEP
1987	P. triestinum		WLIS	July - Sept	3	3	9	Mahoney, 1989
1987	N. atomus	1.00E+08	RB, SHB, JCN	July - Sept	1	3	3	Olsen, NJDEP
1987	Diatoms; C. pelagica, Thalassiosira, Cyclotella	1.00E+07	RB, SHB, JCN	May - Sept	1	3	3	Olsen, NJDEP
1988	Phytoflagellates; O. luteus, K. rotundatum, E. lanowii	2.50E+07	RB, SHB	May - Aug	3	3	9	Olsen & NOAA
1988	C. pelagica	2.00E+07	JCN, RB	May - June	1	3	3	NJDEP
1989	Diatoms; S. costatum, C. closterium	1.00E+08	RB, SHB, JCN	July - Sept	1	3	3	Olsen, NJDEP
1989	Phytoflagellates; K. rotundatum	5.00E+07	RB, UH, JCN	June - July	1	3	3	Olsen, NJDEP
1989	Phytoflagellates; O. luteus, K. rotundatum, E. lanowii	5.00E+07	JCN, JCM	Oct	1	2	2	Olsen, NJDEP
1990	N. atomus	1.00E+08	RB, SHB	June - Sept	1	3	3	Olsen, NJDEP
1990	Diatoms; many common	1.00E+08	RB, SHB, JCN	July - Sept	1	3	3	Olsen, NJDEP
1990	K. rotundatum	1.00E+07	RB, SHB	Late June	1	2	2	Olsen, NJDEP
1990	O. luteus	1.00E+07	SHB	June - July	1	2	2	Olsen, NJDEP
1991	Diatoms; S. costatum, many common	5.00E+07	RB, SHB, JCN	May - Sept	1	3	3	Olsen, NJDEP
1991	P. minimum	2.50E+07	RB, SHB	May - June	1	2	2	Olsen, NJDEP
1992	K. rotundatum	3.00E+07	RB, SHB	July	3	2	6	Olsen, NJDEP
1992	Diatoms; S. costatum, other common	6.00E+07	RB, SHB, JCN	May - Aug	1	3	3	Olsen, NJDEP
1993	Red Tides; species diverse	1.00E+07	RB, SHB, JCN	May - Sept	1	3	3	Olsen, NJDEP
1993	Diatoms; S. costatum, sp. diverse	2.00E+08	RB, SHB	May - Sept	1	3	3	Olsen, NJDEP
1994	Diatoms; many common	2.50E+07	RB, SHB, JCN	May - Sept	1	3	3	Olsen, NJDEP
1994	E. lanowii	2.50E+07	RB, SHB	June - July	1	3	3	Olsen, NJDEP
1995	Diatoms; many common	3.00E+07	RB, SHB, JCN	May - Sept	1	3	3	Olsen, NJDEP
1995	Phytoflagellates; O. luteus, K. rotundatum, E. lanowii	2.40E+07	RB, SHB, JCN	July	3	2	6	Olsen, NJDEP
1995	N. atomus	1.00E+08	RB, SHB	July	1	2	2	Olsen, NJDEP

Green Tides - Chlorophytes	
D. sensu	Didymocystis sensu
N. atomus	Nannochloris atomus
Green Tides - Dinoflagellates	
G. aureolum	Gyrodinium aureolum
Red Tides	
C. tripos	Ceratium tripos
D. acuta	Dinophysis acuta
E. lanowii	Eutreptia lanowii
K. rotundatum	Katodinium rotundatum
O. luteus	Olisthodiscus luteus
P. micans	Prorocentrum micans
P. minimum	Prorocentrum minimum
P. triestinum	Prorocentrum triestinum
Ceratia	
Diatom Blooms	
C. pelagica	Cerataulina pelagica
C. closterium	Cylindrotheca closterium
S. costatum	Skeletonema costatum
Chaetoceros	
Thalassiosira	
Cyclotella	
Blue-green Blooms	
Chroomonas	

VIII. Appendix I

DOCUMENTED OCCURRENCES OF HARMFUL ALGAE IN NEW JERSEY WATERS

A. HUMAN HEALTH:

Dinoflagellates/Pyrrhophyceae:

Gyrodinium cf. aureolum (green tide): mild sickness in bathers; Mahoney et al. 1990; U.S. Environmental Protection Agency Green Tide Environmental Inventory 1987; Olsen *1989.;*

Massartia rotundata (Katodinium rotundatum)(red tide): bloomed annually in NJ coastal waters from 1962-1976; while occurrence appeared benign, some had adverse effects on biological and recreational resources in the area, including discomfort among bathers, and a diminished aesthetic value of the beaches; (as reported in Mahoney & Mclaughlin 1977; Olsen & Mulcahy 1991)

Prorocentrum micans (red tide) and other *Prorocentrum* spp.: minor irritation to *bathers*; *Mahoney & Mclaughlin 1977;* dominated blooms from 1962-1976 and while presumed to be benign, there were reports of adverse effects such as respiratory discomfort among bathers (as reported in Mahoney & McLaughlin, 1979);

Pfiestera piscicida: human health effects and associated neurocognitive disorders in researchers working on the organism in close proximity and high concentrations proximity (Bay Journal Archive, 1997; Congressional Research Service Report, 1999).

Diatoms/Bacillariophyceae

*Pseudonitzschia (Nitzschia) spp. (*Amnesic Shellfish Poisoning, or ASP, by production of domoic acid), *P. pungens* forma *multiseries, P. seriata, and P. delicatissima;* closely associated with ASP and have been abundant in New Brunswick, CA and Prince Edward Island; organism has been observed at times in NJ coastal and nearshore waters during fall and winter months; **no cases of blooms in NJ** *(*Anderson, 1994; summarized in Mahoney 1989; NJDEP Annual Summary 1998; U.S. EPA Reports; Olsen and Cohn, 1979;

Golden algae/Raphidophyceae

Olisthodiscus luteus Carter: dominated blooms from 1962-1976 and while presumed to be benign, there were reports of adverse effects such as respiratory discomfort among bathers (as reported in Mahoney & McLaughlin, 1979).

Algal species known to cause Ciguatera Poisoning in humans, from consumption of fish from tropical and subtropical waters, **have not been found to bloom in NJ.** Other harmful algal species have not bloomed **in NJ waters including the dinoflagellate species,** *Alexandrium tamarense* (Paralytic Shellfish Poisoning), *Gonyaulax tamarensis (red tide),* Cohn et al. 1988; Mahoney et al. 1995; Olsen et al., 1988; Science Applications International Corporation, 1987, *Dinophysis spp. acuta,* (Diarrhetic Shellfish Poisoning)(diarrhetic shellfish toxin detected in *D. acuminata* in Narragansett Bay in mid-1980s (Maranda and Shimizu, 1987; summarized in Mahoney 1989; NJDEP Annual Phytoplankton Summary reports 1998), *D. novegica(implicated as possible cause of diarrhetic shellfish poisoning in NY but not NJ)(*Freudenthal and Jijina 1985; summarized in Mahoney 1989), *Gymnodinium breve (= Ptychodiscus breve) (*Neurotoxic Shellfish Poisoning in humans and cause of deaths of hundreds bottlenose dolphins washed ashore in NJ but **no cases of the organism have been observed in NJ**)(NJDEP Annual Phytoplankton Summary 1998). The dinoflagellate, *Pfiesteria spp. (P. piscicida),* is lethal to fish (Burkholder et al. 1995) and has neurotoxic effects on humans.

B. ECOLOGICAL IMPACTS: Classes of algae associated with ecological impacts in New Jersey

Dinoflagellates/Pyrrhophyceae:

Ceratium tripos (red tide): oxygen deficiency off the coast of NJ due to decomposition of algae in 1976 (Malone 1978; Mahoney 1989; Mahoney & Steimle, 1979); NJDEP Annual Phytoplankton Summary Reports, 1978, 1998; U.S. EPA Annual Reports;

Cochlodinium heterolobatum (red tide)(formerly, Polykrikos kofoidi, Mountford, 1965; and *Polykrikos barnegatensis,* Mountford, 1965; observed in upper Barnegat Bay in 1964 causing distress and mortality to several species of fish and shellfish with concomitant pungent odor. NJDEP Annual Phytoplankton Reports, 1998; Olsen 1989;

Gyrodinium cf. aureolum (green tide): detrimental to marine biota; and in Carmans River, NY in early 1980s (summarized in Mahoney 1989; Chang and Carpenter, 1985); bloomed in NJ coast in 1984-85 with associated kills of blue mussel, *Mytilus edulis*, and lady crab, *Ovalipes ocellatus*, were coincident with these occurrences (summarized in Mahoney 1989; Mahoney et al. 1990;

Massartia rotundata (Katodinium rotundatum)(red tide): hypoxia and consequences of fauna kills; Olsen & Mulcahy, 1991; Mahoney & Mclaughlin 1977; Olsen & Mulcahy 1991*;* bloomed annual in NJ coastal waters from 1962-1976 and while occurrence appeared benign, some had adverse effects on biological and recreational resources in the area, including a putative role in fish mortality and a diminished aesthetic value of the beaches; (as reported in Mahoney & Mclaughlin 1977; Olsen & Mulcahy 1991; Mahoney & Mclaughlin 1977; Olsen & Mulcahy 1991 *Katodinium (Massartia) rotundatum (*

Prorocentrum lima: *abundant in Barnegat Bay and associated with a blueclaw* crab kill west of Barnegat Inlet in 1987; NJDEP Annual Summary 1998;

Prorocentrum micans (red tide and other spp.): anoxia/hypoxia-related mortality of marine fauna; fish kill associated with prolonged bloom off NJ in 1968; bloomed annually in NJ coastal waters from 1962-1976 and while occurrence appeared benign, some had adverse effects on biological and recreational resources in the area, including a putative role in fish mortality and a diminished aesthetic value of the beaches; (as reported in Mahoney & Mclaughlin 1977; summarized in Mahoney 1989; Ogren and Chess, 1969);

Prorocentrum redfieldi (red tide): Mahoney 1989; implicated in mild discomfort to bathers (NJDEP Annual Phytoplankton Reports)

Scripsiella trochoidea (=Protoperidinium trochoideum, P. brevipes): common species throughout New Jersey's coastal waters but **not directly implicated in toxicity** (but toxicity found in other regions); NJDEP Annual Summary, 1998;

Pfiesteria piscicida: associated with large fish kills in the nutrient-enriched estuaries along coastal waters of North Carolina, Maryland (Chesapeake Bay) and Virginia. While *Pfiesteria* was detected in bottom sediments from the Tuckahoe River in NJ, the results of the toxicity tests, to determine whether the organism caused a local fish kill, are not yet available from the NJDEP (Atherholt, pers. comm.).

Golden algae/Raphidophyceae

Olisthodiscus luteus (red tide) (confused with *Heterosigma carterae)* common or abundant in NJ waters and associated with potential toxicity to fish (Mahoney & Mclaughlin 1977; NJDEP Annual Phytoplankton Summary 1998); dominated blooms from 1962-1976 and while presumed to be benign, there were reports of adverse effects on biological and recreational resources in the area, including a putative role in fish mortality fish (Mahoney & Mclaughlin 1977); dense summer red tides contributed to hypoxia (Olsen and Mulcahy 1991).

Golden-brown algae/Pelagophyceae

Aureococcus anophagefferens "brown tide" algae: associated with reduction in juvenile hard clam growth, damage to shellfish (e.g., scallops, clams, oysters, etc.), and damage to seagrasses during prolonged periods of occurrence (e.g., eelgrass beds); (references included in discussions above); caused catastrophic effects on bay scallops, *Argopecten irradians*, in Long Island bays in 1985-86 through starvation (Cosper et al. 1987; Mahoney, 1989); destruction to eelgrass, *Zostera marina*, in Long Island bays in 1985-86; adverse effects on zooplankton, blue mussel, benthic larvae, anchovy, *Anchoa mitchilli*, fecundity, and kelp, *Laminaria saccharina* and *L. digitata* (Mahoney, 1989; Smayda and Fofonoff, 1989).

Ciguatera fish poisoning associated with dinoflagellate, *Prorocentrum spp.*, has **not been observed in NJ** (Olsen & Mulcahy 1989*)*.

C. AESTHETIC IMPACTS: Classes of problem algae associated with aesthetic impacts in New Jersey

Dinoflagellates/Pyrrophyceae

Gyrodinium cf. *aureolum* Hulburt; causes greenish water discoloration and odors along the southern New Jersey coast in the summers of 1984-85 caused diminished aesthetic enjoyment of the affected New Jersey beaches; some reports of mild sickness (Malone et al. 1990).

Prorocentrum micans (P. minimum and P. triestinum, P. redfieldi); red water and flocculent material in NJ; NJDEP Annual Phytoplankton Reports

Katodinium rotundatum: red water and floc; NJDEP Annual Phytoplankton Reports;

Golden algae/Raphidophyceae

*Olisthodiscus luteus (red tide)**:*** red-orange water color and flocculent material; NJDEP Annual Phytoplankton Reports*)* (possibly confused with *Heterosigma carterae)* common or abundant in NJ waters and associated with potential toxicity to fish (Mahoney & Mclaughlin 1977; NJDEP Annual Phytoplankton Summary 1998); dominated blooms from 1962-1976 and while presumed to be benign, there were reports of adverse effects on biological and recreational resources in the area, and a diminished aesthetic value of the beaches; (as reported in Mahoney & Mclaughlin 1977;

*Heterosigma akashiwo (*previously misnamed as *O. luteus* according to P. Hargreaves); produces reddish discoloration to the Narragansett waters (Thomas, 1977) and NJ waters (NJDEP Annual Phytoplankton Reports);

Diatoms/Bacillariophyceae

Skeletonema costatum: brown water and foam/flocculent material; NJDEP Annual Phytoplankton Reports

Thalassiosira spp. : brown water and foam/flocculent material; NJDEP Annual Phytoplankton Reports

*Cerataulina pelagica (*Cleve) Hendy: brown water and foam/flocculent material; NJDEP Annual Phytoplankton Reports.

Golden brown algae/Pelagophyceae

Aureococcus anophagefferens "brown tide" algae: causes brown water discoloration in Barnegat Bay and Little Egg Harbor (NJDEP Annual Phytoplankton Summary Reports (1978-1998);

Green Algae/Chlorophyceae

Nannochloris atomus: causes greenish-brown water discoloration (Olsen, 1996).