Sea Grant
New York

Brown Tide Research Initiative

Report #9 March 2006

It is a pleasant summer day and you are on your way to Peconic Bay to enjoy Long Island's great outdoors, but you see that the water is coffee brown! That fall, you read about the collapse of the bay scallop fishery. This was the situation two decades ago in 1985 when brown tide first appeared in Long Island's Peconic and south shore bays. Since 1985, many investigations have uncovered a great deal about brown tide's biology, ecology and impacts.

This report is the final installment in the Brown Tide Research Initiative (BTRI) Report Series and summarizes what is known about brown tide. Drs. Christopher Gobler, Darcy Lonsdale and Greg Boyer have recently synthesized brown tide research conducted since 1997 in a peer-reviewed scientific paper published in the journal *Estuaries* (2005). In this report, we present a generalized version of that document along with other brown tide related information.

INSIDE

THE BROWN TIDE STORY

FIRST APPEARANCE

In 1985, blooms of the small phytoplankton, *Aureococcus anophagefferens* (figure 1), occurred in the eastern and southern bays of Long Island, NY, and in Narragansett Bay, RI. *A. anophagefferens* may also have been part of a co-occurring bloom in Barnegat Bay, NJ. In New York's Peconic and south shore estuaries, and in Narragansett Bay, *A. anophagefferens* abundance exceeded one million cells per milliliter and turned the estuarine water brown, prompting the name "brown tide." *A. anophagefferens* has also been identified as a member of phytoplankton communities in estuarine areas from Maine to Florida. This species has also been found on the continental shelf off the northeastern United States. Bays in New Jersey, Maryland, Virginia and Saldanha Bay, South Africa have also experienced brown tides suggesting that these blooms are expanding southward (figure 2).

Continued on page 2

Brown Tide Research Initiative

Report #9

Writer: Patrick Dooley

Editors: Gregory Boyer
Barbara Branca
Darcy Lonsdale
Christopher Gobler
Jack Mattice
Cornelia Schlenk
BTRI Steering Committee Members

Designers: Barbara Branca
Loriann Cody

BTRI Steering Committee:

Cornelia Schlenk, Chair, NYSG

Richard Balla, US Environmental Protection Agency, representing the Peconic National Estuary Program (PEP)

Susan Banahan, NOAA Coastal Ocean Program

Kenneth Koetzner, NYS Dept. of Environmental Conservation, representing New York State

Dr. Robert Nuzzi, Suffolk County Dept. of Health Services, representing Suffolk County

Roger Tollefsen, NY Seafood Council, representing SSER and PEP Citizens Advisory Committees

William Wise, Marine Sciences Research Center, Stony Brook University, representing the South Shore Estuary Reserve (SSER) Council

Sea Grant New York

New York Sea Grant is part of a national network of universities meeting the challenging environmental and economic needs of the coastal ocean and Great Lakes regions. Unique among the 32 Sea Grant programs nationwide because it has both marine and Great Lakes shorelines, New York Sea Grant engages in research, education, and technology transfer to promote the understanding, sustainable development, utilization, and conservation of our diverse coastal resources. NYSG facilitates the transfer of research-based information to a great variety of coastal user groups which include businesses, federal, state and local government decision-makers and managers, the media, and the interested public.

New York Sea Grant Staff
Director: Dr. Jack Mattice
Associate Director: Dale Baker
Assistant Director: Cornelia Schlenk
Communicator: Barbara Branca
Project Assistant & BTRI
Outreach Specialist: Patrick Dooley

For a complete staff listing visit www.nyseagrant.org

Continued from cover

A. anophagefferens was likely a member of the phytoplankton community in the northeastern U.S. prior to 1985. This species was positively identified in preserved samples from Narragansett Bay dating back to 1982. Pigment signatures in sediments of the Peconic estuary suggest that *A. anophagefferens*, or a very similar alga, was present in the phytoplankton over the past 120 years. However, it seems Long Island bays have experienced sporadic brown tide events only since 1985. The last major bloom in the Peconic estuary occurred in 1995, while the south shore estuaries on Long Island have experienced blooms in varying degrees through 2004. Today, *A. anophagefferens* persists as a member of the phytoplankton community in these bays.

IMPACTS

Although brown tide has no known impacts on human health, severe brown tides have negatively affected important estuarine nursery grounds by reducing eelgrass beds, commercially important shellfisheries, and plankton that are a base component of the food web. An intense brown tide can reduce or prevent sunlight from reaching the bottom of the bay. Reduced sunlight can inhibit the growth of attached plants such as eelgrass (*Zostera marina*) that serve as a vital nursery for finfish and shellfish, and as a refuge for many other estuarine organisms.

These impacts have resulted in losses to the local economy. In the Peconic and Gardiners Bays, the bay scallop (*Argopecten irradians*) fishery was the hardest hit with an estimated loss of up to $3.3 million annually. Hard clams (*Mercenaria mercenaria*) were also affected. Adult hard clams stopped feeding when brown tide cells reached approximately 35,000 cells per milliliter; most juvenile hard clams died under bloom conditions. Fortunately, those clams that survived usually resumed growth after the bloom ended. The chronic recurrence of brown tides in Great South Bay over the past two decades may also have affected the ability of hard clams to recover from a population decline first noted in the late 1970s.

There does not seem to be a direct effect of brown tide on finfish, but there is evidence that *A. anophagefferens* can negatively affect some zooplankton whose growth and egg production were lower during a brown tide. While some zooplankton can consume *A. anophagefferens*, it is at lower rates when compared to their consumption of other phytoplankton normally present in these bays and estuaries.

ABOUT *AUREOCOCCUS ANOPHAGEFFERENS*

After some debate regarding *A. anophagefferens*'s classification in the phylogenic "tree of life," the available genetic evidence, physiological traits, and morphological characteristics place *A. anophagefferens* in the class Pelagophyceae of the phylum Chrysophyta (brown algae). Most pelagophytes are oceanic, relatively rare, and do not form blooms. However, oceanic pelagophytes and *A. anophagefferens* do share many other traits including the ability to grow under low light conditions that may exist in a turbid estuary and in low nutrient environments often found in the middle of the ocean.

It is important to understand the biology and the environmental conditions that allow *A. anophagefferens* to grow in order to predict when blooms might occur. *Aureococcus anophagefferens* is a microscopic alga (2-3 µm or 0.002-0.003 millimeters) whose name means "golden sphere causing cessation of feeding." It contains chloroplasts that absorb light for energy and can use carbon dioxide to obtain needed building blocks. On Long Island, *A. anophagefferens* commonly bloomed when bay water temperatures ranged between 15º and 25ºC (59º and 77ºF). At temperatures higher than 25ºC, the bloom often diminished. Although *A. anophagefferens* can survive in water with a low salinity, it grows best in water with salt concentrations approaching normal seawater. In addition, it seems to appear in embayments that have long water residence times where the water does not exchange quickly with ocean waters.

A. anophagefferens is also very adaptable in its use of light and can maintain high growth rates under low light situations where other algae are unable to survive. This ability to grow quickly under low light levels may give *A. anophagefferens* a distinct advantage over other phytoplankton.

ROLE OF NUTRIENTS IN BLOOM EVENTS

Most algal blooms, harmful or otherwise, are attributed to increased nutrient loading. The resulting elevated levels of dissolved inorganic nitrogen and/or phosphorus stimulate the growth of phytoplankton. Because nitrogen is usually the limiting nutrient in coastal marine ecosystems and the availability of its most common form, nitrate, plays a key role in many algal blooms, we will concentrate on it here.

For *A. anophagefferens*, there are two forms of dissolved nitrogen that are important to consider, organic and inorganic.

Continued on page 4

BTRI – A COORDINATED RESEARCH EFFORT

Prior to the start of BTRI research in 1996, research and monitoring were primarily funded through New York Sea Grant, the Suffolk County Department of Health Services and other various sources. Investigators from Stony Brook University, Brookhaven National Laboratory, Southampton College, and other institutions were involved. The Suffolk County Department of Health Services continues to monitor Long Island bays for harmful algal blooms including brown tide.

The BTRI involved two three-year (1996-1999 and 1999-2001) programs totaling $3 million in funding. They were developed to increase knowledge concerning brown tide by identifying the factors and understanding the processes that initiate and sustain brown tides. The National Oceanic and Atmospheric Administration's (NOAA) Coastal Ocean Program (COP) funded the BTRI programs while New York Sea Grant administered the projects. Funding for the second three-year effort came from the COP under the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) program. From its inception, the BTRI effort included workshops where investigators could coordinate their research projects allowing for the maximum use of resources. The initiative also developed a public outreach component that included this Report Series and periodic public symposia.

There were many coordinated research projects involving multiple investigators and institutions or agencies (see list page 9). Projects were solicited using national calls for proposals. They were chosen for funding through a rigorous peer review process that evaluated the science of the proposed work. The potential value and importance was determined by a BTRI Steering Committee of state, local and government agency representatives, and citizen's groups (see sidebar on page 2 for a list of steering committee members).

Many new findings resulted from the BTRI and other studies, but it is important to pull them all together. Presenting a comprehensive state of the knowledge picture is the purpose of this last step of the BTRI. Further background information and copies of the BTRI Reports 1-9 and the Estuaries (2005) journal article are available at the BTRI website: www.seagrant.sunysb.edu/BTRI.

Continued from page 3

Most algae, including *A. anophagefferens*, can directly utilize dissolved inorganic nutrients such as nitrate and nitrite (common components in fertilizers), but not dissolved organic nutrients such as urea or amino acids (from waste and breakdown of cells). Urea and amino acids must first be converted to nitrate or nitrite for use by most algae. However, *A. anophagefferens* has all the enzymes needed to use both dissolved inorganic and organic sources of nitrogen without this intermediate step.

When dissolved inorganic nitrogen levels are high, other algae out-compete *A. anophagefferens* and can bloom while *A. anophagefferens* remains at background levels. In contrast, brown tides in Long Island waters often occurred when the levels of dissolved inorganic nitrogen were low. In fact, the concentrations of dissolved organic carbon and dissolved organic nitrogen often decreased during a brown tide suggesting that *A. anophagefferens* can obtain both carbon and nitrogen from these compounds. This additional source of food and energy could circumvent the need for light and photosynthesis in this environment. This ability may give *A. anophagefferens* a competitive edge over other, strictly photosynthetic, algae in low light situations.

Now that we know that the type of dissolved nitrogen is significant relative to a brown tide, it is important to understand the sources of dissolved inorganic and dissolved organic nitrogen. Nitrogen sources to Long Island's estuaries include groundwater underflow, surface runoff, atmospheric deposition, and remineralization. The primary source of dissolved inorganic nitrogen to many of Long Island estuaries is in fact groundwater underflow. When groundwater underflow was high (e.g., a rainy spring) increases of dissolved inorganic nitrogen inputs would also be high so that phytoplankton other than *A. anophagefferens* would be favored. On the other hand, when groundwater underflow was low (e.g., a dry spring) dissolved inorganic nutrient inputs would also be low. Examination of an 11-year period in the Peconic Estuary showed that *A. anophagefferens* tended to bloom when groundwater underflow rates were below average.

Dissolved organic matter in brown tide-prone estuaries can also come from multiple sources. The most important sources of dissolved organic nitrogen for brown tide comes from the decay of phytoplankton in the water column and other organic matter in bottom sediments. As phytoplankton cells die, or are damaged, they leak organic nutrients into the surrounding water thus providing dissolved organic nitrogen that *A. anophagefferens* can use. Organic matter from dead or decaying phytoplankton, fish and other estuarine organisms also settles on the bottom where it is transformed into dissolved organic nitrogen in the sediments. The estuary bottom, or benthic sediments, can then act as a source of dissolved organic matter as the nutrients leave the sediments and move into the overlying water column. The dissolved organic nitrogen and carbon in these benthic sediments can be ten times greater than in the water column, and, in shallow estuaries such as those on Long Island, the release of nutrients from bottom sediments can have a strong influence on water chemistry and nutrient content.

While low inorganic and high organic nitrogen levels can have a direct effect on fostering brown tides, dissolved inorganic nitrogen loading may also promote *A. anophagefferens* growth, but indirectly. Inorganic nitrogen stimulates growth of other algae. As these other phytoplankton and seaweeds grow, they remove inorganic nitrogen from the water. When their cells die, they supply dissolved organic matter to the water through cell leakage and decomposition. This cycle of algae growth, depletion of dissolved inorganic nitrogen, and cell death releasing organic nutrients can then fuel a subsequent *A. anophagefferens* bloom.

Since *A. anophagefferens* can utilize both dissolved inorganic and organic nutrients present in the water column, it can thrive and bloom under conditions when other algal species cannot.

Another influence on brown tides is the competition for nutrients between *A. anophagefferens* and other organisms such as bacteria, benthic algae, and eelgrass. Sometimes the environmental conditions become just right for a particular species of phytoplankton to dominate. This is referred to as that species' "niche." In late spring, such a niche opens up in the Long Island bays for small algae the size of *A. anophagefferens*. *Synechococcus*, a photosynthetic blue-green algae similar in size to *A. anophagefferens*, typically fills this picoalgae-niche (or small size-class niche) in non-brown tide years. Both *Synechococcus* and *Aureococcus* may compete for available nutrients. The nutrient type (organic versus inorganic) may be the deciding factor that determines which species eventually dominates and blooms. For example, if the groundwater underflow is high (e.g., a wet spring), then inorganic nutrient inputs to the estuary would be high and *Synechococcus* would be expected to bloom. A year with low groundwater underflow would lead to low inorganic nitrogen inputs to the estuary and would favor a bloom of *A. anophagefferens.*

CELL GROWTH AND LOSS

If *A. anophagefferens* is to bloom and dominate the phytoplankton community, its net population growth must be higher than that of the competing phytoplankton species. The net population growth is determined by how fast the *A. anophagefferens* cells multiply (that is, their growth rate) and how fast they disappear from either grazing or death and decay. In Long Island bays, *A. anophagefferens* can double its population in 12 hours. The fact that there have been brown tides indicates that *A. anophagefferens's* growth can keep pace with or even exceed the growth of many co-occurring algae.

Figure 1: Under high magnification is an ***Aureococcus anophagefferens*** cell with a distinct cell wall. The photomicrograph shows a phytoplankton assemblage that includes the circular brown tide cells and elongated diatoms. Photo composite by Anita Kusick, photos by Robert Waters and Robert Andersen.

Continued on page 8

A TYPICAL LONG ISLAND BAY ESTUARY WITHOUT A BROWN TIDE AND DURING A BROWN TIDE.

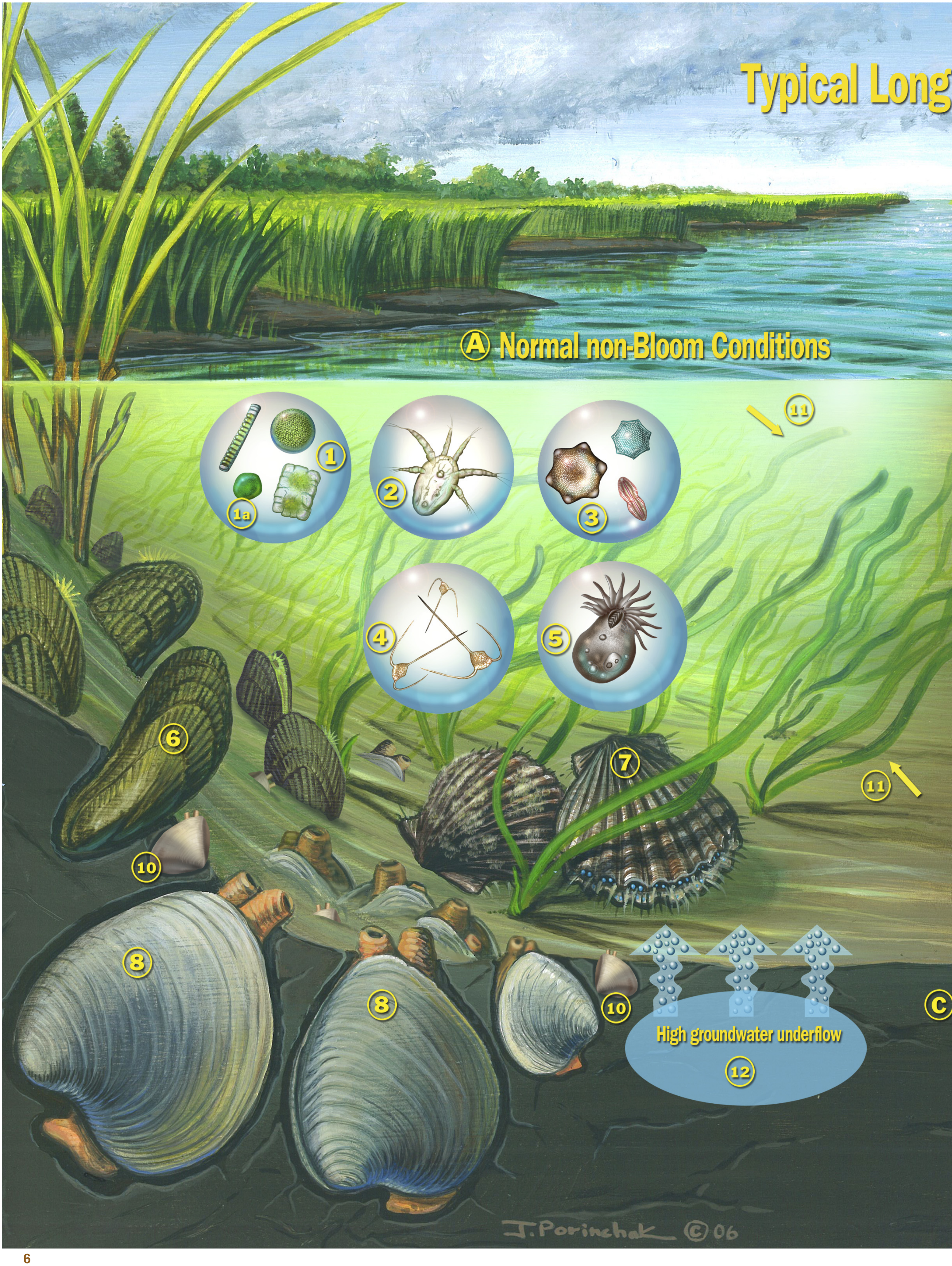
(OVERLEAF, PAGES 6-7)

ILLUSTRATION BY JAN PORINCHAK.

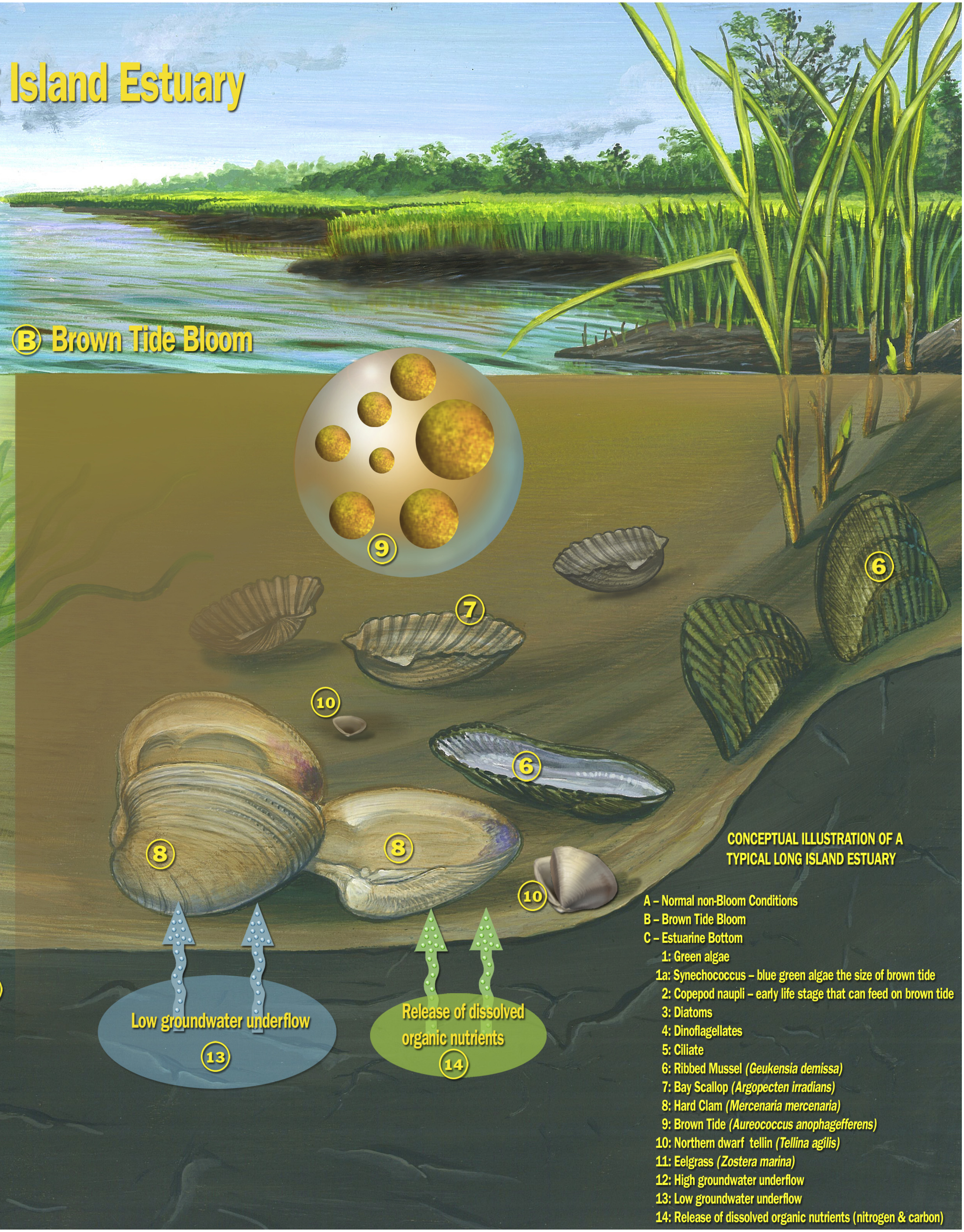
In estuarine environments, such as Great South Bay, Long Island, New York, multiple species of phytoplankton normally mix and coexist as a community forming the base of the food chain. Depending on the location and time of year, there can be tens or even hundreds of different phytoplankton species in an estuary at any given time. Phytoplankton populations fluctuate up or down, depending on environmental conditions such as light, nutrients, and grazing pressure from zooplankton and other filter feeders. When phytoplankton species reach a high abundance, they make up an algal bloom. Such multi-species blooms are normal and important in maintaining estuarine environments, removing carbon dioxide from the atmosphere, adding dissolved oxygen to the water, and they serve as a food source for fish stocks and other organisms in the estuary. Year after year, seasonal phytoplankton blooms help keep estuarine environments thriving.

Under normal light conditions, *A. anophagefferens*, like other algae, can use inorganic nutrients for growth and reproduction although at a lower rate compared to the co-occurring algae species. When sufficient inorganic nitrogen is present, other algae within the phytoplankton community out-compete *A. anophagefferens*, which remains a minor member of the phytoplankton community.

Late spring and early summer typically are associated with reductions in groundwater flow rates and decreased inputs of dissolved inorganic nitrogen. Springtime algal blooms sometimes use up available dissolved inorganic nitrogen. As a non-brown tide phytoplankton bloom ends, its organic matter is recycled. When light conditions are low or when inorganic nutrient supplies are depleted, *A. anophagefferens* has the ability to utilize organic compounds, such as dissolved organic nitrogen (e.g., urea) and carbon to grow. A combination of low light levels, mostly organic nutrients, low inorganic nutrients and reduced grazing pressure sets the stage for *Aureococcus anophagefferens* to bloom.


Typical Long
Ⓐ Normal non-Bloom Conditions
11
1
1a
2
3
4
5
6
7
11
10
8
8
10
C
High groundwater underflow
12
J. Porinchak ©06

Island Estuary



CONCEPTUAL ILLUSTRATION OF A TYPICAL LONG ISLAND ESTUARY

A – Normal non-Bloom Conditions
B – Brown Tide Bloom
C – Estuarine Bottom
- 1: Green algae
- 1a: Synechococcus – blue green algae the size of brown tide
- 2: Copepod nauplii – early life stage that can feed on brown tide
- 3: Diatoms
- 4: Dinoflagellates
- 5: Ciliate
- 6: Ribbed Mussel *(Geukensia demissa)*
- 7: Bay Scallop *(Argopecten irradians)*
- 8: Hard Clam *(Mercenaria mercenaria)*
- 9: Brown Tide *(Aureococcus anophagefferens)*
- 10: Northern dwarf tellin *(Tellina agilis)*
- 11: Eelgrass *(Zostera marina)*
- 12: High groundwater underflow
- 13: Low groundwater underflow
- 14: Release of dissolved organic nutrients (nitrogen & carbon)

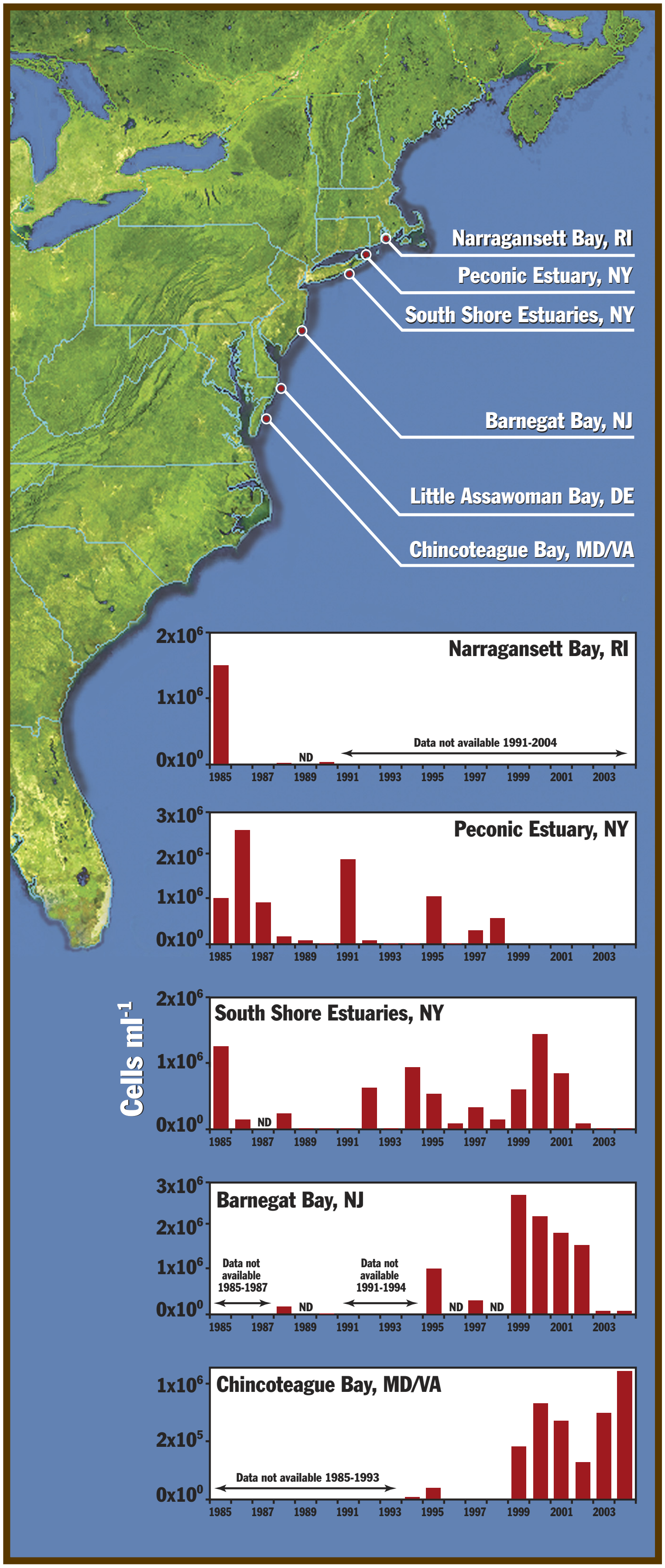


Figure 2: Brown tide locations along the north Atlantic shore and maximum annual abundances of ***Aureococcus anophagefferens***. Graphs supplied by Chris Gobler, artwork by Loriann Cody. Cell ml^{-1} = cells per milliliter.

Continued from page 5

During a phytoplankton bloom, important sources of cell loss include grazing by zooplankton and benthic filter feeders such as hard clams. Recent field and laboratory studies have shown that small zooplankton (less than 0.2 millimeters) readily graze on *A. anophagefferens*. If these grazing animals could consistently consume *A. anophagefferens* at a rate faster than its growth rate, their grazing could help prevent a bloom. Benthic filter feeders, such as hard clams (*Mercenaria mercenaria*) and the dwarf surf clam (*Mulinia lateralis*), also feed on phytoplankton (including *A. anophagefferens*) and zooplankton. This grazing pressure from benthic filter-feeding shellfish can be dramatic. When hard clam populations were at their peak in Great South Bay in the 1970s, it has been estimated that the entire volume of Great South Bay was "filtered" through the benthic shellfish once every three days. With the dramatic decline in the hard clam population of Great South Bay, by 1993 the estimated time to filter the bay increased to once every 25 days. Field and laboratory results confirmed the importance of these benthic filter feeders in helping to control *A. anophagefferens* populations. In tank experiments, under certain conditions, water filtration by hard clams prevented *A. anophagefferens* from blooming.

These results suggest that the reduction in benthic filter feeders, such as hard clams, has caused a shift of the dominant grazers on phytoplankton from benthic filter feeders to the zooplankton grazers in the water column. Accordingly, a combination of a healthy population of benthic filter feeders and pelagic grazers could potentially control *A. anophagefferens* abundance and help prevent a brown tide.

TOXICITY AND MORTALITY

While dense blooms of *A. anophagefferens* can cause the demise of shellfish such as bay scallops, a specific toxic agent or substance remains unidentified. Since *A. anophagefferens* is similar nutritionally to other algae that are considered good food sources, mortality of grazing shellfish and some zooplankton during a brown tide was not dietary in nature. Although laboratory and field studies produced conflicting results, it was clear that *A. anophagefferens's* "toxicity" varied with different geographical locations and environments such as nutrient availability or physical conditions.

The toxic effect *A. anophagefferens* has on bivalve grazers depends upon the abundance of cells in the environment, the species of bivalve (e.g., hard clam or blue mussel) and the bivalve's age or developmental stage (e.g., larvae, juvenile or adult). In the case of hard clams, juveniles seem to be more sensitive to *A. anophagefferens* than adults. Putting this in context with *A. anophagefferens* abundance, below 20,000 cells per milliliter there seemed to be no impact and hard clams grazed on *A. anophagefferens.* When a bloom reached between 20,000-35,000 cells per milliliter, the effects tended to be sub-lethal and involved inhibited feeding and slower growth rates. At cell abundances above 150,000 cells per milliliter, larvae and juvenile growth stopped. Above 400,000 cells per milliliter, *A. anophagefferens* became lethal to most larval and juvenile hard clams. Survivors, however, could recover after the bloom subsided. It appears that *A. anophagefferens* produces a chemical substance that stops the activity of the hair-like filter-feeding structures, called cilia, thereby inhibiting feeding and causing affected organisms to starve.

For some zooplankton (i.e., ciliates and copepods), brown tide may be a poor nutritional food source. A diet containing more than 98% *A. anophagefferens* did not support growth and survival of certain zooplankton species that grazed on brown tide. If, however, there were alternate food choices available, such as other algae mixed in with the *A. anophagefferens*, no detrimental effects on the zooplankton were observed.

MITIGATION

What can be done, if anything, to prevent or mitigate the effects of brown tide? Advances in our understanding of the ecology of *A. anophagefferens* suggest several possible management options. These are unproven at this time, however, and any mitigation strategy based on these suggestions should be fully tested before implementation as part of a management plan.

Within limits, shellfish such as hard clams can feed on *A. anophagefferens* and offer one possible control mechanism. Recent results show that high numbers of hard clams can keep *A. anophagefferens* abundances in check. Thus, reestablishment of the hard clam population bay-wide would increase water filtration rates and could help prevent brown tides.

A few recent studies suggest that viruses may provide a different approach to controlling brown tides. Unlike benthic filter feeders,

Continued on page 10

CORE BTRI (I & II) INVESTIGATORS

The following list represents the initial BTRI (I & II) funded institutions and investigators. Some investigators have since changed affiliations so please contact NYSG if help is needed in reaching any of these scientists.

Bermuda Biological Station for Research, Bermuda
Dr. Michael W. Lomas

Bigelow Laboratory for Ocean Sciences, ME
Dr. Robert A. Andersen
Dr. Maureen Keller (deceased)
Dr. Charles O'Kelly
Dr. Michael Sieracki

Brookhaven National Laboratory, NY
Dr. Julie La Roche

NOAA National Marine Fisheries, Northeast Fisheries Science Center, CT
Dr. Richard A. Robohm
Dr. Gary Wikfors

Old Dominion University, VA
Dr. John Donat

Stony Brook University, NY
Dr. Robert M. Cerrato
Dr. Christopher Gobler
Dr. Darcy J. Lonsdale
Dr. Sergio Sañudo-Wilhelmy

SUNY College of Environmental Science and Forestry, NY
Dr. Gregory L. Boyer

University of Delaware, DE
Dr. David A. Hutchins

University of Maryland Horn Point Environmental Laboratories, MD
Dr. Jeffrey C. Cornwell
Dr. Patricia M. Glibert
Dr. Todd M. Kana
Dr. Hugh L. MacIntyre

University of Rhode Island, RI
Dr. Theodore J. Smayda

Woods Hole Oceanographic Institution, MA
Dr. David A. Caron

Continued from page 9

viruses are very specific to the algal species they target. Recent work has identified viral strains that can infect and kill *A. anophagefferens*. Viruses can produce hundreds of offspring within their short life cycles and have the potential to eliminate a harmful algal bloom in a short time period. On the negative side, one would have to factor in the possibility that their use may select for viral resistant strains of *A. anophagefferens*.

Flocculent materials such as clays can successfully mitigate some algal blooms. Moderate success has been obtained using clays to reduce *A. anophagefferens* abundances in the laboratory. However, the secondary impacts of these clays on benthic organisms and the natural ecosystem are unknown. In addition, the typical shallow nature of Long Island bays may intensify any adverse effects. For example, bay turbulence could result in clays remaining in the water column for longer periods than where the water is deeper.

Increasing tidal exchange between brown tide-prone estuaries and the coastal ocean may also remove brown tide biomass, by flushing it out. The ratio of dissolved inorganic nitrogen to dissolved organic nitrogen could also be changed helping to decrease *A. anophagefferens's* growth rates. Increased flushing apparently ended "green tides" during the 1950s in these same bays when an inlet was unintentionally formed. The formation and maintenance of a flushing method (e.g., an inlet) would require tremendous logistical and engineering challenges and costs and may have other, undesirable impacts.

Direct alteration of nutrients by reductions in nitrogen entering these bays may provide another mitigation possibility. In the short term, reductions in nutrients (i.e., inorganic nitrogen) could lead to an environment that favors the growth of *A. anophagefferens* (e.g., higher dissolved organic nitrogen compared to inorganic nitrogen). However, over longer periods, the reduced nitrogen loading would facilitate a reduction in the dissolved organic nitrogen and reduce the likelihood of a brown tide. Nutrient manipulations might also change the structure of planktonic communities in that lower concentrations of nitrogen and phosphorus relative to silica might be more favorable for the growth of other, possibly beneficial, phytoplankton. However, the potential suite of benefits and ancillary effects of such nutrient manipulations have not been established and possible changes to the entire ecosystem must be carefully considered.

Clearly, these options should be carefully weighed and evaluated in a larger context than just brown tides before any managerial or control option might be selected.

Continued on page 12

BIBLIOGRAPHY

This list of publications includes journal articles and theses from NYSG- and BTRI-funded projects. For additional brown tide references please see the literature cited section in Gobler, C.J., D.J. Lonsdale, and G.L. Boyer (2005) A review of the causes, effects, and potential management of harmful brown tide blooms caused by *Aureococcus anophagefferens* (Hargraves et Sieburth) *Estuaries*, 28(5):726-749.

1 Bailey, C.J. and R.A. Andersen (1999). Analysis of clonal cultures of the brown tide algae *Aureococcus* and *Aureoumbra* (Pelagophyceae) using 18S rRNA, rbcL and RUBISCO spacer sequences. *Journal of Phycology* 35: 570-574.

2 Boissonneault-Cellineri, K.R., M. Mehta, D.J. Lonsdale and D.A. Caron (2001). Microbial food web interactions in two Long Island embayments. *Aquatic Microbial Ecology* 26:139-155.

3 Boyer, G. L., D. B. Szmyr, and J. A. Alexander (1999). Iron and nitrogen nutrition in the brown tide organism *Aureococcus anophagefferens*. In: J.L. Martin and K. Haya (eds) Proceedings of the Sixth Canadian Workshop on Harmful Marine Algae. Can Tech Rep. Fish. *Aquatic Science* 2261:11-13.

4 Boyer, G. L., and L. Brand (1998). Micro nutrient availability and trace metal chelator interactions. Physiological Ecology of Harmful Algal Blooms, D.M. Anderson; A.D. Cembella; G. M. Hallegraf, (eds.), Springer-Verlag, Heidelberg. pages 489-508.

5 Breuer, E., S.A. Sañudo-Wilhelmy and R. A. Aller (1999). Distributions of trace metals and dissolved organic carbon in an estuary with restricted river flow and a brown tide. *Estuaries* 22 603-615.

6 Bricelj, V.M. and D.J. Lonsdale (1997). *Aureococcus anophagefferens*: Causes and ecological consequences of brown tides in U.S. mid-Atlantic coastal water. *Limnology and Oceanography* 42(5): 1023-1038.

7 Bricelj, V.M., S.P. MacQuarrie, and R.A. Schaffner (2001). Differential effects of *Aureococcus anophagefferens* isolates ("brown tide") in unialgal and mixed suspensions on bivalve feeding. *Marine Biology* 139(4): 605-615.

8 Caron, D.A., C.J. Gobler, D.J. Lonsdale, R.M. Cerrato, R.A. Schaffner, J.M. Rose, N.J. Buck, G. Taylor, K.R. Boissonneault, and R. Mehran (2004). Microbial herbivory on the brown tide alga, *Aureococcus anophagefferens*: results from natural ecosystems, mesocosms and laboratory experiments. *Harmful Algae* 3:439-457

9 Cerrato, R.M., D.A. Caron, D.J. Lonsdale, J.M. Rose, and R.A. Schaffner (2004). Experimental approach to examine the effect of the northern quahog, *Mercenaria mercenaria*, on the development of blooms of the brown tide alga, *Aureococcus anophagefferens*. *Marine Ecology Progress Series* 281:93-108

10 Giner, J.-L. and X. Li (2000). Stereospecific Synthesis of 24-Propylchlesterol Isolated from the Texas Brown Tide. *Tetrahedron* 56(49):9575-9580.

11 Giner, J.-L., and G.L. Boyer (1998). Sterols of the brown tide alga *Aureococcus anophagefferens. Phytochemistry* 48:475-477.

12 Giner, J.-L., J.A. Faraldo, and G.L. Boyer (2003). Unique Sterols of the toxic dinoflagellate *Karenia brevis* (Dinophyceae): A defensive function for unusual marine sterols. *Journal of Phycology* 39:315-319

13Giner, J.-L., X. Li, and G.L. Boyer (2001). Sterol composition of *Aureoumbra legunensis*, the Texas brown tide alga. *Phytochemistry* 57:787-789.

14Gobler, C.J. (1999). A biogeochemical investigation of *Aureococcus anophagefferens* blooms: Interactions with organic nutrients and trace metals. Ph.D. Dissertations, Stony Brook University, NY, 179 pages.

15Gobler, C.J., and S.A. Sañudo-Wilhelmy (2001). Temporal variability of groundwater seepage and brown tide bloom in a Long Island embayment. *Marine Ecology Progress Series* 217:299-309.

16Gobler, C.J., D.A. Hutchins, N.S. Fisher, E.M. Cosper and S.A. Sañudo-Wilhelmy (1997). Release and bioavailability of C, N, P and Fe following viral lysis of a marine chrysophyte. *Limnology and Oceanography* 42(7): 1492-1504

17Gobler, C.J., D.A. Hutchins, N.S. Fisher, E.M. Cosper, and S.A. Sañudo-Wilhelmy (1997). Cycling and bioavailability of elements released by viral lysis of a marine phytoplankter. *Limnology and Oceanography* 42, 1492-1504.

18Gobler, C.J., D.J. Lonsdale, and G.L. Boyer (2005). A review of the causes, effects, and potential management of harmful brown tide blooms caused by *Aureococcus anophagefferens* (Hargraves et Sieburth). *Estuaries* 28(5):726-749

19Gobler, C.J., J.R. Donat, J.A. Consolve III, and S.A. Sañudo-Wilhelmy (2002). Physicochemical speciation of iron during coastal algal blooms. *Marine Chemistry* 77:71-89.

20Gobler, C.J., M.J. Renaghan and N.J. Buck (2002). Impacts of nutrients and grazing mortality on the abundance of *Aureococcus anophagefferens* during a New York brown tide bloom. *Limnology and Oceanography* 47(1):129-141.

21Gobler, C.J. and S.A. Sañudo-Wilhelmy (2001). Effects of organic carbon, organic nitrogen, inorganic nutrients, and iron additions on the growth of phytoplankton and bacteria during a brown tide bloom. *Marine Ecology Progress Series* 209:19-34.

22Greenfield, D.I. (2002). The influence of variability in plankton community composition on the growth of juvenile hard clams *Mercenaria mercenaria* (L.) Ph.D. Dissertation, Stony Brook University, NY, 189 pages.

23Greenfield, D.I. and D.J. Lonsdale (2002). Mortality and growth of juvenile hard clams *Mercenaria mercenaria* during brown tide. *Marine Biology* 141(6):1045-1050.

24Greenfield, D.I., D.J. Lonsdale, and R.M. Cerrato (2005). Linking phytoplankton community composition with juvenile-phase growth in the northern quahog *Mercenaria mercenaria* (L.). *Estuaries* 28:241-251

25Greenfield, D.I., D.J. Lonsdale, R.M. Cerrato, and G.R. Lopez (2004). Effects of background abundances of *Aureococcus anophagefferens* (brown tide) on growth and feeding in the bivalve *Mercenaria mercenaria*. *Marine Ecology Progress Series* 272:171-181.

26Kana, T M., M W. Lomas, H. L. MacIntyre, J. C. Cornwell and C. J. Gobler (2004). Stimulation of the brown tide organism, *Aureococcus anophagefferens*, by selective nutrient additions to *in situ* mesocosms. *Harmful Algae* 3:377-388.

27Laetz, C.A. (2002). Reconstructing the growth of hard clams, *Mercenaria mercenaria*, under brown tide conditions. Master's Thesis, Stony Brook University, NY, 57 pages.

28Lomas, M. W., T. M. Kana, H. L. MacIntyre, J. C. Cornwell (2004). Interannual variability of *Aureococcus anophagefferens* in Quantuck Bay Long Island: Natural test of the DON hypothesis. *Harmful Algae* 3: 389-402

29Lomas, M.W. (2002). Temporal and spatial dynamics of urea uptake and regeneration rates and concentrations in Chesapeake Bay. *Estuaries* 25(3): 469-482.

30Lomas, M.W., P.M. Glibert, D.A. Clougherty, D.R. Huber, J. Jones, J. Alexander, and E. Haramoto (2001). Elevated organic nutrients ratios associated with brown tide algal blooms of *Aureococcus anophagefferens* (Pelagophyceae). *Journal of Plankton Research* 23(12):1339-1344.

32MacIntyre, H. L., M. W. Lomas, J. Cornwell, D. J. Suggett, C. J. Gobler, E. W. Koch and T. M. Kana (2004). Mediation of benthic-pelagic coupling by microphytobenthos: An energy- and material-based model for initiation of blooms of *Aureococcus anophagefferens*. *Harmful Algae* 3: 403-437.

33Magaletti, E. (1998). Detection and characterization of cell cycle-related proteins in the brown tide alga *Aureococcus anophagefferens*: a potential tool for growth rate estimations. Master's Thesis, Stony Brook University, NY, 41 pages.

34Mehran R. (1996). Effects of *Aureococcus anophagefferens* on microzooplankton grazing and growth rates in the Peconic Bays system, Long Island NY. Master's Thesis, Stony Brook University, NY, 55 pages.

35Milligan, A.J. and E.M. Cosper (1997). Growth and photosynthesis of the "brown tide" microalga *Aureococcus anophagefferens* in subsaturating constant and fluctuation irradiance. *Marine Ecology Progress Series* 153:67-75.

36Mulholland, M.R., C.J. Gobler, and C. Lee (2002). Peptide hydrolysis, amino acid oxidation, and nitrogen uptake in communities seasonally dominated by *Aureococcus anophagefferens*. *Limnology and Oceanography* 47(4): 1094-1108.

37Nichols, D.B. (1999). Iron and nitrogen utilization in the brown tide alga, *Aureococcus anophagefferens*. Master's Thesis, State University of New York, College of Environmental Science and Forestry, NY, 158 pages.

38Nichols, D.B., M.F. Satchwell, J.E. Alexander, N.M. Martin, M.T. Baesl, and G.L. Boyer (2000). Iron nutrition in the brown tide alga, *Aureococcus anophagefferens*: Characterization of a ferric chelate reductase activity. Harmful Algal Blooms, Hallegraeff, G., et al (Eds), Intergovernmental Oceanographic Commission of UNESCO 2001, pages 340-343.

390'Kelly, C.R., M.E. Sieracki, E.G. Thier, and H.C. Hobson (2003). A transient bloom of *Ostreococcus* (Chlorophyta, prasinophyceae) in West Neck Bay, Long Island, New York. *Journal of Phycology* 39(5): 850-854

40Schaffner, R.A. (1999). The role of suspension feeding bivalves in the initiation and control of *Aureococcus anophagefferens* blooms. Master's Thesis, Stony Brook University, NY, 86 pages.

41Sieracki, M.E., C.J. Gobler, T.L. Cucci, E.C Thier, I.C. Gilg, M.D. Keller (2004). Pico- and nanoplankton dynamics during bloom initiation of *Aureococcus* in a Long Island, NY bay. *Harmful Algae* 3(4):459-470

If you have any questions about brown tide, would like a copy of ***Reports #1, 2, 3, 4, 5, 6, 7*** or ***8,*** or would like to be added to our mailing list, please contact Patrick Dooley at New York Sea Grant (patrick.dooley@stonybrook.edu or 631-632-9123) .

You may also read these reports by visiting our website: www.seagrant.sunysb.edu

This publication may be made available in an alternative format and is printed on recycled paper.

SUMMARY

Brown tide, *Aureococcus anophagefferens*, cells are present along the entire Atlantic coast of the United States. Large blooms of these tiny algae first appeared in 1985 in Narragansett Bay and Long Island embayments. In the past decade, brown tides have appeared southward in mid-Atlantic estuaries of New Jersey, Delaware, Maryland and Virginia. Blooms of *A. anophagefferens* are most likely to occur in shallow estuaries with reduced freshwater flow, high salinities and low rates of exchange with the ocean. Since *A. anophagefferens* can exploit either inorganic or organic nutrients, it can potentially out-compete other co-occurring phytoplankton under some circumstances.

In a typical brown tide scenario, the bloom is preceded by a non-*A. anophagefferens* spring phytoplankton bloom supported by the high flow of inorganic nutrients such as nitrate in groundwater. *A. anophagefferens* abundance is insignificant during this spring bloom. After a few weeks, the spring groundwater input is reduced and light penetration through the water column decreases as the spring phytoplankton bloom density increases. Then, the non-brown tide phytoplankton bloom eventually subsides or dies off, releasing dissolved organic nitrogen to the system. Since *A. anophagefferens* is adapted to grow under low light conditions and can utilize the available dissolved organic nutrients, it proliferates as the waning algal bloom uses up the inorganic nutrients and shades the water column with its biomass. The reduced groundwater underflow combined with an organically enriched environment provide ideal conditions for the brown tide, allowing it to out-compete other species that rely on inorganic nutrients alone and higher light levels for photosynthesis. Predation on *A. anophagefferens* by some benthic and pelagic grazers can control *A. anophagefferens* and could help prevent a bloom.

Thus, looking at the whole picture of what is known about *A. anophagefferens* confirms that brown tides appear to be caused by a combination of factors that tie together in a unique way. Research during the BTRI has identified several possibilities for control of brown tides.

Sea Grant
New York
Brown Tide Research Initiative

Bringing Science to the Shore

121 Discovery Hall
SUNY at Stony Brook
Stony Brook, NY 11794-5001