Division of Science, Research and Technology

Research Project Summary

August, 2006

Brown Tide Assessment Project in NJ Coastal Waters: A comparison of three bloom years (2000-2002) with two non-bloom years (2003-04)

Joel A. Pecchioli[1], Richard Lathrop[2], Ph.D., and Scott Haag[2]

Abstract

Brown tides are caused by the rapid population growth ("bloom") of a minute alga, *Aureococcus anophagefferens*. To determine whether these blooms are a threat to coastal waters in New Jersey, the Division of Science Research and Technology implemented the Brown Tide Assessment Project from 2000-2004. The primary objectives of this study are to (1) characterize the spatial and temporal occurrence of brown tides in Barnegat Bay-Little Egg Harbor, (2) identify those environmental factors that may promote the development and maintenance of brown tides, and (3) analyze the risk of brown tides to submerged aquatic vegetation communities. Category 2 (> 35,000 cells ml^{-1}) and Category 3 (> 200,000 cells ml^{-1}) *A. anophagefferens* blooms occurred throughout the study area in 2000-2002 (mean abundances exceeded 190,000 cells ml^{-1}), while none of the monthly means in 2003/04 were classified as a Category 2 or 3 bloom. Category 3 blooms generally occurred during months with mean water temperatures above 14 C, and a minimum temperature above 13.5 C; and with mean salinity between 26 and 31 ppt, and a minimum salinity of at least 17 ppt. However, these environmental conditions do not always result in the occurrence of a Category 3 bloom. Concentrations of total nitrogen, dissolved organic nitrogen, and nitrite + nitrate were higher during the bloom year of 2002 compared to the non-bloom years of 2003/04. In contrast, ammonia showed lower concentrations during 2002. Category 3 brown tides did not occur in any month where the Toms River flow exceeded 200 $ft^3 sec^{-1}$. A Cartographic and Regression Tree Analysis identified ammonia and dissolved organic nitrogen concentrations, and the Toms River flow, as factors that distinguished Category 1 (< 35,000 cells ml^{-1}) and Category 3 *A. anophagefferens* blooms. However, it appears that the observed differences in nitrogen species concentrations may be a result of *A. anophagefferens* blooms impacting nutrient cycles, rather than nutrient levels initiating the brown tides. Analysis of the risk of brown tides to submerged aquatic vegetation habitat indicated that 50% of the mapped habitat in Barnegat Bay-Little Egg Harbor is potentially at risk of negative impacts. Graphic displays of the spatial patterns of *A. anophagefferens* abundance and selected environmental factors can be viewed at: http://crssa.rutgers.edu/projects/btide/index.html.

Introduction

Brown tides are caused by the rapid population growth ("bloom") of a minute alga, *Aureococcus anophagefferens.* While not reported to be harmful to human health, brown tides may negatively impact shellfish (e.g., hard clams, scallops) and submerged aquatic vegetation (SAV) communities. Based on the Brown Tide Bloom Index of Gastrich and Wazniak (2002), Category 3 (> 200,000 cells ml^{-1}) and Category 2 (35,000 – 200,000 cells ml^{-1}) *A. anophagefferens* blooms may negatively impact shellfish by causing reduced feeding, lower growth rates, and/or mortality. Submerged aquatic vegetation may be impacted due to the shading effects of brown tides (Dennison et al., 1989).

Although brown tides were suspected to have occurred in Barnegat Bay in 1985-86, they were first documented in 1995 in Little Egg Harbor and in southern Barnegat Bay. Brown tides were also reported in Barnegat Bay in 1997 and 1999. In response, in 1999 the Division of Science, Research and Technology, in cooperation with several partners, implemented the Brown Tide Assessment Project. Monitoring activities were conducted from 2000 through 2004. The primary objectives of this study were to (1) characterize the spatial and temporal occurrence of brown tides in Barnegat Bay-Little Egg Harbor (BB-LEH), (2) identify those environmental factors that may promote the development and maintenance of brown tides, and (3) analyze the risk of brown tides to SAV communities.

A number of reports and publications (including annual NJDEP project reports) were previously prepared that included analyses, interpretations, and conclusions based on data collected during the years 2000-2003 (for example, Gastrich et al., 2004, 2003). This Research Project Summary presents a summary of the analysis of the data collected during the entire five-year period of the study (2000-2004), as presented in Lathrop and Haag (2005). The major focus of this analysis was a comparison of the data from three years in which brown tides were observed in BB-LEH (2000-2002) with two "non-bloom" years (2003-2004).

Methods and Data Analysis

Water samples for analysis of *A. anophagefferens* abundance (n = 815) were collected at selected NJDEP Water Quality Network stations (NJDEP, 2000) during a five-year period (2000-2004), with a focus on locations in Barnegat Bay-Little Egg Harbor (BB-LEH; see Figure 1). *Aureococcus anophagefferens* abundance was determined using a monoclonal antibody technique (Caron et al., 2003). Data were also simultaneously collected for a number of environmental parameters, including salinity, temperature, and Secchi disk depth. In 2002-2004, water samples were also collected and analyzed for various nitrogen species (ammonia [NH_3], nitrite + nitrate [NO_2 + NO_3], total nitrogen [TN], dissolved inorganic nitrogen [DIN], and calculated dissolved organic nitrogen [DON]) at five sites (1651D, 1675, 1719E, 1818D, and 1824B). Samples were typically collected (and analyzed) from April to September, as detailed in Gastrich et al. (2004). The monthly average daily flow of the Toms River measured by the U.S. Geological Survey was used as an indicator of the prevailing precipitation and/or drought conditions throughout BB-LEH.

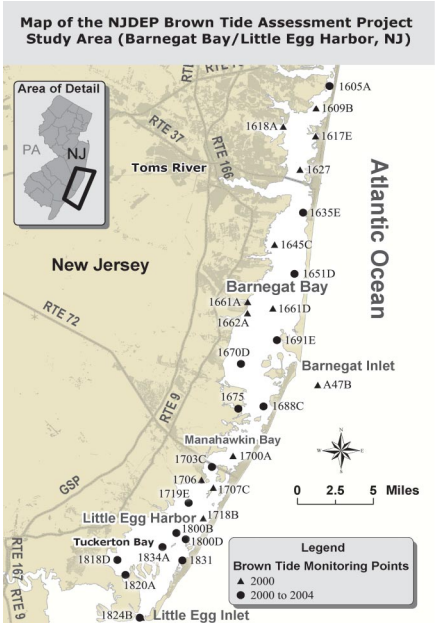

Figure 1 *Aureococcus anophagefferens* monitoring stations 2000-2004.

The Brown Tide Bloom Index of Gastrich and Wazniak (2002) was used to classify the *A. anophagefferens* abundance data, which was then mapped using ArcView geographic information system (GIS) software (Lathrop and Haag, 2005; Gastrich et al., 2004). The analysis of the risk of brown tides to SAV habitat involved the overlay and comparison of two types of maps: (1) the annual median *A. anophagefferens* abundance; and (2) previously generated maps of SAV spatial distributions from the mid-1990s (Lathrop et al., 2001).

Statistical analysis of the environmental data is described in Lathrop and Haag (2005). To evaluate differences in the measured environmental parameters between "bloom" and "non-bloom" years, 2001 and 2002 were considered bloom years and the data were aggregated and compared to the data from the non-bloom years of 2003 and 2004. Data from 2000 was excluded from this analysis due to the non-standard temporal frequency of the sampling during this first year of the program. Basic univariate statistics were calculated using the SAS™ Statistical Package UNIVARIATE procedure (SAS, 1985). The Wilcoxon rank sum test (α= 0.05) was used to compare environmental parameters between the bloom years of 2000/02 and the non-bloom years of 2003/04. The nitrogen species data was also analyzed using a Kruskal-Wallis procedure as a nonparametric form of the ANOVA test. The Kruskal-Wallis test was run using the NPAR1WAY command within SAS ™. A p-value at the 95% confidence interval was used to test whether median values for 2002, 2003, and 2004 were significantly different.

A Cartographic and Regression Tree (CART) Analysis was used to develop a "predictive" model of *A. anophagefferens* abundance. Temperature, salinity, nitrogen species concentrations, and the Toms River freshwater inflow data were used in the CART modeling effort. See Lathrop and Haag (2005) for additional detail.

Results

Table 1 shows the overall mean and monthly maximum abundance of *A. anophagefferens* for each year of the project. Category 2 and 3 blooms occurred throughout the study area in 2000-2002; see Gastrich et al. (2003, 2004) for a detailed presentation of the 2000-2002 data. Mean *A. anophagefferens* abundances in 2000-2002 exceeded 190,000 cells ml^{-1}, while those in 2003 (8,900 cells ml^{-1}) and 2004 (15,700 cells ml^{-1}) were substantially lower. None of the monthly means in 2003/04 were high enough to be classified as a Category 2 or 3 bloom. In 2003, Category 2 level abundances greater than 35,000 cells ml^{-1} (but < 55,000 cells ml^{-1}) were only observed at Station 1818D in June. In 2004, abundances greater than 35,000 cells ml^{-1} (but < 50,000 cells ml^{-1}) were only observed in June (Stations 1818D, 1675, and 1719E) and August (Station 2720B). Graphic displays of the spatial patterns of *A. anophagefferens* abundances (and selected environmental factors) can be viewed at http://crssa.rutgers.edu/projects/btide/index.html.

Table 1. Annual mean and monthly maximum abundance (cells ml^{-1}) of *Aureococcus anophagefferens*, 2000-2004.

Year	Overall Mean (cells ml^{-1})	Monthly Maximum (cells ml^{-1}) [June of each year]
2000	190,500	2,155,000
2001	246,500	1,883,000
2002	281,900	1,561,000
2003	8,900	54,000
2004	15,700	49,000

Comparing water temperatures in the bloom years of 2001 and 2002 with the non-bloom years of 2003/04, there was a statistically significant difference with higher water temperatures during bloom years (mean for 2001/02 = 21.3 C, mean for 2003/04 = 20.5 C). However, the highest overall mean water temperature was observed in the non-bloom year of 2004. Likewise, there was a statistically significant difference in salinity, with the bloom years experiencing higher salinity (mean for 2001/02 = 28.1 ppt, mean for 2003/04 = 25.9 ppt). However, this should be interpreted with caution since the mean salinity during the non-bloom year of 2004

(27.21 ppt) was higher than during the bloom year of 2001 (26.65 ppt). Thus, the observed trend towards higher water temperatures and salinity in the bloom years of 2001/2002 appeared to be largely due to low water temperatures and salinity in 2003.

Based on the analysis of the 2000-2002 data, there appear to be thresholds in water temperature and salinity that are needed for Category 3 *A. anophagefferens* blooms to occur. Category 3 blooms generally occur during months with mean water temperatures above 14 C, and a minimum temperature above 13.5 C; and with mean salinity between 26 and 31 ppt, and a minimum salinity of at least 17 ppt. While the highest *A. anophagefferens* abundances were generally observed when conditions in BB-LEH were above these water temperatures and within this salinity range, these environmental conditions do not guarantee that a Category 3 bloom will occur.

Comparing the bloom years of 2001/02 with the non-bloom years of 2003/04, there was a statistically significant difference in Secchi disk depth (mean for 2001/02 = 0.8 meters, mean for 2003/04 = 1.2 meters). In addition, all of the mean monthly Secchi disk depths for 2003 and 2004 were consistently higher than those observed for 2001 and 2002.

Overall mean and maximum nitrogen species concentrations (μmole L^{-1}) were higher during the bloom year of 2002 compared to the non-bloom years of 2003/04 for total nitrogen (TN), dissolved organic nitrogen (DON), and nitrite + nitrate (NO_2+NO_3). In contrast, ammonia (NH_3) showed lower overall mean and maximum concentrations during the bloom year of 2002. Median values of all nitrogen species concentrations, except for dissolved inorganic nitrogen (DIN), were found to be statistically different using the Kruskal-Wallis test between the bloom year of 2002 and the non-bloom years of 2003/04. Differences in the median value of nitrogen species concentrations between 2002 and 2003/04 were found to be significantly different using the Wilcoxon sum rank test for all of the nitrogen species. There does not appear to be any evidence of a simple linear relationship between *A. anophagefferens* abundance and any of the nitrogen species examined. In addition, early season (April) nitrogen levels did not appear to be a consistent indicator of later *A. anophagefferens* abundance.

Analysis of the monthly mean freshwater discharge data for the Toms River indicates that Category 3 *A. anophagefferens* blooms occurred when these flows were between 133 and 162 ft^3 sec^{-1} (although blooms did not always occur during months with such flows). Category 3 *A. anophagefferens* blooms did not occur in any month where the Toms River flow exceeded 200 ft^3 sec^{-1}. The 3-month average water flow from April to June in 2003 (289.5 ft ^{3} s^{-1}) was the only year with water flow above the long-term mean (234.9 ft ^{3} s^{-1}). In addition 2004 had the second highest stream flow average across April to June (232.2 ft ^{3} s^{-1}).

The Cartographic and Regression (CART) Tree Analysis provided a "prediction" of *A. anophagefferens* bloom conditions (Figure 2). The CART analysis selected a NH_3 concentration of 0.985 μmole L^{-1} as the environmental factor separating the majority of the Category 1 bloom condition samples (82 out of 98) from all of the Category 3 bloom condition samples. However, NH_3 concentration also separated the Category 2 bloom samples into two equal size groups. Dissolved organic nitrogen (DON) concentrations above and below 11.09 μmole L^{-1} divided the remaining Category 1 samples, while keeping the Category 3 samples together. Finally, a Toms River stream flow value of 119.5 ft ^{3} s^{-1} / 60 days kept all 20 Category 3 values grouped together, but separated half of the remaining Category 1 samples and most of the remaining Category 2 values.

Analysis of the data at individual sites in bloom and non-bloom years can provide interesting information on the progression of the blooms and the associated physical and nutrient parameters. Nitrogen species data were collected at five sites (1651D, 1675, 1719E, 1818D, and 1824B) in 2002-2004; detailed graphical analyses of the data for station 1719E are presented in Lathrop and Haag (2005), with the other four stations qualitatively compared to Station 1719E.

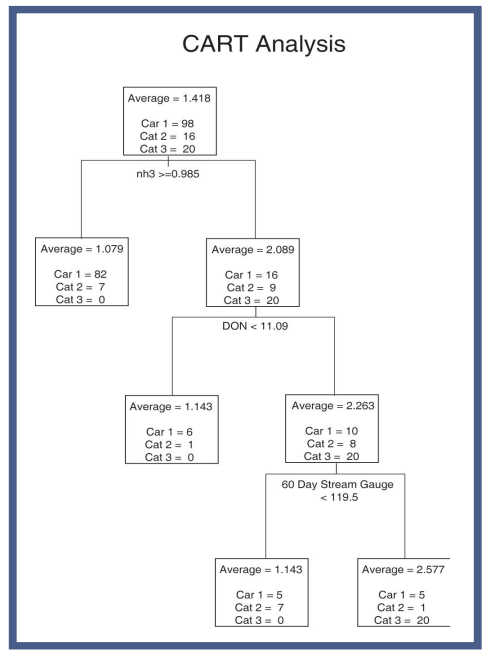

Figure 2
Cartographic and Regression Tree (CART) Analysis

Station 1719E had an average of 358,000 cells ml^{-1} in 2002, 7,100 cells ml^{-1} in 2003, and 16,600 cells ml^{-1} in 2004 (Figure 3a). Note that *A. anophagefferens* abundances peaked at approximately Day 176 in 2002 and 2004. Water temperature was lower in 2003 compared to 2002 and 2004 during the early part of the growing season, but was comparable during the mid-summer months (Figure 3b). Salinity was consistently lower during 2003 compared to 2002 and 2004 (Figure 3c). The physical water parameters appeared to be very similar for both 2002 (a bloom year) and 2004 (a non-bloom year), but were different in 2003 (a non-bloom year).

Total Nitrogen (TN), DON, and NO_2+NO_3 concentrations for the bloom (2002) and non-bloom (2003/04) years appeared to track very closely early in the growing season, but diverged in 2002 after the bloom die-off between Day 176 and Day 188 (Figure 3d shows TN as an example). Ammonia concentrations were consistently lower during the bloom year of 2002 than during the non-bloom years of 2003 and 2004 (Figure 3e). The NH_3 concentration data did not show the same change in levels associated with the bloom die-off observed for TN, DON, and NO_2+NO_3. The trends in A. anophagefferens abundance and the measured

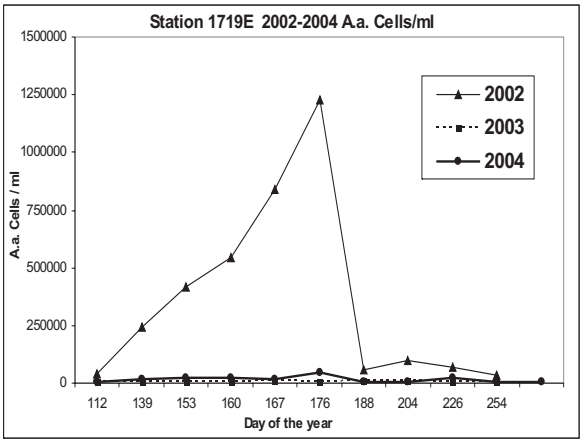

Figure 3(a). Analysis of the data at Station 1719E, 2002-2004. *A. anophagefferens* abundance (cells ml^{-1})

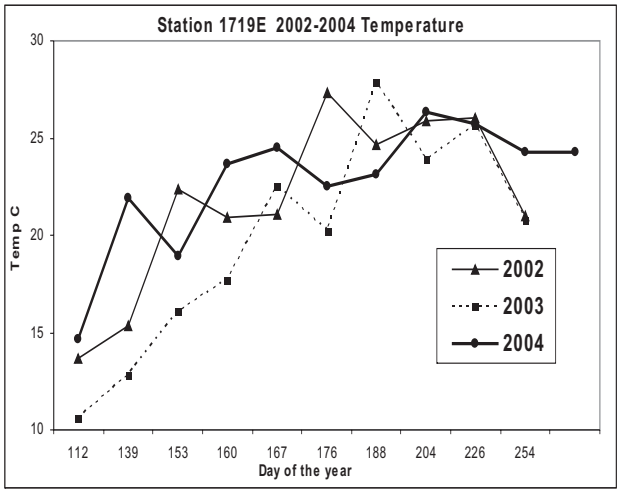

Figure 3(b). Analysis of the data at Station 1719E, 2002-2004. water temperature

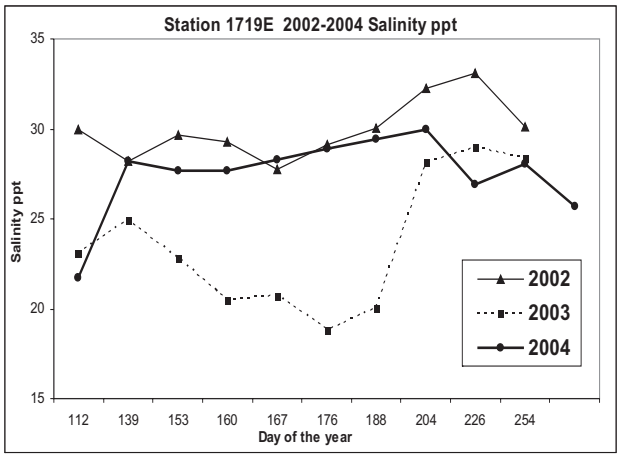

Figure 3(c). Analysis of the data at Station 1719E, 2002-2004. salinity (ppt)

environmental parameters were similar at Stations 1719E, 1651D, 1675, and 1818D.

In contrast, trends in *A. anophagefferens* abundance and the measured nitrogen species concentrations appeared to be somewhat different at Station 1824B, and may be due to its location near the Little Egg Harbor Inlet. First, the maximum abundance of *A. anophagefferens* at Station 1824B in 2002 occurred in early June (Day 160) and was

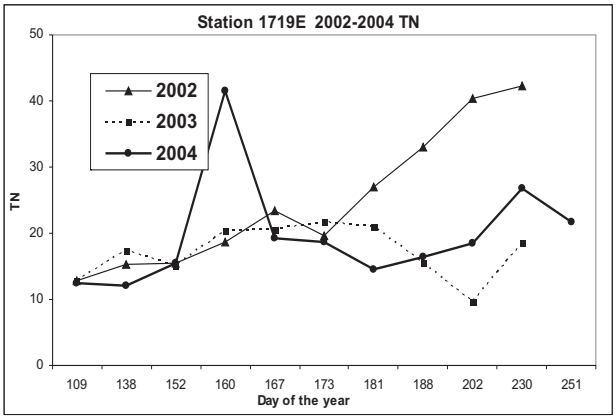

Figure 3(d). Analysis of the data at Station 1719E, 2002-2004. Total Nitrogen (TN; μmole L^{-1})

only 55,000 cells ml^{-1}, so there was no significant die-off as was observed at the other four sites. Despite this, Total N and DON increased in mid-June 2002 after the maximum *A. anophagefferens* abundance (Day 173). Nitrite + nitrate concentrations were relatively similar during all three years until mid-June (Day 173), when they also increased in 2002. Ammonia concentrations were consistently lower during the bloom year of 2002 than during the non-bloom years of 2003 and 2004.

Low Secchi disk depths (a measure of water transparency) are correlated to high *A. anophagefferens* bloom categories, with the non-bloom summers of 2003/04 experiencing

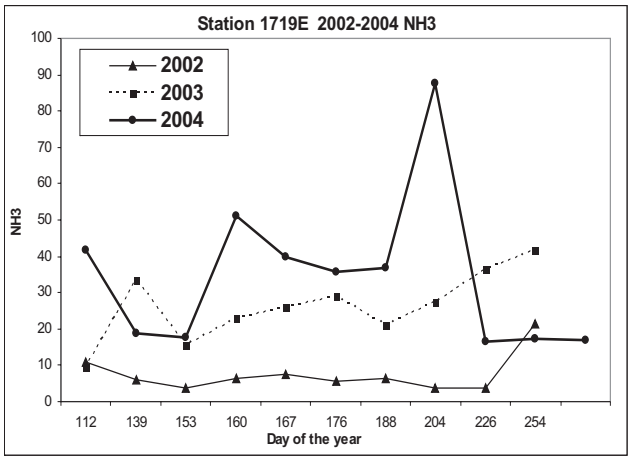

Figure 3(e). Analysis of the data at Station 1719E, 2002-2004. ammonia (NH_3; μmole L^{-1}).

significantly greater Secchi disk depths. Monthly mean Secchi disk depths greater than one meter were only found in months without a Category 3 bloom. Because of differing Secchi disk depths during bloom and non-bloom years, there is a significant difference in the risk to SAV beds between such years as well. During the bloom years of 2000-2002, a significant portion of the BB-LEH estuary SAV beds were potentially affected by Category 2 and 3 *A. anophagefferens* blooms due to shading. In all three years, over 50% of the total mapped SAV habitat area was overlain with a Category 2 or 3 brown tide bloom (Figure 4). In contrast, no SAV beds were affected by such blooms in 2003 and 2004 (Table 2).

A. Acres of SAV

Brown Tide Bloom Category	2000	2001	2002	2003	2004
1	1,905.6	7,386.5	0.0	14,879.0	14,879.0
2	10,373.0	5,197.6	2,006.4	0	0
3	2,600.4	2,294.9	12,872.6	0	0

B. Percent of SAV

Brown Tide Bloom Category	2000	2001	2002	2003	2004
1	12.8	49.7	0.0	100	100
2	69.7	34.9	13.5	0	0
3	17.5	15.4	86.5	0	0

Table 2. Results of the cross-tabulation of the Brown Tide *A. anophagefferens* Bloom Category and SAV

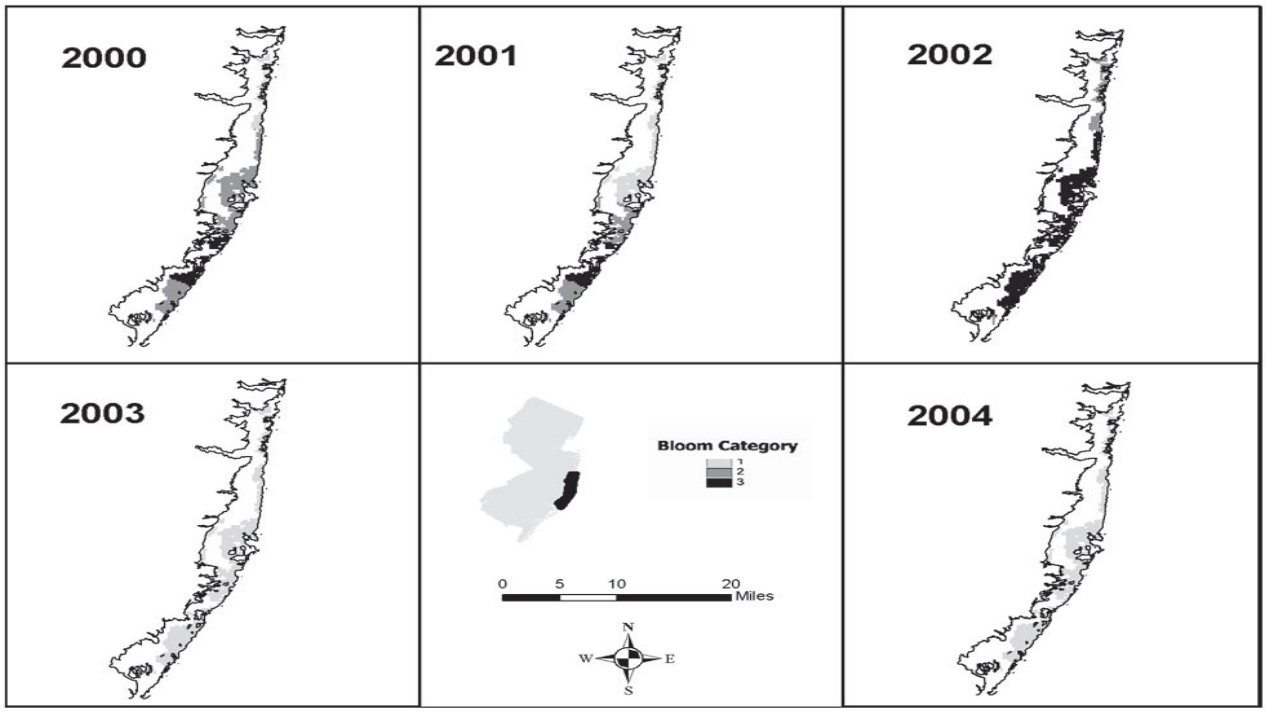

Figure 4. Median A. anophagefferens bloom category vs. SAV beds for the years 2000-2004. [Note: only mapped SAV beds are displayed; non-SAV beds are displayed same as white background.]

Recommendations and Conclusions

This study indicates that elevated abundances of *A. anophagefferens* (Category 2 and 3 blooms) occurred throughout BB-LEH during three of the five years monitored. A number of environmental parameters were found to be associated with brown tides (particularly Category 3 blooms):

- mean monthly minimum water temperatures of 14 C, and a minimum of 13.5 C;
- mean monthly salinity between 26 and 31 ppt, and a minimum of 17 ppt;
- reduced monthly mean freshwater discharge from the Toms River (< 200 ft^3 sec^{-1});
- ammonia (NH_3) concentrations < 1 *µmole* L^{-1}
- dissolved organic nitrogen (DON) concentrations > 11 *µmole* L^{-1}
- monthly mean Secchi disk depths < one meter.

The CART Analysis separated Category 1, 2, and 3 *A. anophagefferens* blooms based on NH_3 (0.985 *µmole* L^{-1}) and DON (11.09 *µmole* L^{-1}) concentrations, and monthly mean freshwater discharge from the Toms River (120 ft^3 sec^{-1}). However, this analysis included data from only one bloom year (2002) and two non-bloom years (2003/04), and thus must be used with caution. The continued monitoring of *A. anophagefferens* abundance, along with associated environmental factors, will provide a better understanding of the pattern of brown tides and the potential factors which may contribute to the promotion and maintenance of these blooms. In addition, because brown tides were detected at every station monitored during 2000-2002, and these blooms have been detected as far south as Maryland, the extension of monitoring for brown tides and environmental factors southward to other coastal bays in New Jersey may be appropriate.

The CART Analysis suggests that freshwater inflow may be

a significant factor effecting the development of brown tides. The balance of surface freshwater vs. groundwater inflow to the BB-LEH estuary could potentially play an important role in controlling the predisposing factors (e.g., salinity and water temperature), as well as possible driving factors (such as the concentrations of macro- or micronutrients), that contribute to the development of *A. anophagefferens* blooms. Likewise, the exchange of estuarine and oceanic waters as a factor effecting the development of brown tides (as seen in the data for Station 1824B) is potentially important for locations in BB-LEH near Barnegat and Little Egg inlets.

The CART Analysis also identified NH_3 and DON as potentially associated with the development and maintenance of brown tides. However, while bloom and non-bloom years have significant differences in nutrient levels, little of this variation can be directly implicated as a causal factor for *A. anophagefferens* blooms. This suggests that the observed differences in nitrogen species concentrations may be a result of *A. anophagefferens* blooms impacting nutrient cycles, rather than nutrient levels initiating the *A. anophagefferens* blooms. Analysis of the data at individual sampling stations supports this observation. However, this statement is still largely speculation as it is based on only three years of data.

More detailed long-term studies of nutrients are needed to develop a better understanding of their role in promoting and maintaining *A. anophagefferens* blooms. Studies evaluating the potential significance of competition for nutrients between *A. anophagefferens* and other phytoplankton and benthic algae in regulating the abundance of *A. anophagefferens* are also needed. In addition, the importance of trophic/food web dynamics and benthic-pelagic coupling should be investigated. Experimental or mesocosm studies will likely be needed to develop a better understanding of brown tides in BB-LEH.

Category 2 and 3 A. *anophagefferens* abundances have been documented in other studies to have negative impacts to SAVs and shellfish (Gastrich and Wazniak, 2002). The results of this study indicate the potential risk of brown tides to negatively impact New Jersey's SAV communities. Category 3 and Category 2 blooms occur during the growing season for juvenile hard clams. Results of a 2001 hard clam stock assessment in Little Egg Harbor indicate that the hard clam population has decreased over 67% from 1986-87 levels (Celestino, 2003). While the brown tides documented in this area have the potential to negatively impact hard clams, there may be other contributing causes of this decline. Information on changes in the distribution and abundance of SAV beds and hard clams, collected in conjunction with brown tide data, would be useful in understanding the potential impact of these blooms on these natural resources in New Jersey's coastal waters.

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Prepared By

[1]Joel A. Pecchioli, Project Manager, NJDEP, DSRT

[2]Richard Lathrop, Ph.D. Principal Investigator and Scott Haag, Rutgers University Center for Remote Sensing and Spatial Analysis

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RESEARCH PROJECT SUMMARY