



## Long-term perspective on the dynamics of brown tide blooms in Long Island coastal bays

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### Abstract

Brown tide, a bloom of the picoplankter *Aureococcus anophagefferens*, first appeared in eastern Long Island (Suffolk County) waters in the late spring of 1985, at about the same time it emerged, although to a lesser degree, in Narraganset Bay, RI. Since then, it has recurred sporadically in Suffolk County, and blooms have been reported in New Jersey, Delaware, Maryland, and only one other area of the world, Saldanha Bay, South Africa. Bloom initiation and maintenance within Suffolk County appear to be related to *A. anophagefferens*' ability to use dissolved organic nitrogen (DON) during periods of limited dissolved inorganic nitrogen (DIN) availability. Factors controlling DIN availability include groundwater influx related to meteorological conditions, introduction of septic leachate from on-site wastewater treatment systems, and biological removal. The complexity of bloom dynamics is illustrated by a cascade of events in Great South Bay involving shellfish clearing rates, a macroalgal bloom, and microbial decomposition.

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### 1. Introduction

In June 1985 reports of brown water in a number of coastal embayments in Suffolk County were investigated by the Suffolk County Department of Health Services (SCDHS) and determined to be due to a massive bloom of a picoplankter, approximately 2.5  $\mu\text{m}$  in diameter. The organism was identified as a new chrysophyte, *Aureococcus anophagefferens* (Sieburth et al., 1988), and, ultimately, placed within the pelagophyceae (DeYoe et al., 1995, 1997). A similar bloom was noted in Narraganset Bay, Rhode Island (Smayda and Villareal, 1989). Monitoring of population dynam-

ics in Suffolk County embayments was initiated immediately, but did not become routine until the bloom reappeared the following year, and after its deleterious effect on shellfish populations, especially the Peconic Bay scallop, *Argopecten irradians*, was recognized (Tettelbech and Wenczel, 1993). Estimates of cell numbers in 1985 exceeded  $2 \times 10^6 \text{ ml}^{-1}$ , although identification and cell enumeration by light microscopy was difficult because of the organism's size and morphological similarity to other picoplankters.

Popular thinking on the apparent worldwide increase in harmful algal blooms (Anderson, 1989; Smayda, 1990; Hallegraeff, 1993) suggests that, in many areas, this increase might be a function of escalating nutrient input (Hecky and Kilham, 1988; Anderson et al., 2002). It has also been suggested that bloom causality may be a function not only of

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nutrient limitation as per Liebig's Law of the Minimum, but also of nutrient levels and ratios (Tilman, 1977; Smayda, 1989, 1997). Results of intensive long-term monitoring of bloom dynamics and water quality within estuaries in eastern Long Island, New York suggest that the *A. anophagefferens* brown tide blooms were a result, not of increased nutrients, but of variations in the proportions of organic and inorganic nutrients (LaRoche et al., 1997).

## 2. Materials and methods

Sub-surface (~0.5 m) water samples for salinity, nutrient (nitrogen, phosphorus, silica), phytoplankton and chlorophyll analysis were collected with a through-hull pump, or by dipping a 4-l wide-mouth Nalgene bottle. The pump was allowed to run for a minimum of 15 s at each station to rinse out remnants of water from the previous station, and the sampling bottle was rinsed at least twice with sample water before being filled.

Sample collection and handling protocol are described in detail in SCDHS (2004), and analytical procedures (Table 1) in SCDHS (1994, 2001, 2003).

### 2.1. Water quality

Salinity samples were collected in 250 ml wide-mouth polypropylene bottles and analyzed with Beckman Instruments RS-7 or RS-10 induction salinometers calibrated with I.A.P.S.O standard seawater. For nutrient samples, appropriate volumes were transferred to factory new 250 ml polyethylene bottles or, for dissolved constituents, to a filtration apparatus consisting of a magnetic funnel and flask, used with a 47 mm diameter Whatman GFC filter pad. As GFC filters had been used at the outset of the County sampling program, it was decided to continue their use rather than to change to the more commonly used, at present, GFF filters. All bottles were pre-rinsed with sample water, and the filtration apparatus was rinsed with filtrate at each station. The sample bottles for the dissolved (filtered) aliquots were rinsed with a portion of the filtrate prior to filling. With the exception of salinity, all samples were immediately placed on ice and delivered to the SCDHS Public and Environmental Health Laboratory (PEHL) on the day

Table 1  
Analytical methods employed by the SCDHS Public and Environmental Health Laboratory (PEHL)

Analyte	Method
Until August 2000 <sup>a</sup>	
Ammonia nitrogen	"Ammonia in Water and Seawater", Industrial Method No. 804-86T, Technicon (Bran + Leubbe)
Total Kjeldahl nitrogen	EPA Method 351.2, Colorimetric, Semi-automated Block Digester, AAIL, Storet No. 00625
Organic nitrogen	TKN minus Ammonia
Nitrate–nitrite nitrogen	"Nitrate/nitrite in Water and Sea Water", Industrial Method No. 818-87T, Technicon TrAacs 800 Method (Bran + Leubbe)
Ortho–phosphate	"Ortho Phosphate in Water and Sea Water", Industrial Method No. 812-86T, Technicon TrAacs 800 Method, Technicon (Bran + Leubbe)
Total phosphorus	Method 365.4, Colorimetric, Automated, Block Digester, AAIL, Storet No. 00665
After August 2000 <sup>b</sup>	
Ammonia nitrogen	Lachat Instruments "QuikChem" methods <sup>c</sup> 31-107-06-1-E
Nitrate–nitrite nitrogen	31-107-04-1-C
Total nitrogen	31-107-04-3-A
Organic nitrogen	Total nitrogen minus nitrate–nitrite and ammonia nitrogen
Ortho-phosphate	31-115-01-3-C
Total phosphorus	31-115-01-3-D

<sup>a</sup> Detailed information can be found in SCDHS, 1994.

<sup>b</sup> Detailed information can be found in SCDHS, 2003.

<sup>c</sup> Lachat Instruments Inc., 6645 West Mill Road, Milwaukee, WI 53218-1239.

of collection, where they were transferred to refrigerators, or frozen, until analyzed. Nutrient samples were analyzed with an auto-analyzer system according to USEPA (1983) approved methodology. As of August 2000, total and dissolved Kjeldahl nitrogen (TKN and TDKN), and total and dissolved phosphate (TPO<sub>4</sub> and TDPO<sub>4</sub>) analyses were replaced with procedures yielding total nitrogen (TN and TDN) and total phosphorus (TP and TDP) (SCDHS, 2001, 2003).

Samples for total chlorophyll analysis were collected by filtering a measured volume of water (150–500 ml, depending on the amount of suspended solids in the water column) through a GFC filter pad, taking care to avoid disruption of cells by limiting the vacuum applied to <100 mmHg. While filtering, 0.5 ml of a magnesium carbonate suspension was added to control pH (Parsons et al., 1984). Fractionated chlorophyll samples were obtained by first passing the water sample through a 10 µm nitex filter to remove the larger organisms, and then processing the filtrate as in the total sample. After final filtration, the pad was folded in half and placed into a labeled petri-slide, immediately wrapped in aluminum foil to prevent light degradation, frozen on dry ice, and delivered to the PEHL for analysis. Chlorophyll samples were analyzed with a Turner Designs Fluorometer Model 10-AU using EPA Method 445.0.

Water temperature and dissolved oxygen measurements were made with a bucket thermometer and YSI instruments.

## 2.2. Cell counts

From 1985 to 1987, samples for the analysis of *A. anophagefferens* abundance were collected in 500 ml wide-mouth polyethylene bottles, and preserved with lugols iodine (Nuzzi and Waters, 1989). The samples were concentrated in settling chambers, and cells counted by light microscopy with a Nikon inverted microscope (Utermöhl, 1938). The use of immunofluorescent methodology beginning in 1988 simplified cell identification, and undoubtedly increased count reliability. For this procedure, samples were collected in 15 ml polypropylene centrifuge tubes containing 0.5 ml of 25% glutaraldehyde, leaving a small air space in the tube to facilitate later mixing. Samples were transported to the laboratory and analyzed using the procedure described by Anderson et al. (1989). A Zeiss Axioplan universal research microscope, outfitted for epifluorescence, was used to count cells in 50–75 fields across two perpendicular transects at a magnification of 600×.

Immunofluorescence has been employed since 1988, with procedural modifications made over the years to enhance accuracy (Mahoney et al., 2003).

## 3. Area of study

While *A. anophagefferens* has been found in many areas along the US northeast coast, (Anderson et al., 1993), until recently, “Category 3” blooms, which have cell numbers in excess of  $2 \times 10^5 \text{ ml}^{-1}$  (Gastrich and Wazniak, 2002), were limited to the Peconic and South Shore Estuaries of Suffolk County in eastern Long Island (Fig. 1). The Peconic Estuary System (Fig. 2) is a typical river to sea estuary with an extremely small riverine input as compared to other estuaries of this type. It is approximately 639 km<sup>2</sup> divided into several interconnected bodies of water: Flanders, Great Peconic, and Little Peconic Bays, Shelter Island Sound, and Gardiners Bay from west to east, and numerous smaller peripheral embayments and tributaries. Except for portions of Gardiners Bay and Shelter Island Sound where water depth reaches ~29 m, the estuary is relatively shallow, and vertically well mixed (Bortman and Niedowski, 1998). The Peconic Estuary was sampled weekly from 1986 through 1999.

The South Shore Estuary (SSE) is a bar-built estuary consisting of Great South Bay (GSB), Moriches, Quantuck and Shinnecock Bays. GSB (Fig. 3), the largest embayment at about 40 km long, with an average depth of 1.3 m, and an area of about 223 km<sup>2</sup> (Bokuniewicz, 1991) is narrowly separated from Moriches Bay to the east. Quantuck Bay connects Moriches and, the easternmost, Shinnecock Bay. The entire system is vertically well mixed (Wilson et al., 1991). Unlike the Peconic Estuary, blooms, to one degree or another, occurred almost every year within the SSE. Until recently, the SSE, primarily GSB, was sampled less routinely than the Peconic Estuary, from seasonally to monthly, although sampling was increased during brown tide events.

## 4. Results

### 4.1. Peconic Estuary System

Cell numbers were highest in Flanders Bay where they exceeded  $2 \times 10^6 \text{ ml}^{-1}$  in 1985. Smaller blooms occurred June–August of subsequent years, decreasing in intensity each year through 1988. Since that time, except for West Neck Bay discussed below,

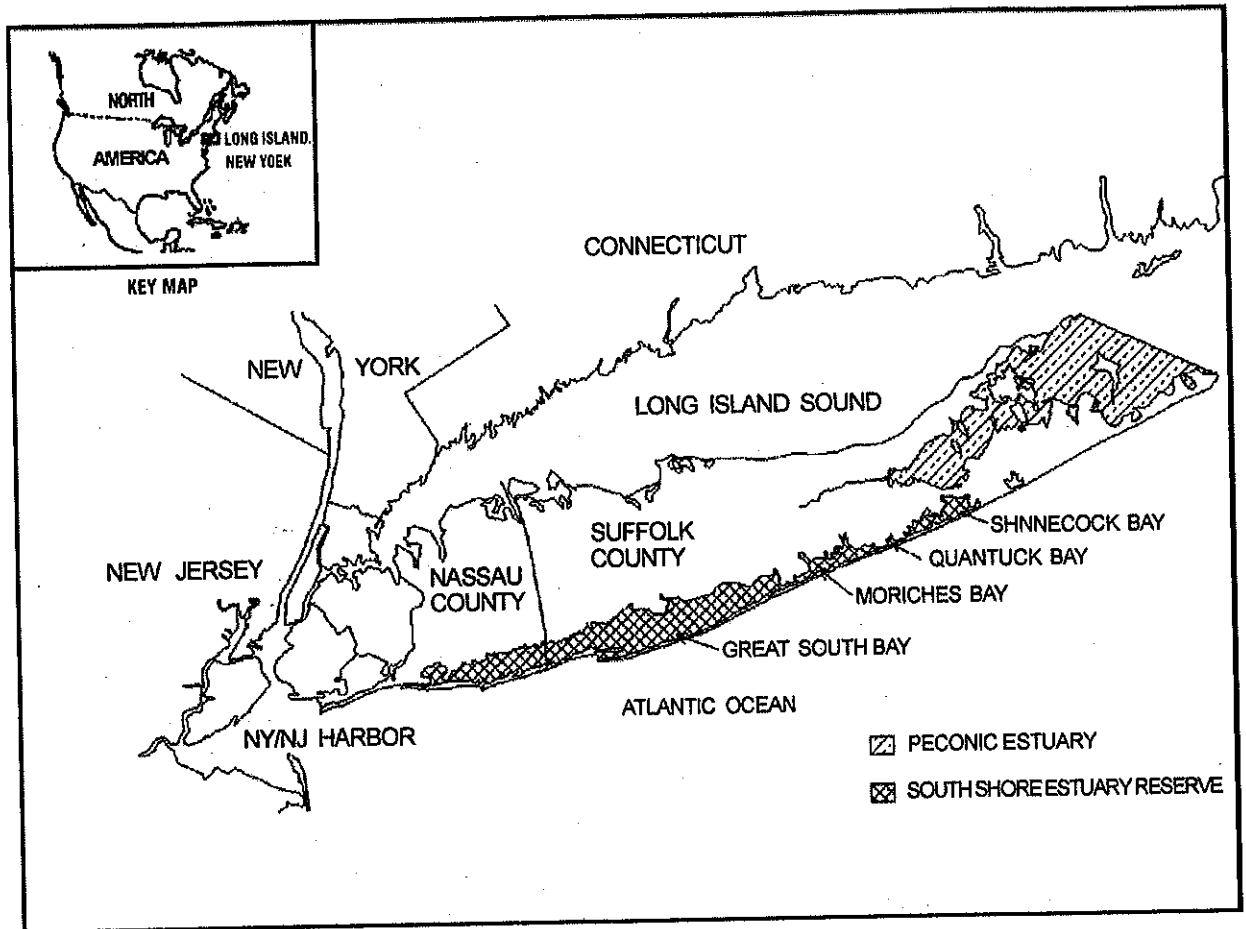


Fig. 1. Long Island, New York. Brown tide occurred only in the Peconic Estuary, and the Suffolk County portion of the South Shore Estuary Reserve.

category 3 blooms in the Peconic Estuary occurred only in 1991 and 1995 (average annual cell numbers are shown in Fig. 4a). Phytoplankton less than  $10\ \mu\text{m}$ , as determined by measuring both total and filtered chlorophyll, made up from about 25% to over 90% of the total population, the percentage being greatest during brown tide years.

Bloom dynamics differed in West Neck Bay, a small embayment on Shelter Island separated from the main estuary by a lengthy tributary that limits exchange of water with the estuary. Monitoring of this site was initiated in 1987 when the first bloom reported here, a category 3, was noted. Other category 3 blooms occurred here in 1991, 1992, and 1995, with smaller blooms in 1988, 1990, 1997, and 1998. Unlike Flanders Bay, in

West Neck Bay the proportion of phytoplankton less than  $10\ \mu\text{m}$  in size was greater than 90% of the total population almost every year (Fig. 4b).

#### 4.2. South Shore Estuary

BT blooms were sporadic in time and space in GSB (Fig. 5). Similar to the Peconic Estuary, the largest bloom recorded in GSB occurred in 1985, reaching cell numbers in excess of  $2 \times 10^6\ \text{ml}^{-1}$ . With few exceptions, the phytoplankton population in GSB always consisted of cells smaller than  $10\ \mu\text{m}$ .

The initial *A. anophagefferens* bloom was most intense in the eastern portion of GSB (Station 120), and in Great Cove (Station 190) on the bay's north cen-

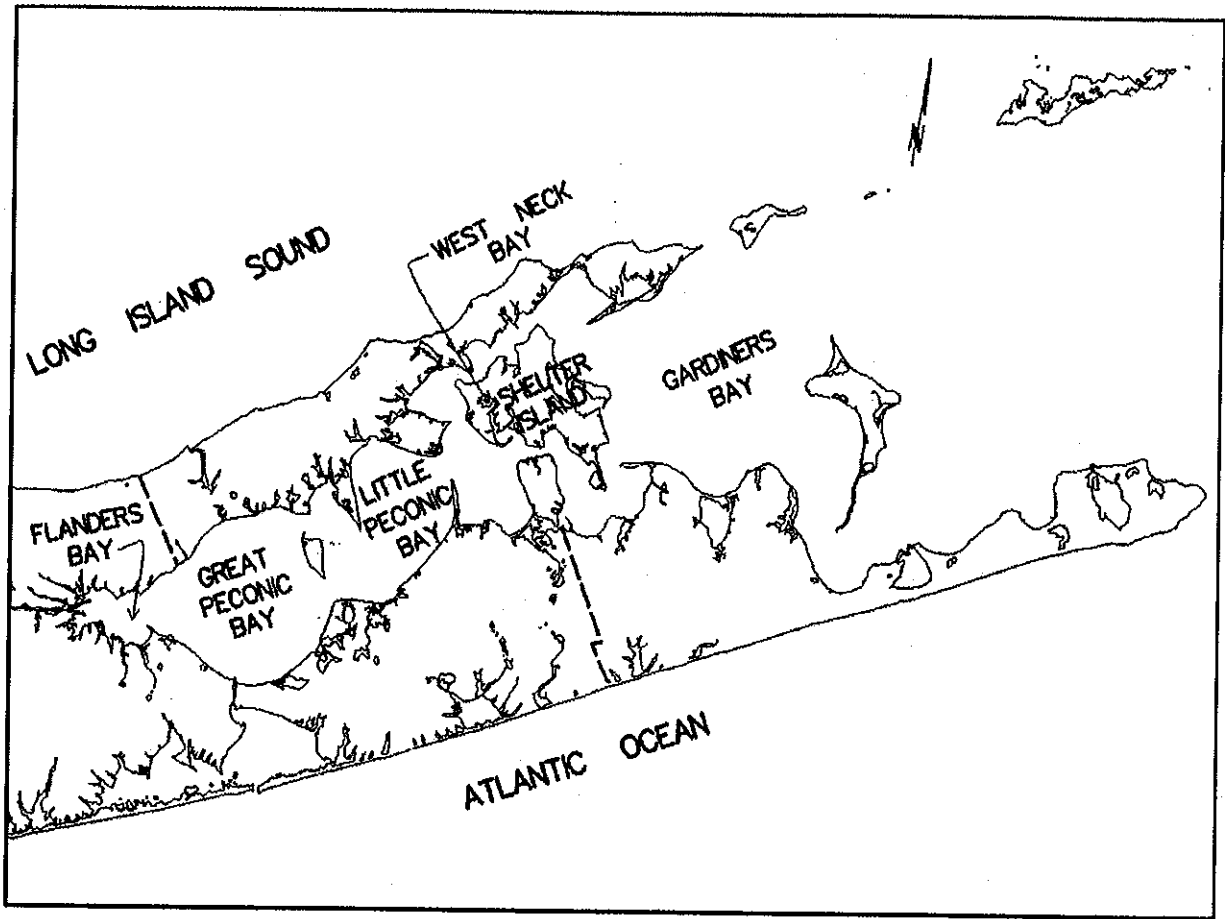


Fig. 2. The Peconic Estuary. Brown tide appeared to originate within Flanders Bay on the west and spread eastward. West Neck Bay on Shelter Island became a focus of brown tide beginning in 1987.

tral shore. It did not extend west of Fire Island Inlet, likely due to the circulation characteristics associated with this, and Jones Inlet to the west, resulting in the presence of a more oceanic water mass and greater flushing.

An unusual bloom, in terms of its onset, occurred in GSB during the fall and winter of 1999–2000, as opposed to the typical spring–summer period. *A. anophagefferens* was essentially absent January–August 1999, before appearing in September and reproducing rapidly throughout the fall and winter into December (Fig. 6). At its peak, the population reached over  $7 \times 10^5 \text{ ml}^{-1}$ .

The long-term data collected in GSB indicates a reduction of DIN values in the northwest region of

the bay by almost an order of magnitude over the 21-year period 1977–1997, likely resulting from sewerage of the adjacent land area (Southwest Sewer District, SWSD). Among eight near-shore bay stations for which sufficient data are available, the decrease in DIN is best exhibited at Station 240 (Fig 7a) adjacent to the Carills River, the major gaining stream within the SWSD. A similar decrease is not seen at stations outside the SWSD as represented by Station 110 (Fig. 7b).

*A. anophagefferens* cell numbers are typically low or undetectable throughout much of western Moriches Bay and eastern Shinnecock Bay, each of which have inlets to the Atlantic Ocean. Quantuck Bay exhibits increased cell densities that were are undoubtedly in-

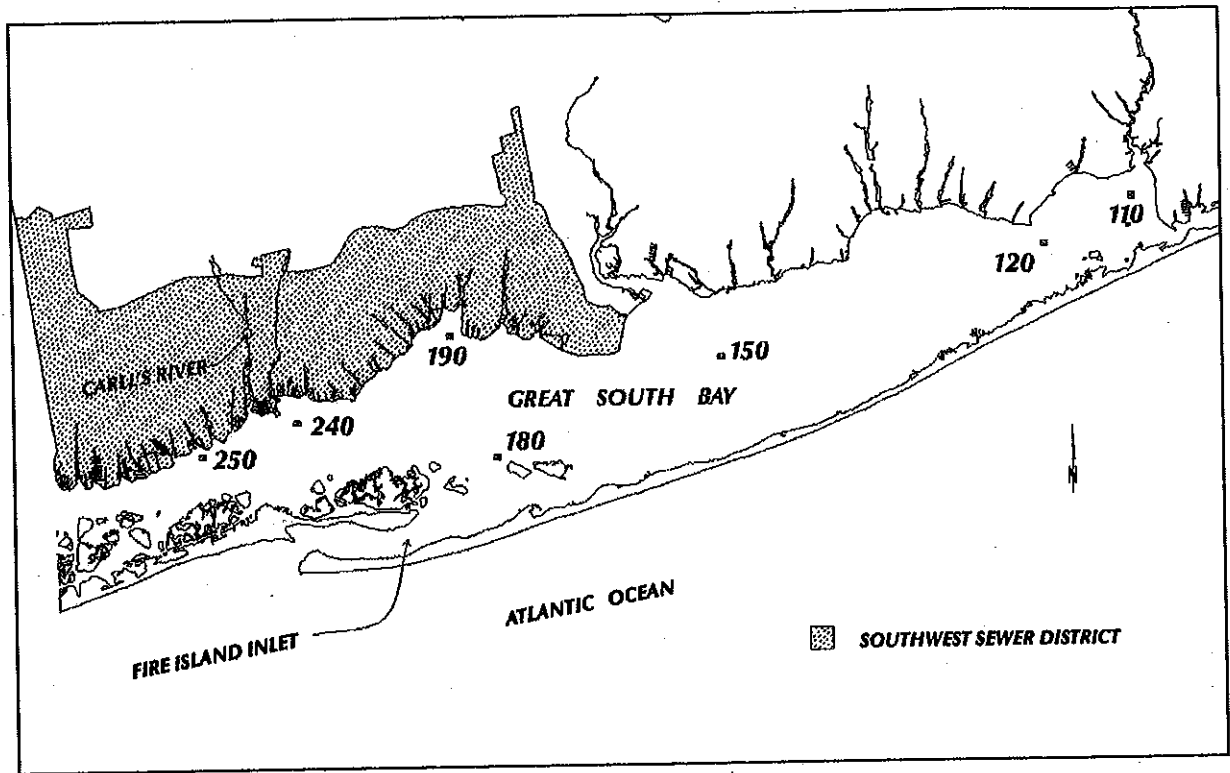


Fig. 3. Great South Bay, the largest embayment within the South Shore Estuary. The introduction of high DIN-containing groundwater along the northwest shore of the bay was eliminated with the advent of the Southwest Sewer District. Numbers indicate sampling locations.

tensified by limited flushing. Average annual cell numbers in Quantuck Bay exceeded  $5 \times 10^4 \text{ ml}^{-1}$  in eight of the 14 years (1989–2002) for which data are available (Fig. 8).

## 5. Discussion

### 5.1. Peconic Estuary

Bloom dynamics in the Peconic Estuary are hypothesized to be associated with a paucity of dissolved inorganic nitrogen (DIN), related to limited input of high nitrate containing groundwater—introduction of which is related to rainfall—and the ability of *A. anophagefferens* to utilize dissolved organic nitrogen (DON) (LaRoche et al., 1997). Several investigators (Keller and Rice, 1989; Dzurica et al., 1989; Lomas et al., 1996, 2001; Berg et al., 1997, 2002; Glibert

et al., 2001; Gobler and Sañudo-Wilhelmy, 2001a; Mulholland et al., 2002) have demonstrated this ability, with the latter two groups postulating a significant role for dissolved organic carbon (DOC) as well.

Although *A. anophagefferens* can utilize DIN for growth (DeYoe and Suttle, 1994; Szmyr et al., 1998; Gobler and Sañudo-Wilhelmy, 2001a), Keller and Rice (1989) and Nixon et al. (1994) found substantial *A. anophagefferens* growth in mesocosms containing low nitrogen and phosphorus levels but not in nitrate enriched systems. Gobler et al. (2002) noted a decrease in *A. anophagefferens* growth rates, accompanied by an increase in the growth rate of non-brown tide phytoplankton, with the addition of nitrate to field samples. This, along with field data clearly showing an inverse relationship between *A. anophagefferens* blooms and DON levels in the water column (LaRoche et al., 1997) suggest that *A. anophagefferens* has a competitive advantage during periods of limited DIN avail-

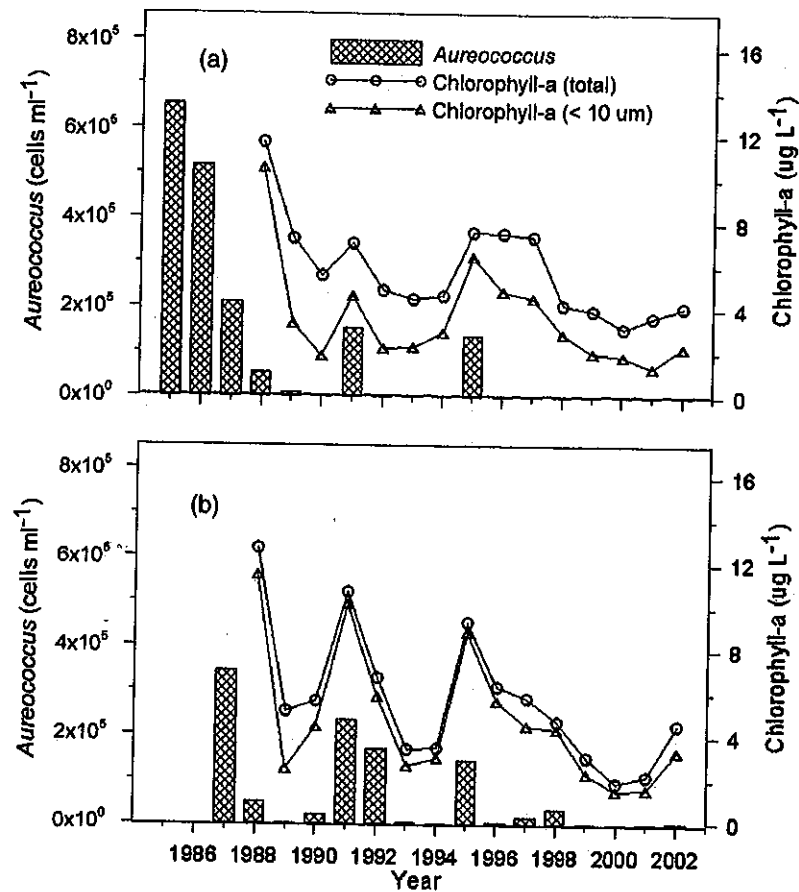


Fig. 4. Average annual concentrations of the brown tide organism, *A. anophagefferens*, and chlorophyll-*a* in Flanders Bay (a), and West Neck Bay (b) within the Peconic Estuary, 1985–2002. Note that blooms are not always coincident.

ability, but not when DIN is plentiful. The occurrence of brown tides during years when the supply of external DIN was relatively low, a mechanism controlled primarily by the introduction of agriculturally and, perhaps, residentially DIN-enriched groundwater into the estuary, associates the bloom with regional climatic events affecting rainfall. While *A. anophagefferens* can utilize inorganic nitrogen, other species might be expected to dominate during years in which groundwater flow, and therefore inorganic nitrogen supply, is adequate. LaRoche et al. (ibid.) hypothesize that, in the Peconic Estuary, *A. anophagefferens* dominates during low flow years by utilizing DON, a nutrient source not efficiently used by phytoplankton more typical of the area, resulting from the partial mineralization of the previous year's algal growth

(Berg et al., 1997). In West Neck Bay, Gobler and Sañudo-Wilhelmy (2001a,b) suggest that mineralization of the same year's spring bloom can initiate a summer brown tide bloom. While the timing of DON introduction may vary (inter or intra-annually), its availability, along with a paucity of DIN, appears to be essential for bloom initiation. That *A. anophagefferens* can maintain levels in excess of  $2 \times 10^6$  cells  $\text{ml}^{-1}$  for extended periods may be due to the utilization of organic metabolic products excreted by living cells, or released upon cell death, and is certainly related to its growth capabilities under low light conditions (Lomas et al., 1996; Berg et al., 1997), including that imposed by self-shading (Cosper et al., 1987). Visibly healthy cells have been found at 20 m depths during a major category 3 bloom (Nuzzi and Waters, 1989),

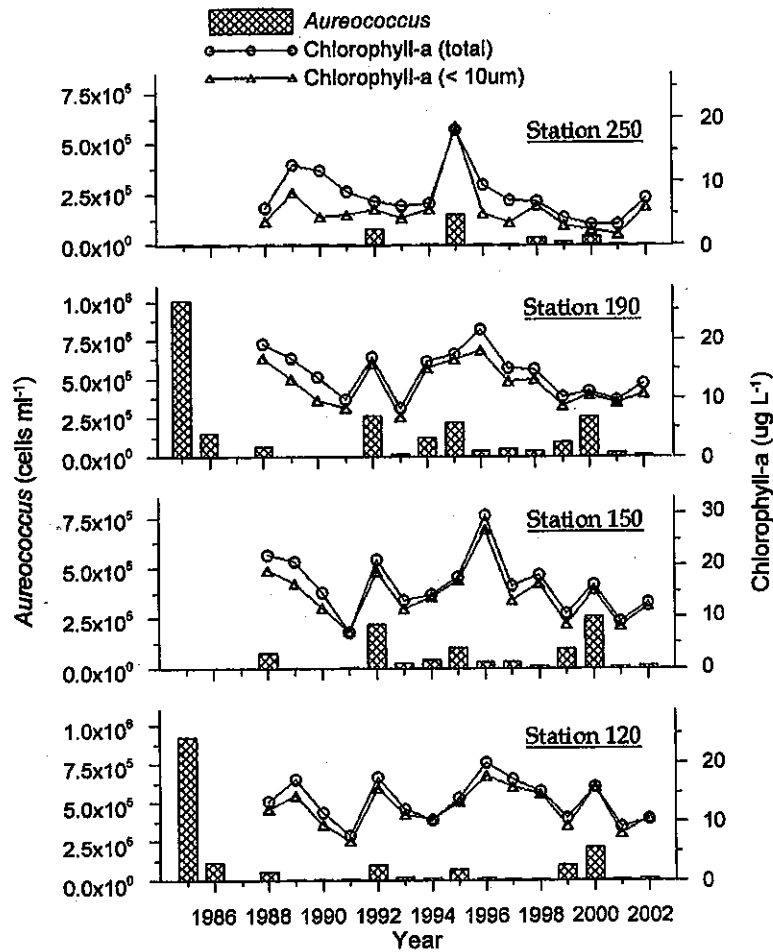


Fig. 5. Average annual concentrations of the brown tide organism, *A. anophagefferens*, and chlorophyll-a in Great South Bay, 1985–2002. From east to west, Stations 250 and 190 are located along the bays northern shoreline, Stations 150 and 120 are more centrally located (see Fig. 3).

and in samples collected beneath significant ice cover (unpublished data).

### 5.2. South Shore Estuary

While the database for the SSE is limited in comparison to the Peconic Estuary, several points suggesting the importance of nitrogen species, and groundwater input deserve attention.

Use of the SWSD Treatment Plant (STP) and collection system prevented the further introduction of DIN-containing wastes to the groundwater, and ultimately to the bay (Capone and Bautista, 1985;

Giblin and Gaines, 1990; Millham and Howes, 1994), by transporting wastewater to the STP, from which the treated effluent was carried several miles offshore into the Atlantic Ocean.

Connections to the STP began in 1981, totaling approximately 45,000 through 1986, and over 60,000 by 1999. Early years included connections of facilities in areas experiencing on-site system problems, and smaller sewage treatment plants that were abandoned with the advent of the STP. That the reduction in DIN concentrations was likely due to sewerage is suggested by the markedly greater degree of change in the northwest section of the estuary (Fig. 7a) as compared

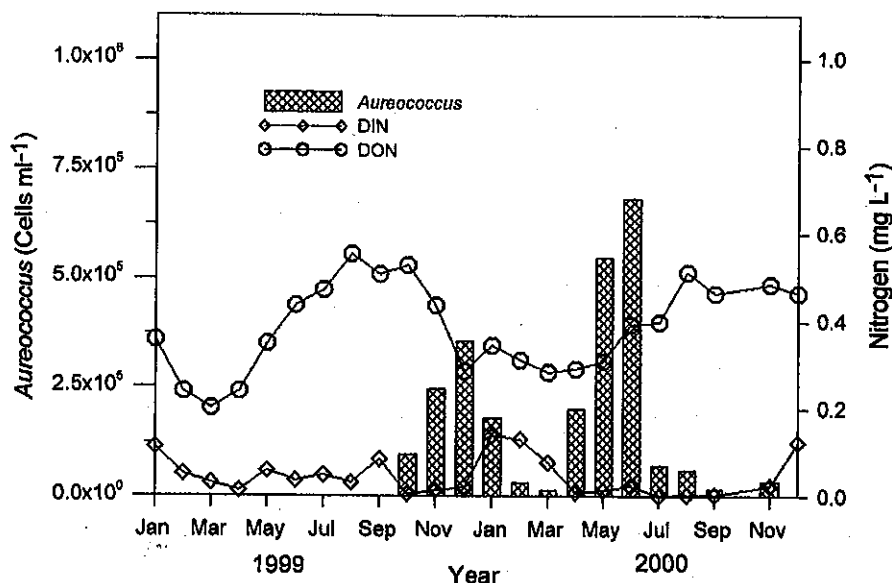


Fig. 6. Average monthly concentration of *A. anophagefferens*, DIN, and DON at GSB Station 150, 1999–2000. The fall–winter bloom of 1999–2000 appears to be associated with the availability of DON, while the initiation of the spring 2000 bloom appears to be associated with DIN.

to other areas (Fig. 7b), and similar trends in nitrogen loads entering GSB from streams and groundwater discharge (Monti and Scorca, 2003). An increase in DON occurred at stations within the SWSD coincidentally with the decrease in DIN (Fig. 7a), but not at stations outside the sewer district (Fig. 7b) where DIN remained relatively constant. As no additional sources of DON were apparent, the reason for its increase remains speculative, although its bay wide distribution suggests a regional, non-point source, perhaps changes in sediment chemistry, or atmospheric deposition related to changing land use or activities distant from the watershed (Paerl et al., 2001; Paerl, 2002). The available data indicate an initial decrease in DON in the early 1980s, perhaps in response to unidentified, less than category 3 brown tide blooms, without which there would be a gentler slope to the linear fit. On the other hand, the lack of data for the last half of the decade, during which the occurrence of category 3 blooms would presumably have reduced the surface water DON, would tend to artificially decrease the slope. In any case, this apparent increase in DON within Great South Bay from 1977 to 1997, while possibly not significant, begs further evaluation.

Bloom Dynamics in Great South Bay during the latter part of 1999 into 2000 were unusual. Although elevated winter counts of *A. anophagefferens* were noted in the past, a cold weather bloom of the magnitude seen over the winter of 1999–2000 was unprecedented, and associated with the following series of events.

- An extensive population of the small bivalve *Mulinia lateralis* was seen in eastern GSB during the spring and summer of 1999. The weighted average clearance rate of  $6.0 \text{ m}^3 \text{ day}^{-1} \text{ per m}^2$  of bottom was estimated to be sufficient to completely filter the waters of the bay each day (Cerrato, personal communication), as was evidenced by the extreme, and unusual, water clarity. Secchi depth at Station 180 (Fig. 9), located in a navigation channel with sufficient depth to reach light extinction, averaged 10.3 ft. during the spring–summer of 1999—significantly greater than during any other year.
- A bloom of the macroalga *Cladophora.sp.* occurred in Great South Bay during the summer of 1999. The luxurious growth of this filamentous alga on the bay bottom was undoubtedly aided by the greater depth of the photic zone and, in the absence of compet-

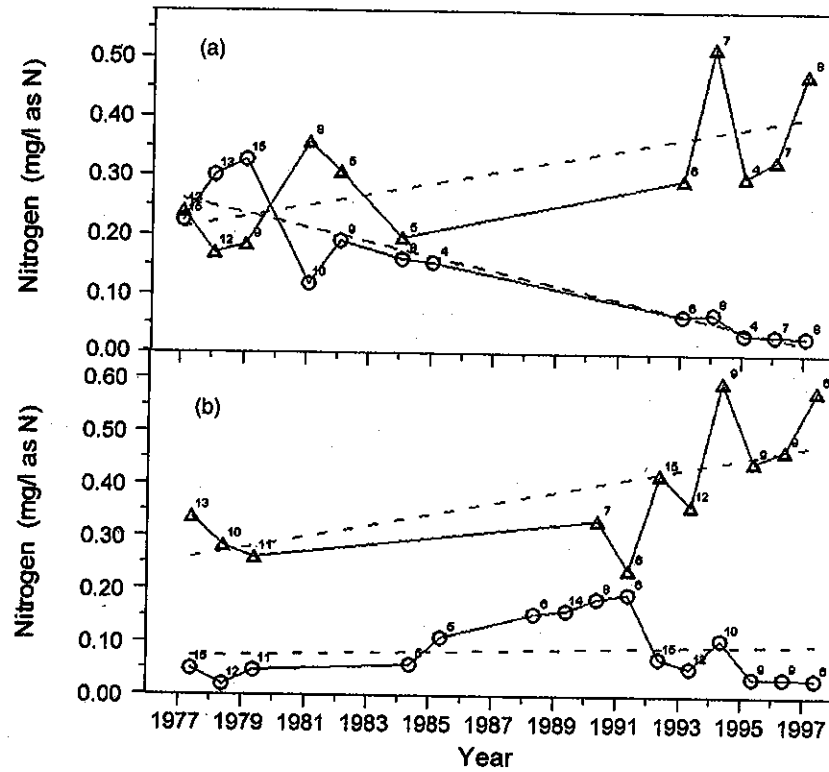


Fig. 7. Average annual DIN (circles) and DON (triangles) concentrations at Station 240 (a) within the Southwest Sewer District and Station 110 (b) outside the Sewer District. The number of data points for each year appears above the plots. Years with fewer than four data points have been excluded. Dotted lines are linear fits.

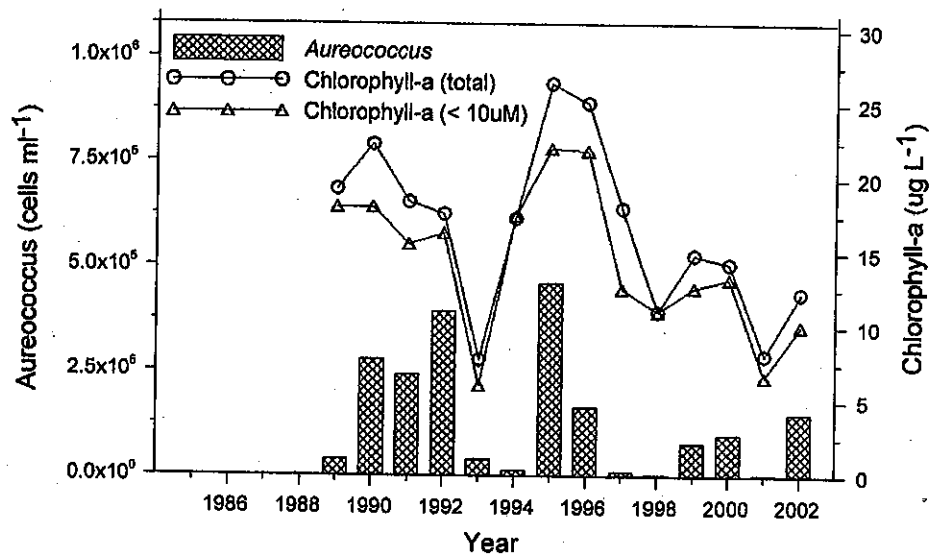


Fig. 8. Average annual concentrations of the brown tide organism, *A. anophagefferens* and chlorophyll-a in Quantuck Bay. Limited flushing undoubtedly influences cell numbers in this area.

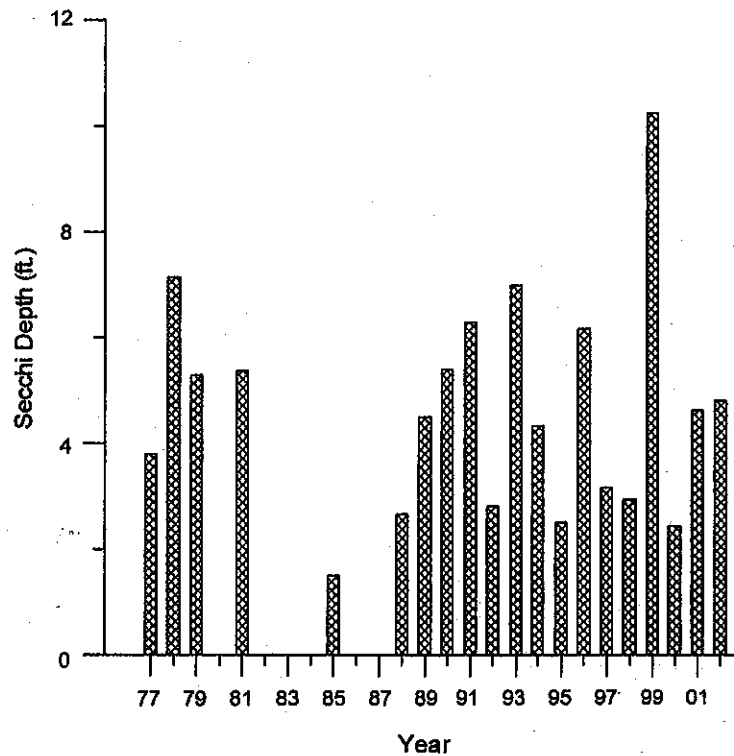


Fig. 9. Average secchi depth at Great South Bay Station 180 during the period April–July 1977–2002. Since this station is in a channel, with a depth exceeding 14 ft., secchi depth was never recorded as “bottom” as it was at many other stations within GSB.

ing planktonic species, an abundance of dissolved nutrients.

- The die-off and decomposition of *Cladophora sp.*, beginning in late summer and extending into the fall.

We suggest that the release of dissolved organic nutrients from the partial mineralization of the macroalgal bloom triggered the *A. anophagefferens* bloom in September. Our data (Fig. 6) agree with that of Gobler et al. (2002) in the finding of high DON, and low DIN levels immediately prior to the bloom. Further, we note a precipitous decline in DON during the winter bloom, but not the spring-summer bloom of 2000 that appears to be associated with a reduction in DIN, leading us to speculate on the potential for *A. anophagefferens* to outcompete other phytoplankters, even for DIN, once it has established itself. The bloom’s collapse in July may be associated with water temperatures exceeding 25 °C, the apparent maximum for maintaining blooms

of *A. anophagefferens* (Nuzzi and Waters, 1989), as the data indicate nitrogen levels sufficient to sustain it. Since *A. anophagefferens* has been found to grow well in the laboratory at 25 °C (Cosper et al., 1989), it is tempting to speculate on possible synergisms, including viral activity, at this temperature.

In addition, the suggestion that sufficient numbers of benthic filter feeders may prevent the proliferation of *A. anophagefferens* to bloom proportions (Cerrato et al., in press; Schaffner, 1999) requires further evaluation in light of the apparent association between *M. lateralis* and the Fall 1999–Winter 2000 brown tide bloom.

## 6. Conclusions

*A. anophagefferens* has been suggested to be an introduced oceanic species (Yentsch et al., 1989), with its proliferation in warmer, lower salinity waters appar-

ently resulting from the concatenation of several factors, the most important of which may be the relative availability of dissolved organic and inorganic nutrients (LaRoche et al., 1997), and the organism's comparative insusceptibility to the effects of self-shading (Yentsch et al., *ibid*; Milligan, 1992) because of its heterotrophic capability (Dzurica et al., 1989; Berg et al., 1997; Gobler and Sañudo-Wilhelmy, 2001a; Mulholland et al., 2002).

The sudden appearance of brown tide, and its localized occurrence interrupted only by its presence in South Africa (Probyn et al., 2001), makes this, indeed, an enigmatic bloom. Its complexity is illustrated by the considerable amount of research undertaken suggesting the importance of interactions among meteorological conditions (LaRoche et al., 1997), surface and groundwater quality (*ibid.*), predator-prey relationships (Bricelj and Lonsdale, 1997; Gobler et al., 2002), and viral activity (Casper et al., 1990; Milligan and Casper, 1994; Gobler et al., 1997; Garry et al., 1998; Gastrich et al., 1998, 2002). Physical factors including salinity, water temperature, especially as related to the organisms ability to prosper at low temperatures and to become stressed as temperatures exceed 25 °C (Nuzzi and Waters, 1989), and flushing rates (Vieira, 1989; Vieira and Chant, 1993) also appear to be important in bloom formation and duration.

Of particular interest is the growing amount of information supporting the idea that blooms are not necessarily related to the absolute amount of available nutrients. Based on brown tide dynamics, it is quite apparent that the classical paradigm linking algal blooms to nutrient quantity continues to require reevaluation. Apparent increases in DON in Great South Bay, accompanied by decreases in DIN as a result of sewerage, the change in DIN-DON ratios in the Peconic Estuary resulting from variations in groundwater input, and the unusual winter bloom in GSB, illustrate the importance of nitrogen quality as opposed to quantity. It has been suggested that the increasing production (Constant and Sheldrick, 1992) and use of urea-based fertilizers has the potential to favor some HAB species (Anderson et al., 2002). Given this information, and the dynamics of brown tide blooms, we agree with Glibert et al. (2001) who, based on their observation that HAB outbreaks in the Chesapeake and adjacent coastal bays appear to be related to elevated DOC:DON ratios, suggest that "organic nutri-

ents should be considered along with inorganic nutrients in the development of nutrient reduction policies".

### Acknowledgements

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