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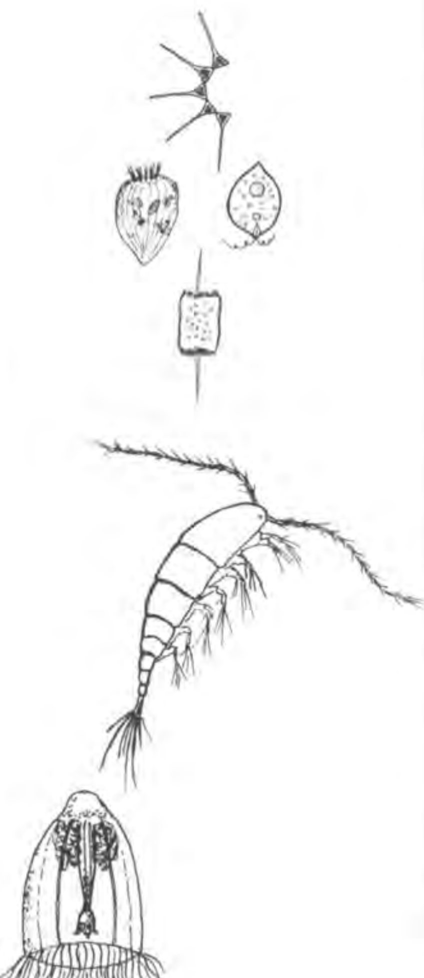

Four types of phytoplankton (top), single cell marine microscopic plants. Also illustrated are two types of zooplankton, a copepod and small jellyfish (bottom), which eat phytoplankton.

The Brown Tide: An Investigation of Why This Unusual Phytoplankton Bloom Occurred

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INTRODUCTION

What are Phytoplankton?

Phytoplankton are microscopic, single-cell plants that float freely in fresh and salt waters and form the basis of most marine food webs. Phytoplankton grow and multiply by absorbing dissolved chemicals (nutrients) from the water in the presence of sunlight during the process of photosynthesis. In turn, phytoplankton are consumed by myriad small animals (zooplankton) as well as by many filter-feeding mollusks, such as clams, oysters, and scallops. Thus, phytoplankton provide food for the smallest animals, which in turn, provide food for larger and larger animals. While phytoplankton are critical to the food web, natural and man-made disturbances can cause an overabundance of one or more species. This is called a phytoplankton, or algal, bloom.

As we shall see in the following discussion, blooms can persist for long periods and over extended areas and can have devastating effects on the ecology of inshore coastal waters. Secondarily, blooms can affect human activities associated with coastal waters (e.g., fishing, boating, and swimming). Besides turning the water an unusual color (brown, green, or red) and having a noxious odor, they often cause the water to be depleted of oxygen, endangering less mobile animal populations such as shellfish. On rare occasions, when the bloom is severe, animal populations can even be killed off.

Environmental Influences on Phytoplankton Communities

The abundance of phytoplankton, the rate at which they grow, and the types of phytoplankton present in a body of water are determined by environmental conditions including the types and amounts of nutrients available, the temperature and salinity (salt content) of the water, and the amount of sunlight present. These environmental conditions vary naturally during the course of the year and therefore cause variation from season to season in the phytoplankton community. The community can vary in abundance (there can be very few or very many cells per liter of water). The species of phytoplankton that the community is composed of can also vary (there can be a lot of different species or only one). The community can also be variable in productivity— the amount of photosynthesis being carried out in these cells.

At times in coastal waters, for example, in Long Island's inshore waters, environmental conditions combine to favor blooms—the explosive growth of one or a small group of phytoplankton species, to the effective

Figure 1. Scanning electron micrograph of brown tide cells (*Aureococcus anophagefferens*). Photo by David Colflesh and Maynard Dewey, Anatomical Sciences.

The brown tide caused eelgrass, a plant important to coastal ecosystems, to die.

exclusion of other species. In recent years, several of Long Island's inshore bays have experienced a series of particularly severe phytoplankton blooms called the "brown tide" (Fig. 1). This bulletin briefly describes the brown tide and its impact on the ecology of these areas, and summarizes current knowledge on the probable causes of this bloom.

BROWN TIDE BLOOM

Occurrence and Distribution

Several bays of Long Island's coast have recently experienced novel phytoplankton blooms—blooms of a species never before recorded. These blooms of only a single species of phytoplankton were popularly called the "brown tide" because they turned coastal waters a golden-brown color. In the early summer of 1985, the brown tide first appeared, not just on Long Island but in widely separated bodies of water along the northeast coast of the United States: embayments of Long Island, New York; Barnegat Bay, New Jersey; and Narragansett Bay, Rhode Island (see map, Fig. 2). The blooms were restricted to these three coastal bay systems, but did not appear to follow a pattern of spreading from one bay system to the next. Rather, the brown tide developed simultaneously in these separate environments. This suggests that the environmental factors contributing to these brown tide blooms were not solely local conditions in each bay system but also involved forces acting throughout the region. The particular regional forces behind this outbreak of blooms were meteorological (such as wind and rainfall) changes.

Damage Caused by The Brown Tide

The brown tide on Long Island markedly reduced the extent of eelgrass (*Zostera marina*) beds because of reduced light penetration into the water. Light penetration was reduced because the large numbers of small brown tide cells caused sunlight to scatter and be absorbed at the surface, rather than penetrate to the bottom of the bays where the eelgrass grows.

Eelgrass, a submerged, rooted aquatic plant, is an important component of the coastal ecosystem of Long Island's inshore bays. Eelgrass beds are important because they provide a habitat for many juvenile fish and shellfish, particularly the bay scallop. Eelgrass plays an important role also in the movement of nutrients, oxygen, and

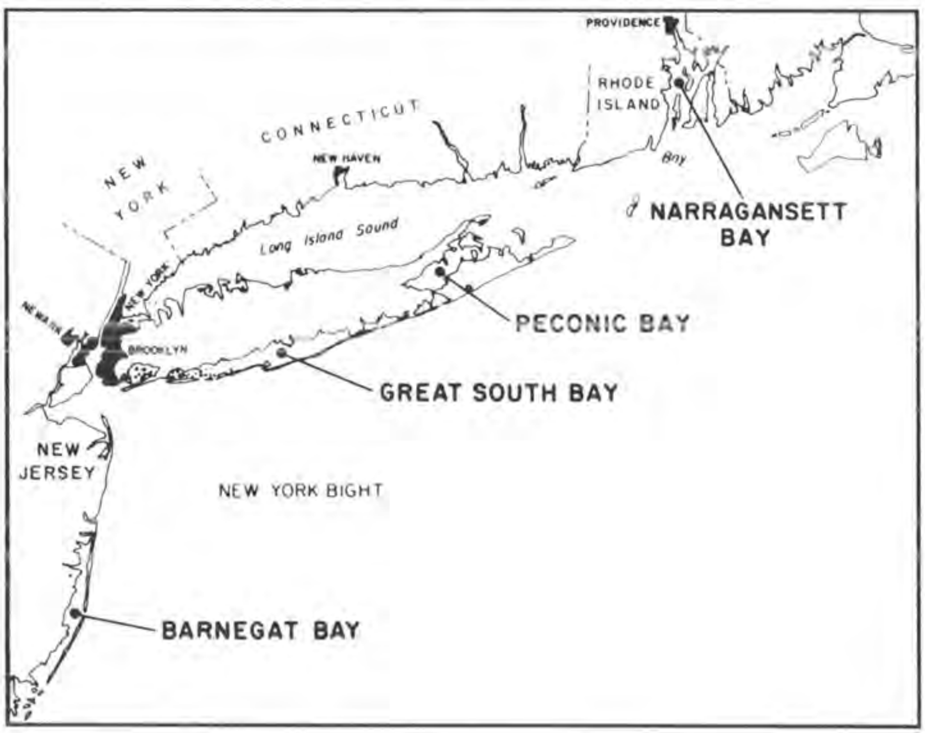

Figure 2. Regional map of northeast coastal areas including bays affected by the brown tide.

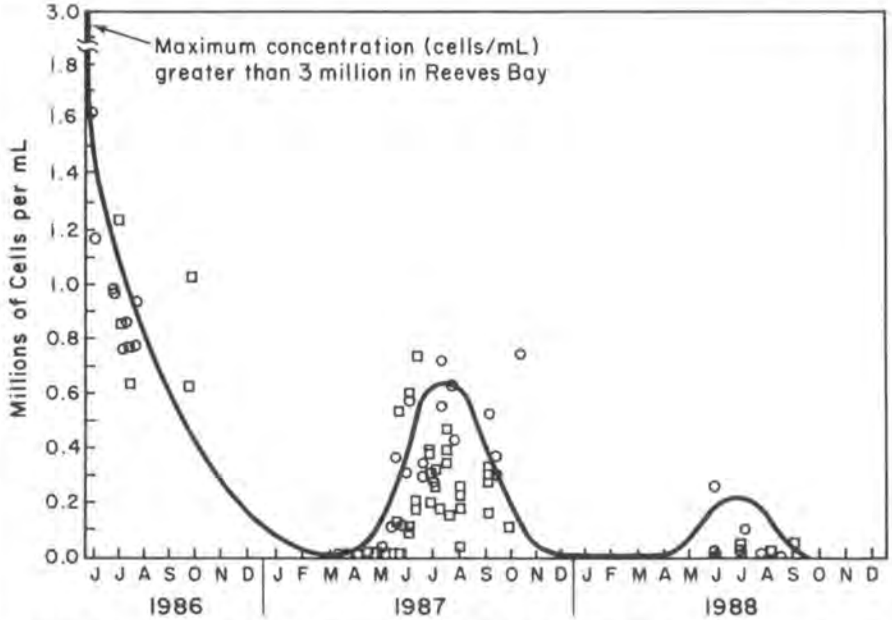

Figure 4. Brown Tide Cell Concentrations for Sites Sampled in Peconic and Great South Bays: 1986, 1987, and 1988
□ = Great South Bay sampling sites; ○ = Peconic Bays sampling sites.

The brown tide effectively eliminated the bay scallop fishery. There has been little or no commercial scallop fishery since 1985.

other important substances between bay sediments and overlying waters. Moreover, eelgrass dies off annually, and the subsequent decomposition of the dead eelgrass blades by bacteria plays an important role in the nutrient and energy cycles in coastal bays. Thus, a significant reduction in the abundance or distribution of eelgrass can produce major disruptions in the ecosystem of these bays.

The brown tide also destroyed populations of the commercially valuable bay scallop *Argopecten irradians irradians* (Fig. 3). While shellfish normally feed on phytoplankton, the bay scallops were unable to feed adequately on the brown tide phytoplankton and, thus, starved to death. Even though the scallops were living in a rich "soup" during the brown tide, apparently, it was not one that nourished them. Similarly, in Narragansett Bay mussels were unable to feed on the brown tide and populations were severely reduced.

The bay scallop was an important seasonal crop for baymen on the eastern end of Long Island. Annual harvests of this species ranged from 250,000-500,000 pounds of meats worth well over $1 million. The 1985 and 1986 occurrences of the brown tide on Long Island effectively eliminated the bay scallop fishery. There has been little or no commercial scallop fishery since 1985. Beginning in 1986, artificially cultured juvenile bay scallops have been planted annually in several areas in the Peconic Bays system in an effort to reestablish the bay scallop population of the region. These attempts have only just recently (1989) met with some success.

In 1986 the brown tide recurred throughout the summer months in the same Long Island embayments. During the summers of 1987 and 1988, the brown tide blooms returned in Long Island and in Barnegat Bay, New Jersey but at diminishing levels (Fig. 4). Since 1985, brown tide blooms have not returned to Narragansett Bay, and since 1988, they have not returned to Long Island bays.

Figure 3. Bay scallop, *Argopecten irradians irradians*. The scallop populations in Long Island bays were destroyed by the brown tide.
Photo by R. George Rowland

THE BLOOM SPECIES
What was the Brown Tide and Where did it Come From?

The species of phytoplankton causing the brown tide had not been previously known to exist and was only recently identified, using the scanning electron

In some coastal waters, the brown tide was present but never bloomed. This implies that the blooms were triggered by a unique set of environmental events in only a few bay systems.

microscope (Fig. 1). It was given the name, *Aureococcus anophagefferens*. *A. anophagefferens* was first grown in the laboratory in culture during the summer of 1986. Individuals of this species are tiny, roundish single cells with a small indentation on the cell surface but have few other distinguishing features. It is among the group of phytoplankton species having the smallest cells. Many species within this group have remained largely unidentified to date and are too often ignored by scientists.

Scientific techniques used to detect the presence of *A. anophagefferens* have already indicated their presence in northeast U.S. coastal waters that were never affected by the brown tide blooms. This implies that this species has been generally present in other coastal embayments and that the blooms were triggered by a unique set of environmental events in only a few bay systems. However, other scientific analyses comparing *A. anophagefferens* to other very small plankton have, along with electron microscope analyses and pigment analyses, shown that *A. anophagefferens* has characteristics similar to a widespread, open ocean phytoplankter, *Pelagococcus subviridis*. The possibility that *A. anophagefferens* is also an open ocean species and has only recently been introduced into nearshore waters is an important issue which remains to be resolved.

ENVIRONMENTAL CONDITIONS FAVORING THE BROWN TIDE

Two-Phases of Rainfall Patterns

The first year of the bloom, 1985, coincided with the start of a drought, which continued for several years. In this year, rainfall on Long Island was the third lowest annual level in the last 37 years (Fig. 5A).

The pattern of rainfall over this time appeared to be important to the formation of the blooms. Low rainfall during the winter and spring months of 1985 and 1986 reduced the freshwater input into the bays through runoff and groundwater flow. Thus, salinity rose during this time.

This period of low rainfall was followed in early summer by abnormally large pulses of rain and resultant large freshwater input into the bays. Along with the runoff water, organic compounds such as fertilizers and other chemicals in the ground, were carried into the coastal marine waters. It was during this time that the brown tide blooms began (Fig. 5B).

While salinities typically are about 25 parts per thousand (ppt) during the summer, during the bloom summers they were generally closer to 30 ppt. In contrast, temperature showed a similar pattern for the three summers of 1986, 1987, and 1988, which does not appear to be different from previous summers nor

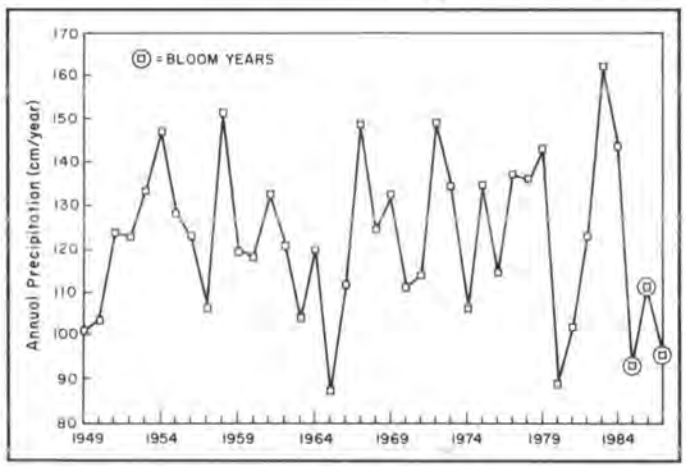

Figure 5A. Total Monthly Precipitation Measured at Brookhaven National Laboratory, Long Island, from 1949 to 1987.

Note: The first year of the bloom, 1985, coincided with the start of a drought. The reasons why the brown tide did not occur in other drought years are explained in the text.

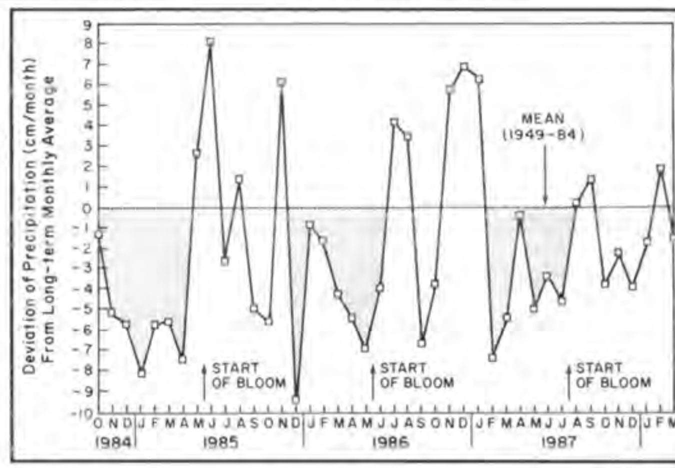

Figure 5B. Precipitation Plotted as Deviations from the Mean for Each Month from October 1984 to March 1988.

Note: Initiation of blooms in each year occurred after a two-phase period of first, low rainfall, followed by a period of heavy rainfall.

to have contributed to the brown tide. Laboratory studies with cultures of *A. anophagefferens* that have adapted to grow at 30 ppt show a severe reduction in growth rate below 28 ppt as compared to rapid growth at 30 ppt.

Role of Winds and Rain, Tides, Currents, and Waves

The water in these bays is usually poorly flushed by coastal water moving through the inlets and connections with the Atlantic Ocean, and the residence time for water can be on the order of weeks to months. During the winter-spring period just prior to the initiation of the brown tide bloom of 1985, meteorological conditions affected the flow of water into these bays so as to further decrease the flushing rate. The longer residence time for the bay water might have allowed a build up of brown tide populations which were starting to grow due to the favorable conditions in the bays. This build-up of brown tide cells during reduced flushing might have also contributed to the development of larger bloom populations.

Historically, a diverse group of small species make up the phytoplankton community in Long Island bays during the summer. But the distinctive feature of the brown tide was the dominance for several months of *A. anophagefferens* (greater than one billion cells/liter, or about 90% of the total phytoplankton).

Brown Tide Able to Outcompete Other Species

The ability of *A. anophagefferens* to outcompete all other phytoplankton species and maintain dominance throughout the summer may be related to its requirement for specific nutrients. Studies of brown tide cultures in the laboratory have shown that this species requires trace elements, substances called chelators[1], and organic nutrients for growth. Some of these requirements are different from those of many common coastal phytoplankton species. Culture studies have also shown that *A. anophagefferens* has the ability to take up organic compounds such as glucose and the amino acid, glutamic acid, very competitively relative to other species of phytoplankton that live in the same waters (Fig. 6A and B).

The added carbon sources might contribute to the rapid growth of *A. anophagefferens* when light needed for photosynthesis is severely diminished as during the bloom periods. The ability of *A. anophagefferens* to photosynthesize under low light levels relative to other species might be particularly important, since recent evidence indicates that this species' light absorption characteristics and pigments are more similar to those of a deep-dwelling oceanic phytoplankton species than to a coastal form.

Reduced Grazing by Zooplankton

Another important factor to be considered is the ability of the zooplankton, small marine animals which consume phytoplankton, to feed on the brown tide and thus control the size of their populations. Studies evaluating the rate of consumption of the brown tide by certain zooplankton species have shown that, although many species are capable of consuming and growing on *Aureococcus anophagefferens*, they appear to selectively avoid doing so if other phytoplankton species are available. This selective consumption would have enhanced the populations of the brown tide and severely reduced the densities of other phytoplankton species, allowing the brown tide to dominate the community.

[1]Chelators are a type of organic chemical which bind to trace metals, thereby affecting their chemistry.

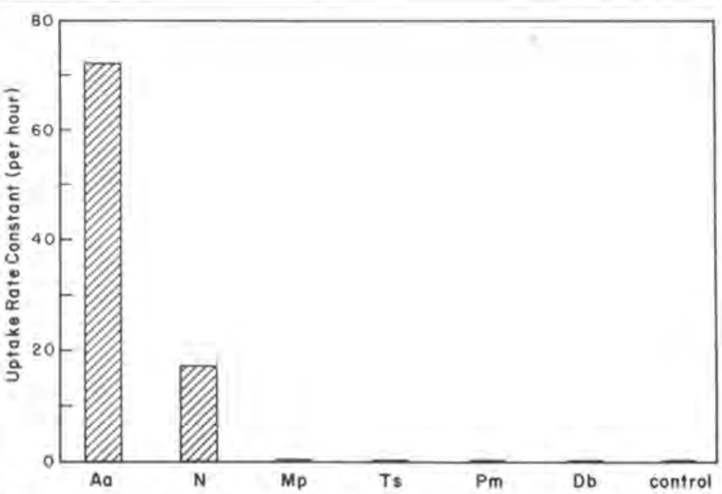

Figure 6A. Glutamic Acid Uptake Rate Constants (Per Unit Cell Volume) for Six Species of Algae*

Note: Glutamic acid in this experiment (concentration = 10 uM) was the sole nitrogen source. Of the six species, only the brown tide (Aa) had a distinctive advantage in its ability to take up and utilize glutamic acid and glucose (see Fig. 6B).

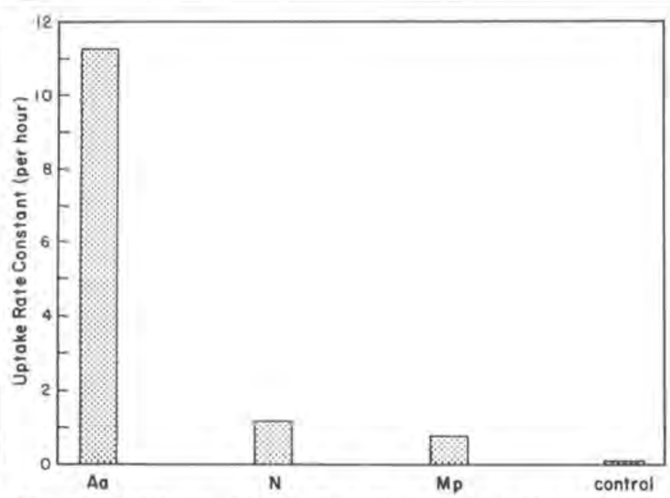

Figure 6B. Glucose Uptake Rate Constants (Per Unit Cell Volume) for Three Species of Algae*

***Aa** = *Aureococcus anophagefferens*
N = *Nannochloris sp*
Pm = *Prorocentrum minimum*
Mp = *Minutocellus polymorphus*
Db = *Ditylum brightwellii*
Ts = *Thalassiosira pseudonana*

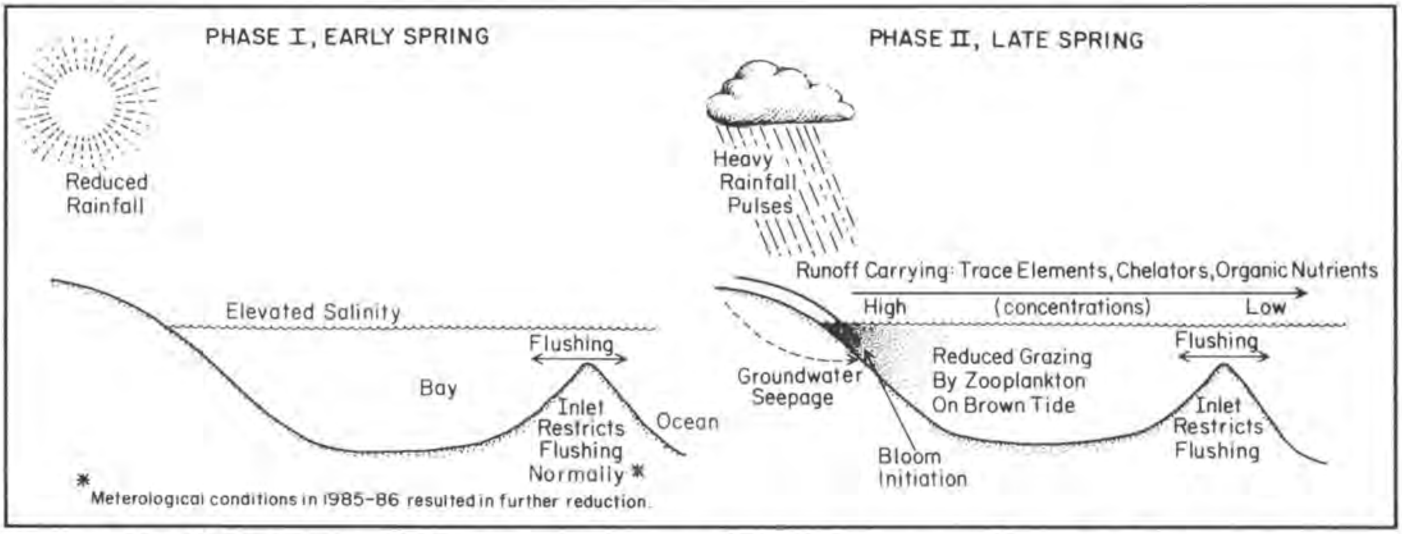

Figure 7A and B. Model Depicting the Two Phases of Conditions Conducive for Initiation of Brown Tide Blooms

CONCLUSIONS

Based on our current knowledge, it appears that brown tide blooms most likely resulted from several factors including: (1) higher than average salinities in the bays during the early summers of 1985 and 1986; (2) pulses of freshwater runoff or groundwater seepage containing organic, and possibly certain inorganic, micro-nutrients—compounds essential to the rapid growth of the *A. anophagefferens*; (3) retention and maintenance of large populations of brown tide cells within the bays as a result of normally reduced water circulation and further reductions in water circulation under bloom-year meteorological conditions; and (4) reduced grazing by zooplankton during the early stages of bloom initiation (see Fig. 7A and 7B). Although laboratory and field studies have demonstrated that many very small zooplankton can consume and grow on *A. anophagefferens*, these animals appear not to eat it if other species are available.

Combined Natural and Human Influences

Since *A. anophagefferens* is a species not previously known to bloom, environmental conditions that contributed to the blooming could in part be related to new human influences in these bays such as the recently introduced chelators, used in detergents to replace phosphates which were banned. Other human influences may come from new lawn treatments containing both fertilizers and pesticides.

Drought conditions, elevated salinities, pulses of rain delivering specific nutrients in runoff waters to the bay, along with restricted flushing of bay waters, may have set the scenario for the formation of a phytoplankton bloom. The conditions then needed for continued, unabated growth of the brown tide species during the early summer of 1985 would have been filled by both input of specific chemicals and grazing that selected species other than the brown tide.

> *Editor's note*: In early August, at the time this bulletin went to press, the brown tide reappeared in several bays of eastern Long Island (see The New York Times, Long Island Weekly article, "Brown Tide Back, Puzzling Scientists Seeking Its Source," August 5, 1990). One of this bulletin's authors, Dr. Elizabeth Cosper, continues researching this bloom phenomenon.

SUGGESTED FURTHER READING

Brown tide and other novel blooms. The besieged bays of the world. T. Bell, Sea Frontiers, 239-245 (July-August 1989).

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