FINAL REPORT

Brown Tide Assessment Project Years 2000-2004: Developing Indicators of Brown Tide Blooms in NJ Coastal Waters

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Executive Summary

The New Jersey Department of Environmental Protection, in partnership with its collaborators at the New Jersey Marine Sciences Consortium (NJMSC), the U.S. Environmental Protection Agency (USEPA), and the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA), has conducted a five year study (2000 to 2004) of potential contributing factors promoting brown tide blooms in New Jersey's coastal estuaries. Brown tide blooms are caused by a minute alga, *Aureococcus anophagefferens* (*A. anophagefferens).* The geographic focus of the study was the Barnegat Bay and Little Egg Harbor (BB/LEH) estuaries. Specifically, this report focuses on the following topics:

1) Comparison of *A. anophagefferens* abundance between bloom and non-bloom years;
2) Comparison of environmental factors between bloom and non-bloom years.

Maps were created in a Geographic Information System (GIS) to display the spatial patterns of *A. anophagefferens* bloom densities and to highlight bloom hotspots. Within this spatial framework, areas of the BB/LEH estuaries have been categorized based on the size, duration, and associated potential ecological impacts of *A. anophagefferens* blooms.

Gastrich and Wazniak (2002) developed a Brown Tide Bloom Index to classify *A. anophagefferens* bloom conditions into three categories based on potential ecological impacts. The categories within this index are

1) Category 1: < 35,000 *A. anophagefferens* cells ml^{-1}
2) Category 2: ≥ 35,000 to < 200,000 cells ml^{-1}, and
3) Category 3: ≥ 200,000 cells ml^{-1}.

During the 5 years of monitoring, three out of the five surveyed years (2000-2002) were considered *A. anophagefferens* bloom years with high incidences of Category 2 and 3 blooms. In 2003 and 2004, *A. anophagefferens* abundances were significantly lower across all sampling stations compared to the three previous years, and thus were considered to be non-bloom years.

Data on a number of environmental parameters were collected simultaneously with *A. anophagefferens* cell abundances. All of the nitrogen species monitored, except ammonia, showed lower overall mean concentrations in the non-bloom years of 2003 and 2004 compared to the bloom year of 2002 (no nutrient data was collected in 2000 and 2001). While bloom and non-bloom years have statistically significant differences in overall mean nutrient levels, little of this variation can be directly correlated to *A. anophagefferens* blooms. Nutrient data collected early in the growing season (April) were not significantly different between the years 2002 and 2003, while some significant differences were found between the 2002 and 2004 data.

It is unclear what processes are driving the nutrient concentrations. Changes in nitrogen species concentrations could be the result of *A. anophagefferens* blooms impacting nutrient concentrations during bloom periods, rather than nutrient levels initiating the *A. anophagefferens* blooms. The potential role that nitrogen (in its various forms) might play in controlling brown tide blooms in the BB/LEH system is still unclear. Experimental or mesocosm studies will likely be needed to conclusively determine the nutrient dynamics of brown tide blooms.

Given adequate knowledge of predisposing and/or driving physical environmental factors (temperature, nutrients, etc.), an *A. anophagefferens* bloom likelihood/severity model could be developed. Ideally, such a model would provide an early warning prediction based on data collected in April or May. However, the results of this study show that there are no solid clear-cut relationships between the level of early season values (i.e., April) for the measured environmental variables and later *A. anophagefferens* abundance.

A. anophagefferens blooms appear to be associated with lower freshwater inflow (<200 $ft^3\ sec^{-1}$), higher salinity (25-31 ppt), and higher water temperatures (14-17 C). The balance between surface freshwater and groundwater inflow to the BB/LEH estuaries could potentially play an important role in controlling the predisposing factors (e.g., salinity and water temperature) associated with blooms. In addition, this balance could act as one of the driving factors effecting the relative concentration of macro- and/or micronutrients.

Due to the potential deleterious impacts of *A. anophagefferns* blooms on seagrass and shellfish beds within the BB/LEH estuary system, as indicated by low Secchi disk values, an early warning model to estimate the likelihood of brown tide blooms occurring later in the growing season would greatly help coastal resource managers. In addition, continued monitoring across bloom and non-bloom years is critical to building up the long-term data set needed to better understand the various, and often-confounding, factors associated with brown tide blooms. It must be recognized that statistical correlations between environmental parameters and the abundance of *A. anophagefferens* do not imply causality, and a greater mechanistic understanding of the underlying processes causing blooms is needed. As a better understanding of the driving factors behind *A. anophagefferens* blooms is developed, an early warning numerical model could be developed and validated. This numerical model should be able to predict bloom severity based on environmental conditions before bloom initiation. A model based on the data collected and analyzed to date shows that the best correlates with *A. anophagefferens* blooms include salinity, temperature, and freshwater stream flow.

Brown Tide Assessment Project Years 2000-2004: Developing Indicators of Brown Tide Blooms in NJ Coastal Waters

Background

The New Jersey Brown Tide Assessment Project is a five-year research and monitoring program that was initiated by the New Jersey Department of Environmental Protection Division of Science, Research and Technology in 2000. The program is a collaboration of the New Jersey Department of Environmental Protection (NJDEP) Division of Science, Research and Technology, the NJDEP Bureau of Marine Water Monitoring, the New Jersey Marine Sciences Consortium/New Jersey Sea Grant (NJMSC/NJSG), the U.S. Environmental Protection Agency (USEPA) Region 2, the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA), and the University of Southern California. The NJDEP funded and managed the study, NJMSC/NJSG and USEPA collected the water samples and environmental data, CRSSA conducted the mapping and data analysis, Dr. David Caron's laboratory at the University of Southern California enumerated *A. anophagefferens* abundances, and the NJDEP Bureau of Marine Water Monitoring conducted the nutrient analyses.

The overall goal of the program is to assess the spatial and temporal occurrence of harmful brown tide algal blooms caused by the minute pelagophycean alga (ca. 3 μm in size) *Aureococcus anophagefferens* in New Jersey's coastal estuaries, with a focus on the Barnegat Bay/Little Egg Harbor estuaries. This includes the identification of potential environmental factors contributing to bloom development, and estimates of the potential risk of blooms to seagrasses and shellfish.

This report details the findings of the fifth year (2004) of the brown tide assessment program. Findings of the first four years of the study are reported in Lathrop and Haag (2003), Lathrop and Haag (2004), and Gastrich et al. (2004), and are briefly summarized below.

Summary of the 2000-2003 Study Years

Based on the preliminary analysis of the first four years (2000-2003) of brown tide monitoring data in Barnegat Bay and Little Egg Harbor (BB/LEH), it appears that *A. anophagefferens* can reach levels of elevated abundances and sufficient duration (i.e. blooms) to have deleterious impacts on this estuarine system. Category 2 and 3 blooms (as defined by Gastrich and Wazniak, 2002) occurred during the 2000 to 2002 time period and covered significant portions of the BB/LEH estuary. In particular, conditions were especially severe in 2002, with Category 3 blooms extending the full length of the

BB/LEH system. Unlike 2000-2002, bloom level abundances of *A. anophagefferens* were not observed in 2003.

In summary, the data from 2000-2003 suggested that Category 3 blooms were positively associated with warmer water temperatures (greater than 13 C). While Category 3 bloom conditions were observed only at higher water temperatures, these temperatures did not assure a Category 3 bloom. Category 2 bloom conditions were observed across all water temperatures and seasons of the year. Similarly, higher salinity (25 ppt) appeared necessary for Category 3 blooms, but was not sufficient by itself to ensure a bloom. It should be noted that there were extended drought conditions with corresponding low freshwater inputs and elevated bay water salinities during most of this time period. There was no evidence of a clear-cut pattern between *A. anophagefferens* abundance and nitrogen concentrations. While water temperature and salinity appeared to be important, a causal relationship was not established, and they were clearly not the sole environmental factors driving the growth and decline of *A. anophagefferens* blooms.

The preliminary analysis of the risk of brown tide blooms to seagrass habitat suggested that *A. anophagefferens* blooms occurred in abundances high enough to pose a significant risk (due to potential shading effects) to submerged aquatic vegetation or seagrass (i.e., eelgrass, *Zostera marina*) beds in Barnegat Bay/Little Egg Harbor. Of particular concern is the potential impact of *A. anophagefferens* on seagrass beds, because at least 50% of the seagrass habitat area was classified as having a high frequency of Category 2 or 3 blooms for three of the four years studied. These findings are particularly important because over 70% of the state's eelgrass beds are located in the Barnegat Bay/Little Egg Harbor estuary system.

The maps and computer animations that accompany the 2000-2003 reports have been developed into an interactive web site by Rutgers University CRSSA and NJDEP/DSRT. This allows researchers and the public to access and view the information from a remote location. The web site graphically displays the spatial patterns of *A. anophagefferens* blooms, salinity, and temperature by date, but does not include the mean, median, maximum, or minimum summary grid maps that were also created as part of the reports. The web site address is

http://www.crssa.rutgers.edu/projects/btide/index.htm

In addition, a Research Project Summary is available on the NJDEP/DSRT web site at: http://www.state.nj.us/dep/dsr/browntide/bt-rps.pdf

Year 2004 Monitoring and Data Analysis Report

This report discusses the findings of the most recent year of sampling (2004), and includes a reevaluation of the data and previously observed trends and relationships expressed in the full long-term data set (2000-2004).

Objectives

The primary objectives of the Brown Tide Assessment Program are:

1) The collection of water samples in order to (a) characterize the spatial and temporal occurrence of brown tide blooms in Barnegat Bay/Little Egg Harbor, and (b) identify those environmental factors that may promote the development and maintenance of these blooms; and

2) The analysis of the monitoring data to develop a suite of environmental indicators that could be used to develop a model that would (a) predict the occurrence of blooms in Barnegat Bay/Little Egg Harbor (and possibly other shallow estuaries with similar characteristics) and (b) help develop management strategies to minimize the size, frequency of occurrence, and duration of brown tide blooms.

The main objective of this most recent year (2004) of monitoring and data analysis was to reevaluate the data and previously observed trends and relationships expressed in the full long-term data set (2000-2004).

The four main tasks of the data analysis were:

1. Mapping of the 2004 sampling data for visualization of the spatial and temporal patterns of bloom onset, progression, and decline in Barnegat Bay/Little Egg Harbor using Geographic Information Systems;
2. Comparisons of *A. anophagefferens* abundances and bloom levels in 2004 with prior years (2000-2003);
3. Comparison of environmental factors, including nutrient data, and *A. anophagefferens* abundances between bloom and non-bloom years;
4. Use of Classification and Regression Tree (CART) techniques to model *A. anophagefferens* abundances based on the background environmental and nutrient factors.

Methods

Mapping and Visualization of Brown Tide Abundance Data and Associated Environmental Parameters

The field data were collected at specific sampling points along the major north-south axis of the Barnegat Bay/Little Egg Harbor (BB/LEH) estuary (Figure 1; for a summary of the *A. anophagefferens* and nutrient samples collected, see Appendix I). The data were collected from April through September (2001-2004) at eleven stations (April 1X, May 1X, June 4X, July 2X, August 1X, and September 1X). During the first year of sampling (2000) the data were collected at more locations and at irregular intervals over a longer time span. To have an adequate number of samples and sufficient geographic coverage for the mapping and analysis, the data collected within a single weekly period during the first year of sampling (2000) were pooled together and treated as data collected during the same single time period. Environmental data collected simultaneously by the NJMSC included: *A. anophagefferens* abundance, salinity, water temperature, light penetration measurements (Secchi disk depth [transmissivity], and photosynthetically active radiation [PAR]), pH, chlorophyll a, and dissolved oxygen. Nitrogen analyses were conducted by NJDEP/BMWM (NH_3, NO_2+NO_3, Total N [TN], dissolved inorganic nitrogen [DIN], and calculated dissolved organic nitrogen [DON]). Secchi disk depth provides a measure of water transparency (or the depth at which a plate-sized black and white disk called a Secchi disk, when lowered into the water, disappears from view). Freshwater inflow was measured by the United States Geological Survey (USGS) at the Toms River gaging station.

In order to compare data that was collected by a variety of government agencies (NJDEP, USGS, NJMSC, Rutgers University Marine Field Station [RUMFS]) over a variety of temporal and spatial scales, a relational database was designed. The sampling data was brought into Microsoft Access ™. This relational database design allows tables to be joined, queried, and exported into a GIS, or statistical software, directly through the SQL (standard query language) structure. In this database samples were joined by year, month, and day as the primary join. Data that were collected at similar geographic areas were also joined by station identification numbers. This made the process of comparing data from different sources much easier and faster.

To visualize the spatial distribution of the *A. anophagefferens* blooms, it was necessary to map the field sampling locations to their geo-referenced location. The ArcView geographic information system (GIS) software was used for the mapping and spatial analysis. Individual sample point locations for an individual sampling time period were then interpolated to create 2-dimensional surface maps for the various sampled parameters. A shoreline boundary file was used as a barrier in the interpolation process. The point data were interpolated to create a grid cell map of 100-meter cell size using an inverse distance weighted interpolation routine to the sixth power. In any interpolation procedure a major concern is how well the resulting outputs "honor the data points"

(Davis, 1986). There is a limit on how fine the output grid cell size can be made given the spatial frequency and distribution of the input sampling points. Due to the limited number of data points sampled within the study area, a coarser grid cell size of approximately 1000 meters would be suitable. However, a grid cell size of 100 meters was chosen to provide a suitably detailed picture of the Barnegat Bay geography. In addition to the *A. anophagefferens* abundances, interpolated grid cell maps were created for salinity and temperature for each time period.

Using the Brown Tide Bloom Index developed by Gastrich and Wazniak (2002), the *A. anophagefferens* abundance data were combined into three broad categories: Category 1 blooms (<35,000 cells ml^{-1}); Category 2 blooms ($\geq$ 35,000 and < 200,000 cells ml^{-1}); and Category 3 blooms ($\geq$ 200,000 cells ml^{-1}). To further elucidate the spatial patterns, the resulting interpolated surface maps were color-coded and additional finer gradations of cell abundances were delineated. The following general color scheme was adopted on the maps for *A. anophagefferens* bloom categories: Category 1 Blue, Category 2 Yellow, and Category 3 Red. These three brown tide bloom categories were further divided into a total of 9 subcategories of *A. anophagefferens* abundances. These 9 subcategories were mapped with different shades of the corresponding colors. For each year and for every grid cell of the interpolated grid cell maps, the summary statistics of the interpolated *A. anophagefferens* abundance data included the: 1) maximum value, 2) median value, and 3) the mean value. These results were mapped to display the spatial patterns of the blooms and to locate 'hotspots' of high bloom activity (e.g., several months of Category 2 or 3 blooms).

To examine the potential influence of freshwater inflow from the upland watershed on *A. anophagefferens* occurrence, the discharge (ft^3 sec^{-1}) of the Toms River, the largest tributary to the BB/LEH system, was assessed. The monthly average daily flow from the Toms River, as well as the 70-year mean freshwater discharge, was graphed across the five-year period (2000-2004). Because of the long residence time of water within the Barnegat Bay/Little Egg Harbor Estuary System (71 days in June/July of 1995; Guo et al. 1997), the amount of rainfall in April and May could affect bay water conditions (such as salinity, temperature, and nutrients) during the peak *A. anophagefferens* cell abundance in June. While these data do not provide a complete picture of the water budget of the BB/LEH system, they do provide an indicator of the prevailing precipitation and/or drought conditions.

<u>Statistical Data Analysis: Physical Environmental Parameters</u>

To examine the difference in the physical 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 program during this pilot year. The environmental parameters that were examined include water temperature, salinity, Secchi disk depth, Photosynthetically

Active Radiation (PAR), and Toms River freshwater input. The exploratory data analysis was conducted on the original point sample data, not the interpolated grid cell data described in the GIS analysis above. Basic univariate statistics were calculated using the SAS™ Statistical Package UNIVARIATE procedure (SAS, 1985). The Wilcoxon rank sum test was used to compare environmental parameters between the bloom years of 2001 and 2002 and the non-bloom years of 2003 and 2004. A two-sided test with an α of 0.05 was used to test the null hypothesis that there was no difference in the environmental parameters between bloom and non-bloom years. The Wilcoxon ranked sum test is a non-parametric procedure for testing that the distribution of a variable has the same central location across two independent groups (i.e., bloom vs. non-bloom years).

Statistical Data Analysis: Nitrogen Species

Nitrogen data were collected only for the Years 2002, 2003, and 2004. The nitrogen concentrations were imported into a relational database (Microsoft Access) and compared within and between years. The nitrogen species included total nitrogen (TN), ammonia (NH_3), nitrite + nitrate (NO_2+NO_3), and dissolved inorganic nitrogen (DIN), all expressed in units of μM/liter. In addition, dissolved organic nitrogen (DON) was calculated by subtracting DIN from TN. The ratio between DIN and DON was created by dividing DIN/DON. Replicate nitrogen species data (when collected) were averaged for each sampling point for later statistical analysis.

For each year, 51 - 55 water samples were collected between April and September for nutrient analysis (excluding 5 data points on July 24, 2002 and 2003, July 21, 2004, and June 30, 2004). The nitrogen data collected on July 24, 2002 were excluded from the later statistical analysis due to a technical error in processing the samples. In order to be consistent in monitoring dates between years, the nitrogen concentrations for July 24, 2003 and July 21, 2004 were also excluded for the statistical analysis between years. June 30, 2004 was also excluded from the statistical analysis because neither 2003 nor 2002 had a similar time period nutrient sample. These excluded nutrient samples were left out of the statistical analysis to remove any seasonal nutrient bias.

To examine whether there were significant differences between years, a Kruskal-Wallis procedure was used 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% CI was used to test whether median values for 2002, 2003, and 2004 were significantly different. To specifically test for a difference between bloom (2002) and non-bloom years (2003-2004), a Wilcoxon rank sum test was used as a nonparametric form of the Student's t-test for testing that the distribution of a variable has the same central location across two independent groups. The Wilcoxon rank sum test was run using the NPAR1WAY procedure using SAS ™. A two-sided test with an $\alpha = 0.05$ was used. In addition, the Kruskal-Wallis and Wilcoxon rank sum tests were used to examine whether there were year-to-year and bloom vs. non-bloom year differences in April nutrient levels.

Multivariate Statistical Data Analysis: Cartographic and Regression Tree Analysis

One objective was to use a Cartographic and Regression Tree Analysis (CART) to develop a "predictive" model of *A. anophagefferens* abundance (i.e., under what environmental conditions would we expect a brown tide bloom to occur?). A CART analysis uses the dependent variables to split the independent variable into discreet groups through several different steps. At each step a binary decision is made by using a one step look-ahead function that selects the independent variable that can best split the dependent variable (Venables and Ripley, 2002). In our particular implementation, we used temperature, salinity, nitrogen species concentrations, and freshwater inflow data in the CART modeling. Specifically, the RPART command was implemented within the R statistical package using the "ANOV" look-ahead function. This process minimizes the variance between groups at each step and stops when groups have reached a predetermined minimum size, in this case twenty (Venables and Ripley, 2002). Subsequent to the initial analysis, the CART was pruned down to make a manageable predictive tree.

The nitrogen data collected on July 24, 2002 were excluded from the later statistical analysis due to a technical error in processing samples. This provided a dataset with a sample size of 134 samples. Because *A. anophagefferens* uses nutrients to grow and produce biomass, synoptic nutrient data could have been influenced by nutrient uptake by blooming populations of *A. anophagefferens* (i.e., high *A. anophagefferens* abundance might depress nutrient levels due to cell uptake). This is problematic in the modeling of brown tides as the dependent variable in this case can directly affect the independent variables. To try and avoid this problem the nutrient data was shifted by one sampling date. That is, the nutrient samples from the previous sampling period were compared to brown tide numbers from the next period at the same stations. By shifting the nutrient data by one time period this CART model could also be considered a "predictive model". This predictive model could then be applied to nutrient values to predict brown tide bloom conditions beforehand.

A new variable was also created to model the amount of freshwater present within the LEH/BB estuary system. Stream gage data is collected by the United States Geological Society at Toms River New Jersey. Stream gauge data is measured in average stream flow by day, and is influenced by rainfall patterns. While the Toms River is not the only freshwater input into the BB/LEH Estuary system, it is the only tributary with a long-term monitoring program. Assuming that large-scale meteorological conditions are roughly similar across the larger BB/LEH watershed, we used the Toms River data as a proxy variable for freshwater input into the estuary system. Gou et al. (1997), calculated the freshwater residence time for the BB/LEH estuary system as roughly 71 days during June and July of 1995. We decided to use freshwater stream flow totals over a sixty day period as a proxy for the amount of freshwater present with the BB/LEH estuary system. The following equation was used as an estimator of total freshwater within the estuary system. This stream flow variable was also shifted by one nutrient sampling date to allow it to be included within the predictive model. For this reason a total of 60 previous day's stream flow was used (instead of the model prediction of 71 days by Gou et al., 1997).

Freshwater = Σ ((D * 60) + (D-1 * 60-1) + (D-2 * 60-2) + … (D-60 * 60 – 59)) / Σ(60 + 60 -1 + 60 – 2 + … 60 – 59)

This equation calculates the amount of freshwater present within the BB/LEH estuary system for any day by adding the percentage of freshwater inflow by day from the previous sixty days with a linear extinction function. In the equation the "D" stands for sidereal days. So for the current day the entire stream flow value is added or 60/60 percent, for the previous day 59/60 of the stream flow value is counted, and so forth until we are back 60 days in which 1/60 of the freshwater flow is added. This equation makes the assumption that water is lost in a linear method from zero to sixty days beforehand. The total of freshwater input is then divided by the total percentage of days or 60 + 59 + 58 …1.

Results

Comparison of A. anophagefferens abundances and environmental data in the non-bloom years (2003-2004) with prior bloom years (2000-2002)

In 2003 and 2004, *A. anophagefferens* abundances were much lower then the previous three years of sampling in 2000-2002 (Table 1a and Figure 2). In 2003 and 2004 the overall mean abundances of *A. anophagefferens* were 8,897 cells ml^{-1} (std dev = 8,616) and 15,686 cells ml^{-1} (std dev = 10,194), respectively. None of the samples or sampling dates in 2003 and 2004 had *A. anophagefferens* abundances that were high enough to be classified as a Category 3 bloom. These levels can generally be described as Category 1 non-blooms, per Gastrich and Wazniak (2002). In comparison, the overall mean for 2000 was 190,488 cells ml^{-1} (std dev = 423,637), 246,540 cells ml^{-1} (std dev = 416,598) in 2001, and 281,922 cells ml^{-1} (std dev = 316,737) in 2002. Based on these differences, the years 2000-2002 were considered to be "Brown Tide Bloom Years" and 2003-2004 were considered to be "Non-Bloom Years".

The abundance of *A. anophagefferens* during the initial sampling period in April (i.e., early season) was examined as a potential indicator of later bloom conditions during the peak summer season. The month of June generally shows the highest peak *A. anophagefferens* abundances in the BB/LEH system during a bloom year. *A. anophagefferens* abundances in April show that 2003 and 2004 had lower average *A. anophagefferens* abundances at 5,364 cells ml^{-1} (std dev = 674) and 7,257 ml^{-1} (std dev = 2,845), respectively, compared to 58,119 cells ml^{-1} (std dev = 30,643) in 2000, and 24,909 cells ml^{-1} (std dev = 27,994) in 2002 (Table 1b). However, this pattern did not hold true in 2001, which had a low April value of 6,529 cells ml^{-1} (std dev = 4,140) but still was considered a bloom year due to high mid-summer high abundances (Table 1b). Thus, an elevated monthly mean *A. anophagefferens* abundance in the early season (i.e., April) is not always a reliable predictor of later bloom severity.

Comparison of environmental and nutrient factors between bloom and non-bloom years.

1. Salinity

Salinity was the lowest during 2003, with an overall mean of 24.53 parts per thousand (ppt; std dev = 4.45; see Table 2a and Figure 3). This low overall mean salinity contrasts with 2002 (the highest bloom year), which had the highest mean salinity value of 29.54 ppt (std dev = 3.12), as well as the highest maximum salinity value of the five years of record (34.14 ppt). Comparing the bloom years of 2001 and 2002 with the non-bloom years of 2003 and 2004, there was a statistically significant difference in salinity, with bloom years experiencing higher salinity on the order of 2 ppt (the mean for 2001/02 = 28.1 ppt vs. the mean for 2003/04 = 25.9 ppt; $Z = 5.95$, $p < 0.0001$). However, this should be interpreted with caution since the mean salinity during the non-bloom year of 2004 (27.21 ppt, std dev = 3.76) was higher than during the bloom year of 2001 (26.65 ppt, std dev = 4.29).

Salinity data in the early part of the year (April; Table 2b) was examined to determine if it could be used as a predictor of later *A. anophagefferens* bloom conditions. While the April salinity data was generally higher in the combined bloom vs. non-bloom years data, the difference was not statistically significant (mean 2001/02 April = 25.1 ppt vs. mean for 2003/04 = 23.9 ppt; $Z = -1.6614$, $p < 0.09$). Further, the monthly mean salinity in April of 2001 (bloom year; 22.00 ppt, std dev = 6.68) was lower than that for the non-bloom years of 2003 (24.11 ppt; std dev = 3.25) and 2004 (23.76 ppt; std dev = 4.33).

The observed trend towards higher salinity in the bloom years of 2001/2002 compared to the non-bloom years of 2003/2004 appears to be largely due to elevated salinity in 2002 (including the highest overall mean salinity, highest maximum salinity, and the highest April and June mean salinity).

2. Water Temperature

Water temperature (Table 3a and Figure 4) was the lowest in 2000 with an overall mean of 17.92 C (std dev = 6.8), and highest in 2004 with an overall mean of 21.76 C (std dev = 3.80). The lower mean temperature in 2000 was due to the increased number of samples taken in spring, fall, and winter, when temperatures are lower, than in subsequent years. For example, the extreme minimum temperature of 0.9 C was recorded on December 12, 2000. To compare water temperature across similar time periods, the 2000 temperature data was excluded from further analysis. Comparing water temperatures in the bloom years of 2001 and 2002 with the non-bloom years of 2003 and 2004, there was a statistically significant difference with higher water temperatures during bloom years (mean for 2001/02 = 21.3 C vs. mean for 2003/04 = 20.5 C; $Z = -1.9796$, $p < 0.0477$). However, the highest overall mean water temperature was observed in the non-bloom year of 2004, which also had the highest mean temperatures for the months of April, May, and July. In addition, the July mean water temperatures were higher for the non-bloom years of 2003 (25.07 C) and 2004 (25.32 C) compared with those for 2001 (23.53 C) and 2002 (23.76 C). Thus, the observed trend towards higher water temperatures in the bloom years of 2001/2002 compared to the non-bloom years of 2003/2004 appears to be largely due to low water temperatures in 2003.

Of more interest is the month of June, which generally shows the highest peak *A. anophagefferens* abundances in the BB/LEH system during a bloom year. The mean temperatures for June during the non-bloom years (2003-2004) were 18.54 C and 21.48 C, respectively, while the bloom years (2000-2002) had mean temperatures of 20.61 C, 22.30 C, and 21.95 C, respectively (Table 3b). The ten highest temperature days in June were all recorded during bloom years of 2000, 2001 and 2002. The lowest temperature value (13.06 C) recorded was in the 2003 non-bloom year. Seven out of the ten lowest temperatures in June were recorded in 2003, two in 2000, and one in 2001.

3. Secchi Disk Depth

The overall mean Secchi disk depth (Table 4a and Figure 5) for the non-bloom year of 2004 was the highest for the study period with a (visible) depth of 1.3 meters (std dev = 0.58). The minimum (0.3 meters) and maximum (3.4 meters) depths were also the highest in 2004. In contrast, 2002 had the highest abundances of *A. anophagefferens* and an overall mean Secchi disk depth of only 0.7 meters. Comparing the bloom years of 2001 and 2002 with the non-bloom years of 2003 and 2004, there was a statistically significant difference in Secchi disk depth (mean for 2001/02 = 0.8 meters vs. mean for 2003/04 = 1.2 meters; $Z = -8.409$, $p < 0.0001$). In addition, all of the mean monthly Secchi disk depths for 2003 and 2004 were consistently higher than those observed for 2001 and 2002 (Table 4b).

Over the 5-year survey (Table 4c), average and maximum Secchi disk depths of Category 1 blooms were 1.17 and 3.4 meters, Category 2 blooms were 0.73 and 2.5 meters, and Category 3 blooms were 0.58 and 1.3 meters. During Category 1 conditions the coefficient of variation (std dev/mean) in Secchi disk depth was slightly higher than under Category 3 conditions (0.55 vs. 0.24, respectively).

4. Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation (PAR) values measured above the water surface (Table 5a and Figure 6) were the lowest in 2003 with an overall mean of 696 $\mu E/sec/m^2$ (std dev = 462), and highest during 2002 with an average of 1,184 $\mu E/sec/m^2$ (std dev = 667). The highest maximum PAR value was also observed in 2002.

The highest mean PAR in June was observed in 2002 (1,497 $\mu E/sec/m^2$; std dev = 531), with the lowest June mean of 818 $\mu E/sec/m^2$ (std dev = 519) observed in 2003 (Table 5b). Comparing the bloom years of 2001 and 2002 with the non-bloom years of 2003 and 2004, there was a statistically significant difference in June PAR (mean for 2001/02 = 983 $\mu E/s/m^2$ vs. mean for 2003/04 = 741 $\mu E/s/m^2$, $Z = 4.1672$, $p < 0.0001$).

PAR values should be interpreted with caution because they can change quickly (over a matter of seconds) and therefore can be more prone to sampling bias.

5. Stream Flow

During the brown tide bloom years of 2000-2002, during most months water flow was less then the long-term average for the Toms River gaging station. The 3-month average stream water flows from April to June show that 2003 (289.5 ft ^{3} s^{-1}; Table 6 and Figure 7) was the only year with water flow above the long term 74-year mean (234.9 ft ^{3} s^{-1}). In addition, the other non-bloom year (2004) had the second highest stream flow average across April to June (232.2 ft ^{3} s^{-1}). In contrast 2002, the highest bloom year, was the farthest below the long-term historic and non-bloom year averages, with an April to June 3-month mean of 141.4 ft ^{3} s^{-1}.

The USGS average stream flow by day data for Toms River New Jersey shows a large increase in water flow during June of 2003, a non-bloom year, with a mean of 388 ft ^{3} s^{-1} This flow is much larger than that in the bloom years of 2000 (133.1 ft ^{3} s^{-1}), 2001 (161.8 ft ^{3} s^{-1}) and 2002 (143.9 ft ^{3} s^{-1}). It is also higher than the June mean for the non-bloom year of 2004, which had a stream flow value of 130 ft ^{3} s^{-1}.

6. Nitrogen Species

Overall mean and maximum nitrogen species concentrations (µM/liter; Table 7a) were higher during bloom (2002) vs. non-bloom years (2003-4) for Total Nitrogen (TN; Figure 8), Dissolved Organic Nitrogen (DON; Figure 9), and Nitrite + Nitrate (NO_2+NO_3; Figure 10). On the other hand, ammonia (NH_3) showed lower overall mean and maximum concentrations during the bloom year of 2002 compared to the non-bloom years of 2003-4 (Table 7a and Figure 11).

Median values of all nitrogen species concentrations, except for DIN, were found to be statistically different using the Kruskal-Wallis test between the bloom year of 2002 and the non-bloom years of 2003-4 (Table 7b). Differences in the median value of nitrogen species concentration between bloom (2002) and non-bloom years (2003-4) were also found to be significantly different using the Wilcoxon sum rank test (TN p-value = 0.0124; DON p-value = 0.0029; NO_2+NO_3 p-value < 0.0001; NH_3 p-value < 0.0001; DIN p-value = 0.0257; DIN/DON p-value < 0.0001; see Table 7b).

Table 7c displays the nitrogen species data for April of 2002-2004. Early season (April) nitrogen levels did not appear to be a consistent indicator of later *A. anophagefferens* abundance. Except for NH_3, all of the nitrogen species concentrations did not show a statistically significant difference between the bloom and non-bloom years for April values using the Kruskal-Wallis test (Table 7d).

There are no strong linear relationships between the various nitrogen species concentrations and log-transformed *A. anophagefferens* abundance (TN $R^2 = 0.0498$; DON $R^2 = 0.0229$; NO_2+NO_3 $R^2 = 0.0520$; NH_3 $R^2 = 0.0909$; DIN $R^2 = 0.0726$; see Table 7e).

7. Cartographic and Regression Tree Analysis (CART)

The Cartographic and Regression Tree Analysis (CART) provides a "prediction" of *A. anophagefferens* bloom conditions (Figure 12). The CART analysis selected a NH_3 concentration above and below 0.985 µM/L as the first split. This binomial split does a "good" job of separating the majority of the Category 1 bloom condition samples (82 out of 98), while not splitting the Category 3 bloom condition samples. However, this cut does separate the Category 2 bloom samples into two equal size groups. The second binomial split at DON concentrations above and below 11.09 µM/L further divides the Category 1 samples while keeping the Category 3 samples grouped together. The third and final split was a stream flow above and below a value of 119.5 $ft^3\ s^{-1}$ / 60 days. This split still 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.

8. Individual Station Analysis

Analysis of an individual station across the growing season in bloom vs. non-bloom years provides interesting information on the progression of the blooms and the associated physical and nutrient parameters. To illustrate the time series data set, we selected Station 1719E and examined it in more detail over the 3-year study period that nutrient data was available (2002, 2003, and 2004).

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 13). Note that *A. anophagefferens* abundances peaked at approximately Day 176. Water temperature was slightly lower in 2003 compared to 2002 and 2004 during the early part of the growing season, but then caught up during the mid-summer months (Figure 14). Salinity was consistently lower during 2003 compared to 2002 and 2004 (Figure 15). 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).

DON concentrations for the bloom (2002) and non-bloom (2003-2004) years appeared to track very closely early in the growing season (except for a rather large outlier on day 160 in 2004), then diverged after the large increase in DON in 2002 (after the bloom die-off around between Day 176 and Day 188; see Figure 16). Nitrate-nitrite concentrations were also similar before the bloom die-off (Figure 17); afterwards, concentrations were greater in the bloom year (2002) than in the non-bloom years (2003 and 2004). The temporal pattern for Total Nitrogen (TN; Figure 18) was similar to that of DON; Dissolved Organic Nitrogen and Total Nitrogen concentrations rose in 2002 after bloom cessation. In contrast, during the non-bloom years of 2003 and 2004, TN stayed relatively flat throughout the study period (except for a rather large outlier on Day 160 in 2004). Ammonia concentrations were consistently lower during the bloom year of 2002 than during the non-bloom years of 2003 and 2004 (Figure 19). The NH_3 concentration data did not show the same change in levels associated with the bloom die-off (approx. Day 176) as was seen for DON and TN.

Similar trends during 2002-2004 were observed at Station 1675, located about 8 miles north of Station 1719E. However, the mean *A. anophragefferens* abundance was greater in 2004 at Station 1675 (28,545 cells ml^{-1}) due to low-level Category 2 blooms (37,000 – 49,000 cells ml^{-1}) in June through August.

The trends in *A. anophragefferens* abundance and the measured environmental parameters were also similar at Stations 1719E, 1651D (located further north of Station 1675), and 1818D (located south of Station 17189E in Tuckerton Bay).

In contrast, trends in *A. anophragefferens* abundance and the measured nitrogen species appeared to be somewhat different at Station 1824B, and may be due to its location near the Little Egg Harbor Inlet (south of Stations 1719E, 1675, 1651D, and 1818D). First, the maximum abundance of *A. anophragefferens* at Station 1824B in 2002 occurred in early June and was only 55,000 cells ml^{-1}, so there was no significant die-off as was observed at the other three sites. Despite this, Total N and DON increased in mid-June 2002 (after the maximum *A. anophragefferens* abundance), decreased in early-July, and then increased in mid-July through August. Nitrate-nitrite concentrations followed a similar pattern, but concentrations were relatively similar during 2002 and 2003/4 until late-July, when they increased in 2002 (a similar pattern was observed at Station 1818D). Ammonia concentrations were consistently lower during the bloom year of 2002 than during the non-bloom years of 2003 and 2004, as was observed at Stations 1719E, 1675, and 1651D.

Discussion

In 2003 and 2004, the overall mean and the maximum observed *A. anophagefferens* abundances were significantly lower across all sampling stations compared to the years 2000-2002:

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

None of the monthly means in 2003 and 2004 had *A. anophagefferens* abundances that were high enough to be classified as a Category 2 or 3 bloom, as per Gastrich and Wazniak (2002). In 2003, abundances greater than 35,000 cells/mL (but < 55,000 cells/mL) were only observed at Station 1818D in June. In 2004, abundances greater than 35,000 cells/mL (but < 50,000 cells/mL) were only observed in June (Stations 1818D, 1675, and 1719E) and August (Station 2720B). Thus, these two years have been categorized as Category 1 non-bloom years. The years between 2000-2002 have been considered to be "Brown Tide Bloom Years".

Based on our prior analysis of Bloom Year data (2000-2002), we had concluded that there appear to be thresholds in water temperature and salinity that are needed for the highest concentration *A. anophagefferens* Category 3 blooms to occur. However, it was also recognized that the presence of such environmental conditions did not always result in a Category 3 *A. anophagefferens* bloom. Category 3 blooms generally occur during months with mean water temperatures above 14 C, and a minimum temperature above 13.5 C (Table 3a); and with mean salinity between 26 and 31 ppt, and a minimum salinity of at least 17 ppt (Table 2a). While the highest *A. anophagefferens* concentrations 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.

The Year 2003 overall mean water temperature was lower than that in the years 2001 and 2002 (Table 3a). Monthly mean water temperatures in 2003 were lower than those in 2000-2002 for April, May and June, but were higher for July. The monthly mean temperature in 2003 exceeded the 14-17 C threshold in June and July (Table 3b). The overall mean salinity in 2003 of 24.53 ppt (std dev = 4.45) was lower than that in the years 2000-02 (Table 2a). Monthly mean salinity for May and July slightly exceeded the 25 ppt mean salinity threshold, but the 17 ppt minimum salinity threshold was not exceeded.

The Year 2004 overall mean salinity and temperature data were similar to the 2000-2002 time period data. Monthly mean salinity exceeded the 25 ppt threshold in each month from May through July, but the minimum 17 ppt threshold was only exceeded in May and June. Monthly mean temperatures in 2004 also exceeded the 14-17 C threshold in the months of May through July. Despite these similarities with the 2000-2002 data, 2004 did not experience Category 2 or 3 *A. anophagefferens* blooms.

Analysis of the monthly mean freshwater discharge data for the Toms River (Table 6) 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 $ft^3\ sec^{-1}$. Averaged over the 3-month period April to June, the Years 2003 and 2004 had more freshwater input to the BB/LEH estuary than the other three survey years (Table 6). The mean freshwater discharge to the BB/LEH system (as measured at the Toms River gaging station) for the April to June time period in 2003 (289.5 $ft^3\ sec^{-1}$) was higher than during the Bloom Years of 2000-2002. The mean freshwater discharge in 2004 (232.2 $ft^3\ sec^{-1}$), while also higher than during the Bloom Years of 2000-2002, closely approximated the mean for the longer period of record (1928-2002; 234.9 $ft^3\ sec^{-1}$). Also, note that the year with the lowest amount of freshwater inflow in the spring (2002) had the highest overall mean *A. anophagefferens* counts. 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 relative concentration of macro- or micronutrients), that contribute to the development of *A. anophagefferens* blooms.

Based on our analysis, we do not see any evidence of a simple linear relationship between A. *anophagefferens* abundance and any of the nitrogen species examined. Nutrient data collected during the 2002 bloom and 2003/2004 non-bloom years showed a significant difference between years for all nitrogen species (Table 7b; except for DIN using the Kruskal-Wallis test). All of the nitrogen species except NH_3 showed lower overall mean concentrations in the non-bloom years of 2003 and 2004 compared to the bloom year 2002. In addition, early season (April) nitrogen levels did not appear to be a consistent indicator of later *A. anophagefferens* abundance.

While the potential role that nitrogen, in its various forms, might play in controlling brown tide blooms in the BB/LEH system is still unclear, the results of the CART model (Figure 12) suggest that NH_3 and DON concentrations, along with freshwater discharge, were important parameters in explaining the occurrence of Category 1 vs. Category 3 blooms.

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. For example, DON collected early in the growing season (Table 7c; April) in 2002 and 2003/2004 shows no significant differences between years. DON concentration does appear to rise in 2002 after the bloom die-off. This finding suggests that the changes in nitrogen species concentration may be a result of *A. anophagefferens* blooms impacting nutrient cycles during bloom periods, rather than nutrient levels initiating the *A.*

anophagefferens bloom. In other words, the change in nutrient concentrations observed may be a consequence of, rather than a cause of, the brown tide bloom. However, this statement is still largely speculation based on only three years of data; a more detailed long term study of nutrient data prior to *A. anophagefferens* blooms is still needed. Experimental or mesocosm studies will likely be needed to conclusively determine the nutrient dynamics of brown tide blooms.

Low Secchi disk depths (Table 4c; a measure of water transparency) are correlated to high *A. anophagefferens* bloom categories, with the non-bloom summers of 2003 and 2004 experiencing significantly greater Secchi disk depths. Monthly mean Secchi disk depths greater than one meter were only found in months without a Category 3 bloom. However, the maximum Secchi disk depth observed in any month was always greater than one meter, irrespective of the occurrence of 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 seagrass beds between years as well. During the bloom years of 2000-2002, a significant portion of the BB/LEH estuary seagrass beds were potentially affected by Category 2 and 3 *A. anophagefferens* blooms due to shading. In 2003 and 2004 no seagrass beds were affected by such blooms.

Continued monitoring across bloom and non-bloom years is critical to building the long-term data set needed to better understand the various, often confounding factors, associated with brown tide blooms. It must be recognized that statistical correlations between environmental parameters and the abundance of *A. anophagefferens* do not imply causality and a greater mechanistic understanding of the underlying processes causing blooms is needed. As a better understanding of the driving factors behind *A. anophagefferens* blooms becomes available, an early warning model could be developed and validated. Due to the potential deleterious impacts on seagrass and shellfish beds within the BB/LEH estuary system, an early warning model to estimate the likelihood of brown tide blooms later that growing season would greatly help coastal resource managers. However, the results of this study show that there are no solid clear-cut relationships between the level of early season values (i.e., April) for the measured environmental variables and later *A. anophagefferens* abundance.

Conclusions

1. In 2004, *A. anophagefferens* numbers were significantly lower across all sampling stations compared to the bloom years of 2000-2002, and 2004 was categorized as a Category 1 non-bloom year.

2. *A. anophagefferens* blooms are associated with threshold levels for salinity, temperature, and freshwater stream flow.

3. All of the nitrogen species (TN, DON, nitrite + nitrate, and DIN), except ammonia, showed lower mean concentrations in the non-bloom years 2003 and 2004 compared to the bloom year 2002. However, the potential role that nitrogen, in its various forms, might play in controlling brown tide blooms in the BB/LEH system is still unclear.

4. During the 2003 and 2004 non-bloom years, little deleterious impacts to seagrass communities due to brown tide induced reductions in water transparency are expected to have occurred.

5. The CART analysis shows that NH_3, DON, and stream flow provide the best predictors among the variables examined for *A. anophagefferens* blooms.

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TABLES, GRAPHICS & APPENDICES

FINAL REPORT

Brown Tide Assessment Project Years 2000-2004
Developing Indicators of Brown Tide Blooms in NJ Coastal Waters:
A Comparison of Bloom and Non-Bloom Years

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Tables

Table 1. ***Aureococcus anophagefferens*** **Abundances (cells ml^{-1})**

Table 1a. *A. anophagefferens* abundance (cells ml^{-1}) – overall mean, standard deviation, minimum, maximum, and number of samples collected.

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2000	190,488	423,637	5,000	2,155,000	248
2001	246,540	416,598	5,000	1,883,000	148
2002	281,922	316,737	5,000	1,561,000	128
2003	8,897	8,616	5,000	54,000	136
2004	15,686	10,194	5,000	49,000	155

Table 1b. *A. anophagefferens* abundance (cells ml^{-1}) – monthly mean, standard deviation, minimum, maximum, and number of samples. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2000	4	58,119	30,643	20,000	134,000	42
2000	6	725,852	719,609	1,353	2,155,000	51
2000	7	162,194	184,699	2,500	476,000	18
2000	8	51,344	28,6444	12,000	140,000	61
2000	9	19,648	10,406	6,000	50,000	37
2001	4	6,529	4,140	5,000	21,000	17
2001	5	204,500	312,488	5,000	1,026,000	16
2001	6	490,428	540,294	5,000	1,883,000	50
2001	7	50,939	82,406	5,000	456,000	33
2001	8	98,454	134,032	14,000	491,000	23
2001	9	475,000	565,691	25,000	1,306,000	11
2002	4	24,909	27,994	5,000	84,000	11
2002	5	374,154	309,397	8,000	851,000	13
2002	6	490,945	300,651	11,000	1,561,000	56
2002	7	119,148	230,442	10,000	1,218,000	27
2002	8	38,727	20,149	14,000	72,000	11
2002	9	27,545	7,474	17,000	43,000	11
2003	4	5,364	674	5,000	7,000	11
2003	5	5,000	0	5,000	5,000	11
2003	6	12,036	12,020	5,000	54,000	56
2003	7	8,818	5,181	5,000	25,000	33
2003	8	5,214	425	5,000	6,000	14
2003	9	5,272	1,420	3,000	9,000	11
2004	4	7,257	2,845	5,000	13,000	11
2004	5	7,636	4,739	5,000	17,000	11
2004	6	17,246	11,205	5,000	49,000	69
2004	7	16,592	8,545	5,000	33,000	27
2004	8	20,136	11,251	5,000	47,000	22
2004	9	12,433	4,813	5,000	21,000	15

Table 2. Salinity (ppt)

Table 2a. Salinity (ppt) - overall mean, standard deviation, minimum, maximum, and number of samples.

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2000	27.38	3.27	18.04	33.80	248
2001	26.65	4.29	14.85	31.62	115
2002	29.54	3.12	18.59	34.14	111
2003	24.53	4.45	10.03	31.91	110
2004	27.21	3.76	14.76	32.05	121

Table 2b. Salinity (ppt) – monthly mean, standard deviation, minimum, maximum, and number of samples. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Dev	Minimum	Maximum	Number of Samples
2000	4	25.79	2.82	18.04	29.9	42
2000	6	27.04	3.19	19.44	31.83	51
2000	7	28.19	3.03	19.58	31.03	18
2000	8	27.27	3.36	18.07	32.29	61
2000	9	27.94	3.52	18.86	33.8	37
2001	4	22.00	6.68	0.03	27.35	17
2001	5	26.49	3.35	18.47	29.59	16
2001	6	26.72	3.13	17	31	50
2001	7	27.51	3.11	18.6	30.36	33
2001	8	29.99	1.33	26.7	31.62	23
2001	9	28.66	3.08	20.86	30.94	11
2002	4	29.94	2.83	23.49	32.78	11
2002	5	28.24	3.34	20.21	31.12	13
2002	6	28.48	3.14	18.59	31.31	56
2002	7	30.64	2.64	23.51	32.94	27
2002	8	32.77	0.72	31.44	34.14	11
2002	9	29.32	2.79	23.7	31.38	11
2003	4	24.11	3.25	17.89	30	11
2003	5	25.24	3.48	16.4	29.42	11
2003	6	22.24	4.15	10.03	28.54	56
2003	7	25.13	4.26	14.71	30.8	33
2003	8	28.99	3.77	18.12	30.52	11
2003	9	27.76	4.16	17.94	32.05	22
2004	4	23.76	4.33	14.76	30.21	11
2004	5	28.49	3.38	20.74	31.87	11
2004	6	27.86	3.28	17.77	31.54	64
2004	7	27.53	3.98	14.87	31.47	27
2004	8	27.82	4.16	17.94	32.05	22
2004	9	24.88	2.66	17.45	26.83	15

Table 3. Water Temperature (C)

Table 3a. Water Temperature – overall mean, standard deviation, minimum, maximum, and number of samples.

Year	Mean	Standard Dev	Minimum	Maximum	Number of Samples
2000	17.92	6.8	0.9	28.3	249
2001	21.56	4.61	9.83	29.2	150
2002	20.93	4.47	11.45	28.18	129
2003	19.06	5.17	9.09	27.89	136
2004	21.76	3.80	8.47	26.52	121

Table 3b. Water temperature – monthly mean, standard deviation, minimum, maximum, and number of samples. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2000	4	10.33	0.85	8.3	13.3	42
2000	6	20.61	2.92	15	25.6	50
2000	7	23.31	1.46	22.1	27.5	18
2000	8	24.04	1.92	20.2	28.3	61
2000	9	20.09	2.69	16.5	25	37
2001	4	11.87	1.14	9.83	14.42	17
2001	5	17.73	0.63	16.1	19	16
2001	6	22.3	2.64	15.04	25.4	50
2001	7	23.53	1.78	17.99	25.9	33
2001	8	26.25	2.82	19.05	29.2	23
2001	9	23.41	0.40	22.81	24.09	11
2002	4	12.87	0.76	11.45	13.68	11
2002	5	14.42	0.73	13.5	15.49	13
2002	6	21.95	2.67	16.24	28.18	56
2002	7	23.76	3.05	14.7	26.37	27
2002	8	25.79	0.61	24.22	26.47	11
2002	9	20.83	0.80	19.36	21.89	11
2003	4	10.01	0.56	9.09	10.85	11
2003	5	12.3	0.44	11.17	12.83	11
2003	6	18.54	2.3	13.06	22.53	56
2003	7	25.07	2.4	20.2	27.89	33
2003	8	23.23	3.52	16.03	25.91	14
2003	9	20.75	0.28	20.3	21.32	11
2004	4	13.00	2.04	8.47	14.98	11
2004	5	20.04	2.40	15.34	22.25	11
2004	6	21.48	2.36	16.57	25.08	55
2004	7	25.32	1.46	19.56	26.52	22
2004	8	23.96	0.60	22.53	24.61	22
2004	9	24.30	0.30	23.8	24.8	15

Table 4. Secchi Disk Depth (meters)

Table 4a. Secchi Disk Depth – overall mean, standard deviation, minimum, maximum, and number of samples.

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2001	0.94	0.5	0.1	2.8	139
2002	0.7	0.48	0.1	3	110
2003	1.11	0.48	0.1	2.5	110
2004	1.30	0.58	0.3	3.4	120

Table 4b. Secchi Disk Depth – monthly mean, standard deviation, minimum, maximum, and number of samples. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2001	4	1.17	0.62	0.5	2.8	21
2001	5	0.79	0.41	0.2	1.5	15
2001	6	0.96	0.57	0.3	2.8	51
2001	7	0.82	0.36	0.1	1.6	20
2001	8	0.94	0.42	0.2	1.6	12
2001	9	0.85	0.39	0.3	1.7	11
2002	4	0.75	0.28	0.3	1.1	11
2002	5	0.66	0.30	0.3	1.2	11
2002	6	0.63	0.41	0.1	2.6	44
2002	7	0.89	0.78	0.25	3	22
2002	8	0.74	0.40	0.2	1.5	11
2002	9	0.56	0.24	0.3	1.2	11
2003	4	1.26	0.46	0.5	2	11
2003	5	1.25	0.42	0.5	1.8	11
2003	6	1.20	0.51	0.2	2.5	44
2003	7	0.98	0.45	0.1	1.9	22
2003	8	0.92	0.50	0.2	1.8	11
2003	9	0.89	0.37	0.3	1.6	11
2004	4	1.57	0.44	1	2.5	10
2004	5	1.54	0.68	0.7	2.9	11
2004	6	1.30	0.67	0.3	3.4	55
2004	7	1.07	0.33	0.5	1.9	24
2004	8	1.01	0.29	0.6	1.5	11
2004	9	1.31	0.46	0.5	2	11

Table 4c. Secchi Disk Depth - *A. anophagefferens* bloom category - mean, standard deviation, minimum, maximum, and number of samples.

Bloom Cat	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
1	1.17	0.55	0.1	3.4	327
2	0.73	0.46	0.1	2.5	74
3	0.58	0.24	0.1	1.3	70

Table 5. Photosynthetically Active Radiation (PAR; $\mu E/sec/m^2$).

Table 5a. PAR – overall mean, standard deviation, minimum, maximum, and number of samples.

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2001	786	540	2	2,079	139
2002	1,184	667	24	3,216	110
2003	696	462	51	2,475	110
2004	760	469	21	2,068	120

Table 5b. PAR – monthly mean, standard deviation, minimum, maximum, and number of samples. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, and 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2001	4	596	347	8	1,318	21
2001	5	258	178	19	616	15
2001	6	1,028	522	49	2,079	51
2001	7	722	567	25	1,686	20
2001	8	1,042	489	103	1,629	12
2001	9	1,309	276	936	1,798	11
2002	4	1,055	486	347	2,152	11
2002	5	1,319	877	254	3,216	11
2002	6	1,497	531	266	2,878	43
2002	7	141	108	24	325	22
2002	8	1,137	541	264	2,077	11
2002	9	1,019	369	325	1,640	11
2003	4	448	163	235	702	11
2003	5	1,009	335	264	1,393	11
2003	6	818	519	144	2,475	44
2003	7	565	277	51	1,016	22
2003	8	498	179	287	953	11
2003	9	601	709	75	2,286	11
2004	4	948	336	114	1,219	10
2004	5	1,067	271	437	1,357	11
2004	6	792	549	135	2,068	58
2004	7	831	346	135	1,350	24
2004	8	534	277	163	927	11
2004	9	278	180	21	606	11

Table 6. USGS Stream Gauge data ($ft^3\ sec^{-1}$) from Toms River, New Jersey: monthly means during the four-year survey period, and the long-term monthly mean over the period from 1928-2002 for April, May, and June.

Year	April	May	June	Mean across all three months
2000	201.7	188.6	133.1	174.5
2001	332.9	150.4	161.8	215.0
2002	139.4	141.5	143.0	141.3
2003	269.2	210.5	388.9	289.5
2004	356.4	211.0	130.1	232.2
Mean 1928-2002	278.7	241.9	184.2	234.9

Table 7. Nitrogen Species (2002-2004).

Table 7a. Nitrogen species (uM/L) for the years 2002, 2003, and 2004: overall mean, standard deviation, minimum, maximum, and number of samples.

Total Nitrogen

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	25.33	13.57	11.03	62.74	46
2003	17.58	6.37	6.72	38.84	46
2004	19.62	8.10	7.54	41.53	45

Total Dissolved Organic Nitrogen

Year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	22.14	12.94	4.48	60.85	46
2003	14.48	5.96	3.92	31.58	46
2004	16.15	7.70	5.16	37.38	45

Total Nitrite + Nitrate

year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	2.28	2.84	0.22	17.11	46
2003	0.52	0.38	0.02	1.93	46
2004	0.48	0.28	0.12	1.53	45

Total Ammonia

year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	0.66	0.60	0.26	3.40	46
2003	2.58	1.39	0.66	6.35	46
2004	2.99	2.03	0.62	9.58	45

Total Dissolved Inorganic Nitrogen

year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	3.19	3.96	0.72	22.06	46
2003	3.10	1.57	0.69	7.26	46
2004	3.47	2.11	0.93	10.68	45

Dissolved Inorganic Nitrogen divided by Dissolved Organic Nitrogen

year	Mean	Standard Deviation	Minimum	Maximum	Number of Samples
2002	0.23	0.58	0.03	3.95	46
2003	0.26	0.22	0.06	1.23	46
2004	0.27	0.20	.04	0.97	45

Table 7b. Nitrogen species: Kruskal Wallis and Wilcoxon p-values between bloom (2002) and non-bloom (2003-04) years.

Nitrogen Species	**Kruskal Wallis P-Value**	**Wilcoxon P-Value**
Total Nitrogen	0.0289	0.0124
Dissolved Organic Nitrogen	0.0078	0.0029
Nitrite and Nitrate	<0.0001	<.0001
Ammonia	<0.0001	<.0001
Dissolved Inorganic Nitrogen	0.0705	0.0257
DIN / DON	<0.0001	<.0001

Table 7c. Nitrogen species (uM/L) for 2002, 2003, and 2004: mean, standard deviation, minimum, maximum, and number of samples.

Total Nitrogen by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	13.28	1.61	11.29	16.03
2002	5	15.94	5.44	11.03	24.79
2002	6	20.92	7.15	12.04	40.99
2002	7	24.48	8.19	16.26	37.35
2002	8	42.60	8.92	32.05	55.85
2002	9	50.42	7.97	42.33	62.74
2003	4	13.01	5.21	6.72	20.76
2003	5	18.59	6.83	9.19	27.09
2003	6	19.17	6.65	10.54	38.84
2003	7	16.02	5.87	10.71	23.56
2003	8	15.03	7.63	8.75	27.38
2003	9	18.57	3.93	12.15	22.41
2004	4	12.31	1.14	10.35	13.28
2004	5	12.66	3.94	7.54	18.58
2004	6	21.16	8.78	9.03	41.53
2004	7	19.53	8.12	13.77	33.24
2004	8	21.42	7.25	9.46	26.79
2004	9	26.01	5.01	19.58	30.78

Total Dissolved Organic Nitrogen by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	11.83	1.99	8.92	14.88
2002	5	14.97	5.42	9.72	23.61
2002	6	18.66	6.84	8.62	37.74
2002	7	22.49	14.36	0.79	47.84
2002	8	38.90	9.08	28.19	51.90
2002	9	44.26	13.30	24.53	60.85
2003	4	11.53	5.36	5.89	19.65
2003	5	16.20	6.51	7.31	25.24
2003	6	15.55	6.08	6.95	31.58
2003	7	12.56	6.91	1.74	24.81
2003	8	12.05	8.11	3.92	24.44
2003	9	14.78	3.63	9.37	19.56
2004	4	8.17	1.67	6.34	9.71
2004	5	10.78	4.11	5.77	17.22
2004	6	16.19	7.68	5.16	37.38
2004	7	17.04	8.49	9.58	33.01
2004	8	19.41	7.58	7.60	25.45
2004	9	21.41	4.34	16.43	27.52

Total Nitrite + Nitrate by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	0.64	0.39	0.30	1.30
2002	5	0.45	0.23	0.22	0.76
2002	6	1.82	1.22	0.38	3.55
2002	7	7.97	9.77	2.28	32.55
2002	8	3.44	0.72	2.18	4.01
2002	9	1.89	2.35	0.73	6.08
2003	4	0.21	0.21	0.02	0.57
2003	5	0.42	0.19	0.30	0.75
2003	6	0.63	0.46	0.15	1.93
2003	7	0.54	0.19	0.33	0.85
2003	8	0.65	0.34	0.30	1.08
2003	9	0.19	0.08	0.15	0.32
2004	4	0.75	0.59	0.27	1.53
2004	5	0.18	0.08	0.12	0.31
2004	6	0.47	0.18	0.21	1.11
2004	7	0.41	0.05	0.34	0.48
2004	8	0.54	0.28	0.31	0.97
2004	9	0.56	0.10	0.48	0.73

Total Ammonia by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	0.82	0.14	0.64	1.07
2002	5	0.53	0.26	0.28	0.96
2002	6	0.44	0.19	0.26	0.98
2002	7	0.43	0.23	0.26	0.99
2002	8	0.26	0.00	0.26	0.26
2002	9	1.98	1.00	1.16	3.40
2003	4	1.27	0.84	0.66	2.69
2003	5	1.97	1.13	0.67	3.66
2003	6	2.99	1.44	1.10	6.35
2003	7	2.84	3.02	1.18	11.16
2003	8	2.34	0.89	1.51	3.75
2003	9	3.60	1.51	2.63	6.24
2004	4	3.39	1.43	2.49	5.93
2004	5	1.70	0.58	1.21	2.63
2004	6	3.08	1.89	0.67	9.58
2004	7	2.38	1.64	1.04	6.26
2004	8	1.46	0.85	0.62	2.87
2004	9	4.04	3.41	1.20	8.83

Total Dissolved Inorganic Nitrogen by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	1.46	0.47	1.15	2.37
2002	5	0.98	0.26	0.72	1.31
2002	6	2.26	1.28	0.74	3.96
2002	7	8.40	9.75	2.54	32.81
2002	8	3.70	0.72	2.44	4.27
2002	9	6.16	8.93	1.06	22.06
2003	4	1.48	0.89	0.69	2.83
2003	5	2.39	1.27	1.08	4.41
2003	6	3.62	1.70	1.24	7.26
2003	7	3.38	3.06	1.52	11.79
2003	8	2.98	1.13	1.81	4.83
2003	9	3.79	1.52	2.78	6.42
2004	4	4.14	1.21	3.15	6.20
2004	5	1.88	0.57	1.36	2.82
2004	6	3.55	2.00	1.16	10.68
2004	7	2.78	1.63	1.42	6.62
2004	8	2.00	0.96	0.93	3.55
2004	9	4.60	3.48	1.69	9.56

Dissolved Inorganic Nitrogen divided by Dissolved Organic Nitrogen by month and year. Note that month 4 = April, 5 = May, 6 = June, 7 = July, 8= August, 9 = September.

Year	Month	Mean	Standard Deviation	Minimum	Maximum
2002	4	0.13	0.07	0.08	0.27
2002	5	0.07	0.04	0.05	0.13
2002	6	0.14	0.10	0.04	0.40
2002	7	4.68	12.96	0.06	41.40
2002	8	0.10	0.03	0.06	0.14
2002	9	0.22	0.38	0.03	0.90
2003	4	0.16	0.13	0.06	0.37
2003	5	0.16	0.09	0.07	0.26
2003	6	0.27	0.20	0.09	0.90
2003	7	0.87	2.08	0.06	6.77
2003	8	0.43	0.47	0.12	1.23
2003	9	0.27	0.11	0.15	0.44
2004	4	0.54	0.27	0.32	0.97
2004	5	0.20	0.09	0.08	0.31
2004	6	0.26	0.17	0.07	0.75
2004	7	0.22	0.20	0.05	0.67
2004	8	0.13	0.09	0.04	0.25
2004	9	0.22	0.18	0.06	0.50

Table 7d. Nitrogen species in April: Kruskal Wallis and Wilcoxon p-values between bloom (2002) and non-bloom (2003-04) years.

Nitrogen Species	Kruskal Wallis P-Value	Wilcoxon P-Value
Total Nitrogen	0.6012	0.4808
Dissolved Organic Nitrogen	0.1531	0.1752
Nitrite and Nitrate	0.0515	0.2123
Ammonia	0.0091	0.0442
Dissolved Inorganic Nitrogen	0.0069	0.2548
DIN / DON	0.0149	0.0927

Table 7e. Nitrogen species correlations with log *A. anophagefferens* abundance (2002-2004).

Nitrogen Species	**R^2 Log A.a.** cells ml^{-1}
Total Nitrogen	0.0498
Dissolved Organic Nitrogen	0.0229
Nitrite + Nitrate	0.0520
Ammonia	0.0909
Dissolved Inorganic Nitrogen	0.0726
DIN / DON	0.0503

Figures

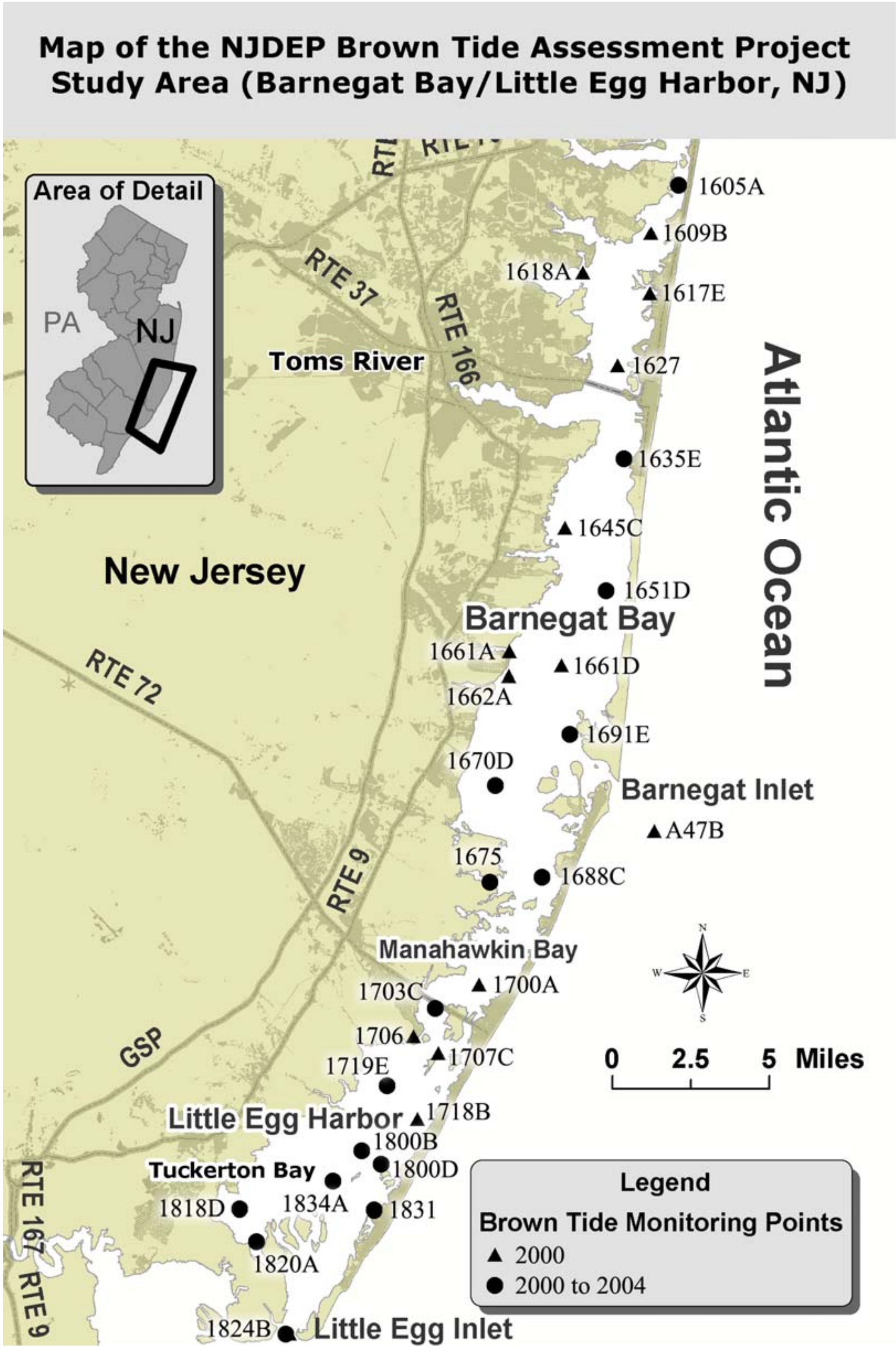

Figure 1. *A. anophagefferens* monitoring stations 2000-2004.

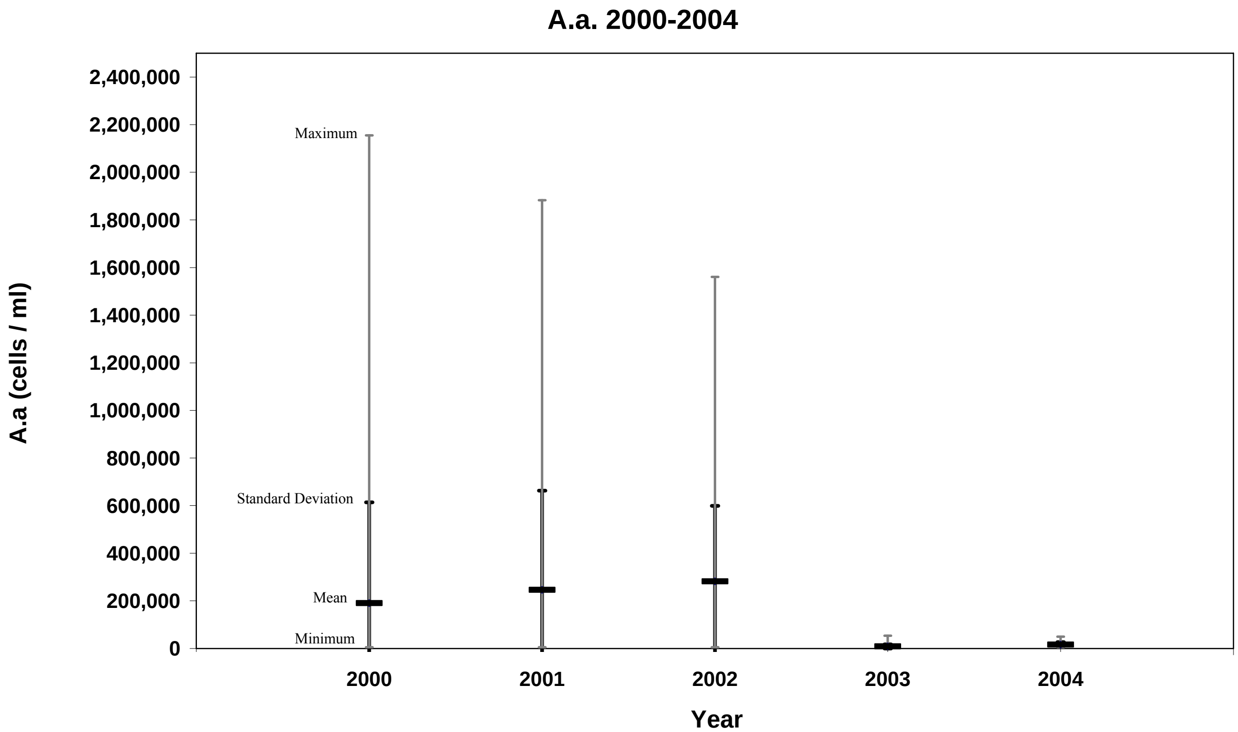

Figure 2. *Aureococcus anophagefferens* abundance (cells ml^{-1}) for the years 2000-2004; overall mean, standard deviation, minimum, and maximum.

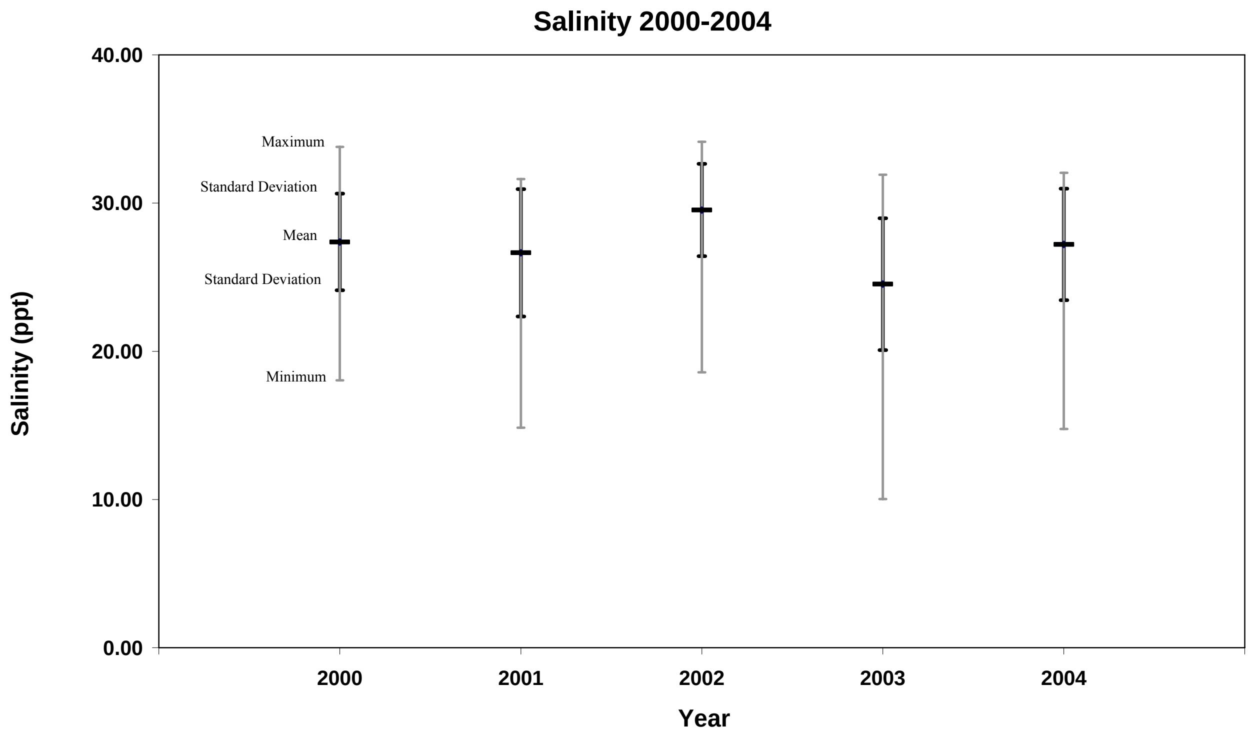

Figure 3. Salinity (parts per thousand) for the years 2000-2004: overall mean, standard deviation, minimum and maximum.

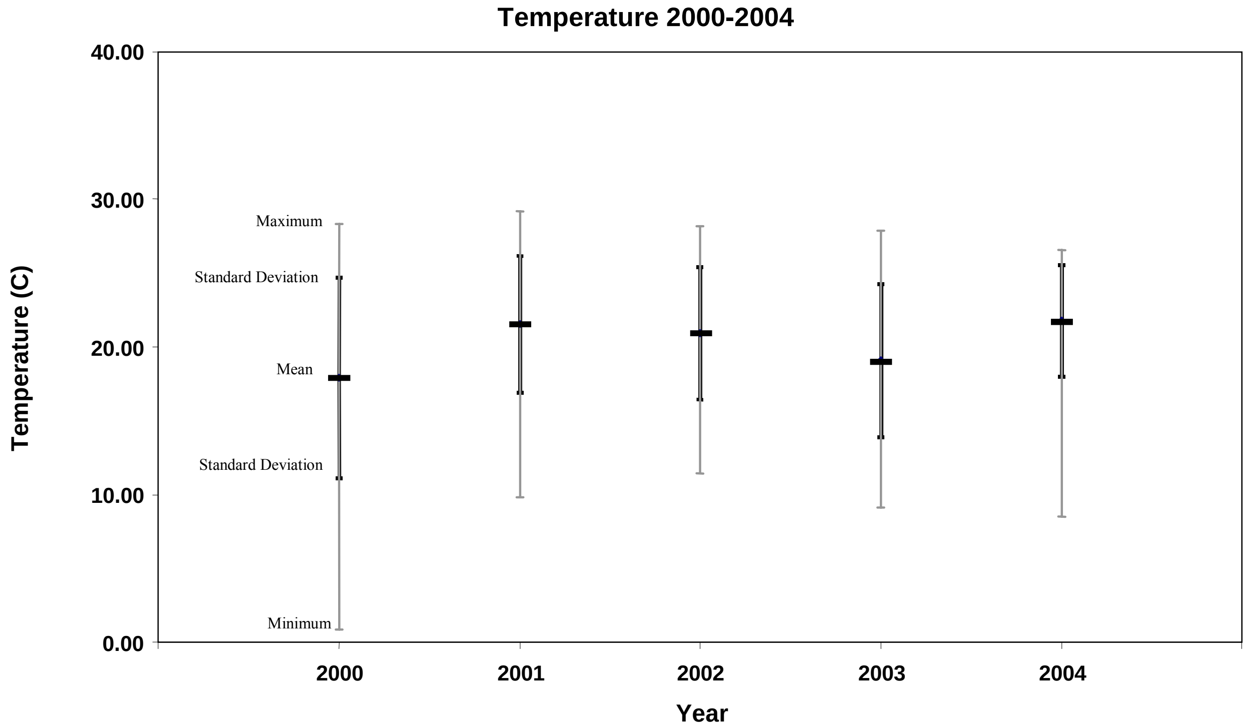

Figure 4. Temperature (C) of water for the years 2000-2004: overall mean, standard deviation, minimum and maximum.

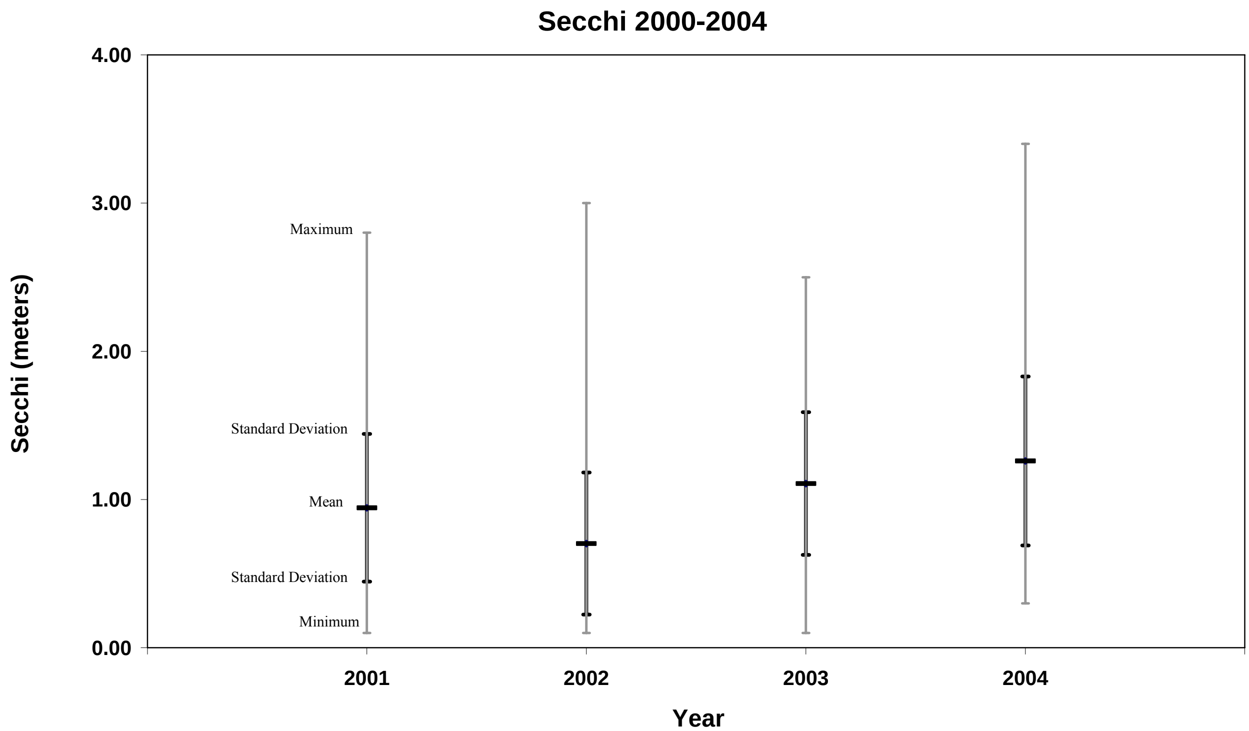

Figure 5. Secchi Disk Depth (meters) for the years 2000-2004: overall mean, standard deviation, minimum and maximum.

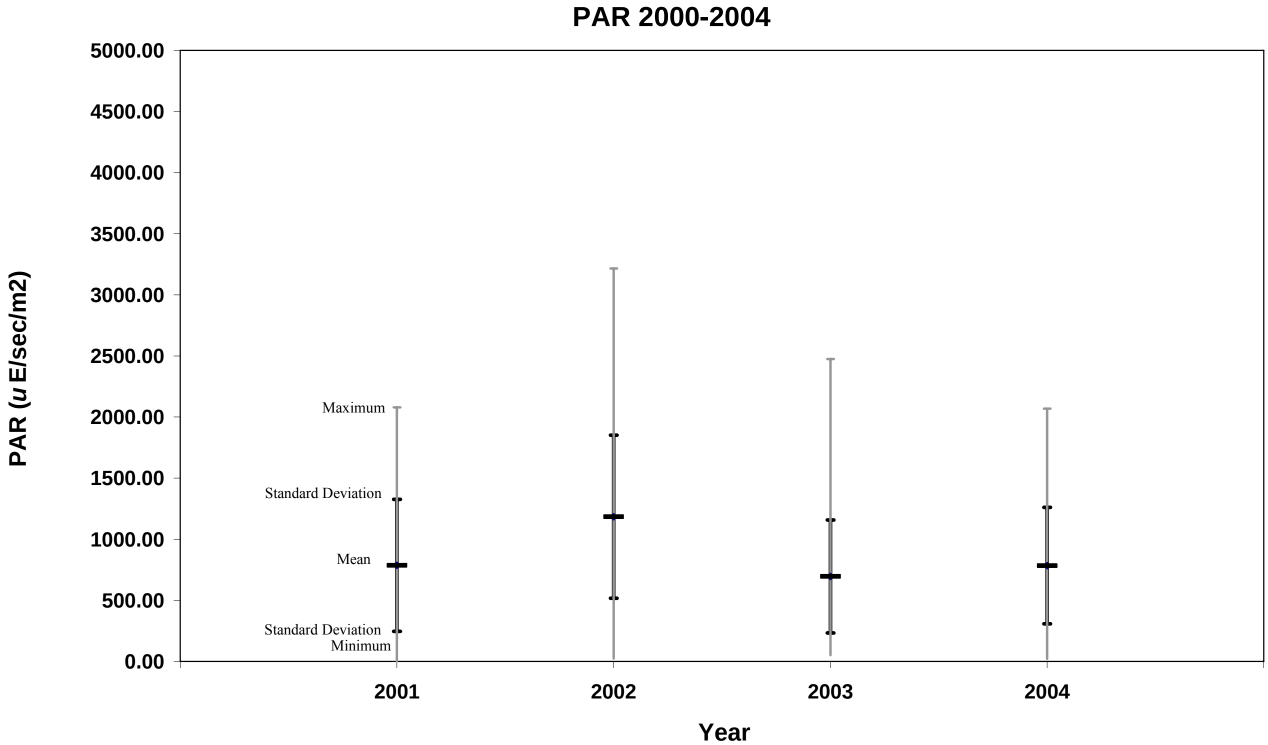

Figure 6. PAR (μE/sec/m^2) for the years 2000-2004: overall mean, standard deviation, minimum and maximum.

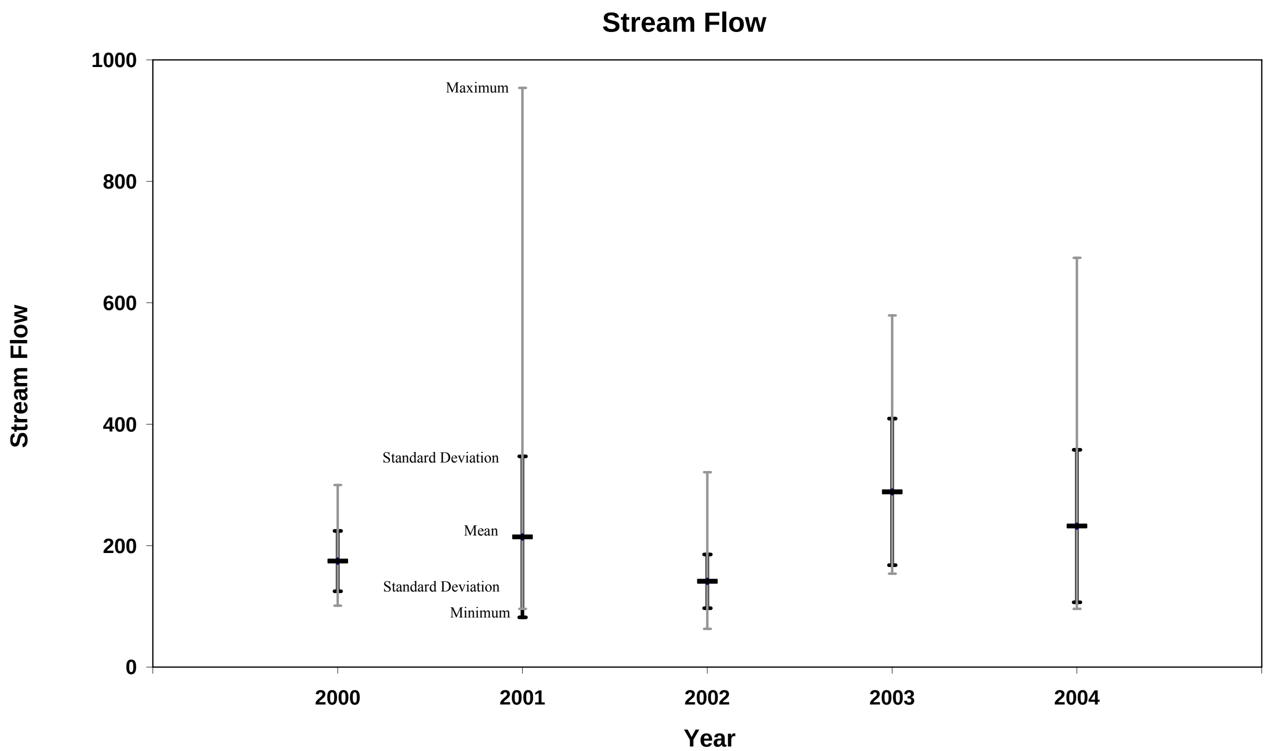

Figure 7. Stream Flow (ft³ sec⁻¹) for April – June 2000-2004: overall mean, standard deviation, minimum and maximum.

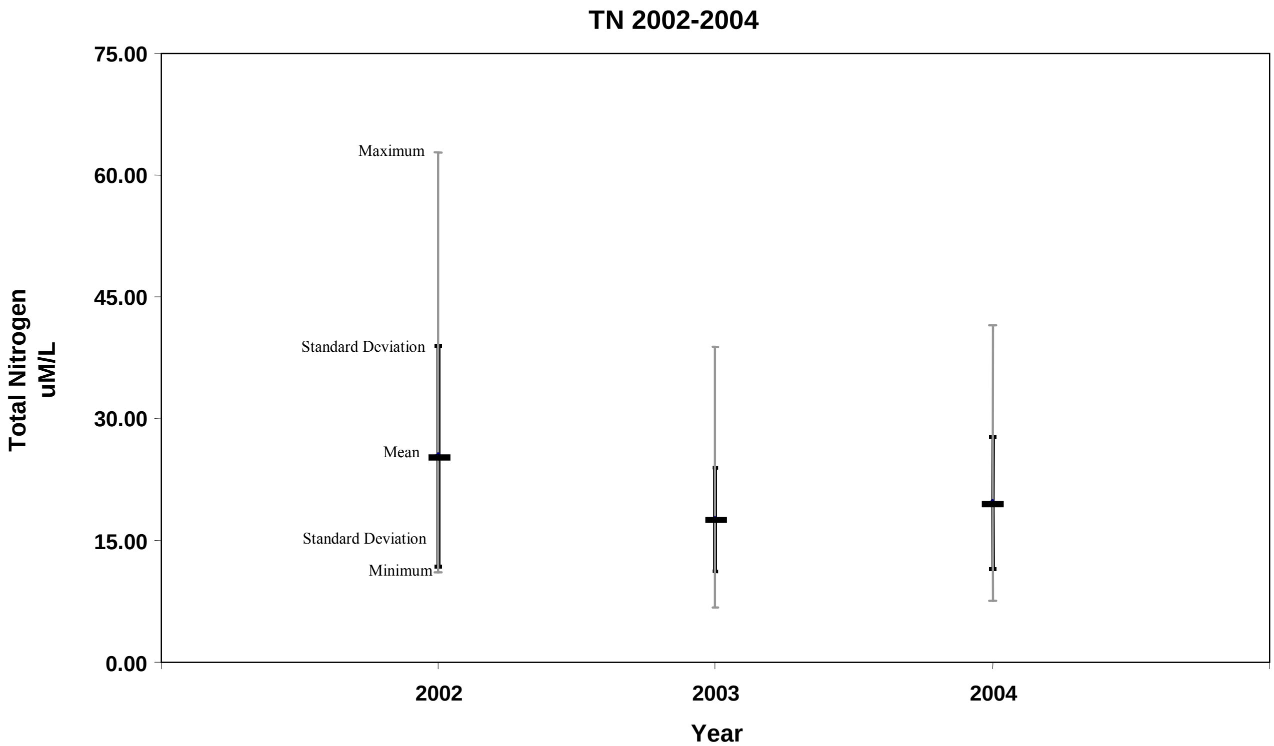

Figure 8. Total Nitrogen (TN; uM/L) for the years 2002-2004: overall mean, standard deviation, minimum and maximum.

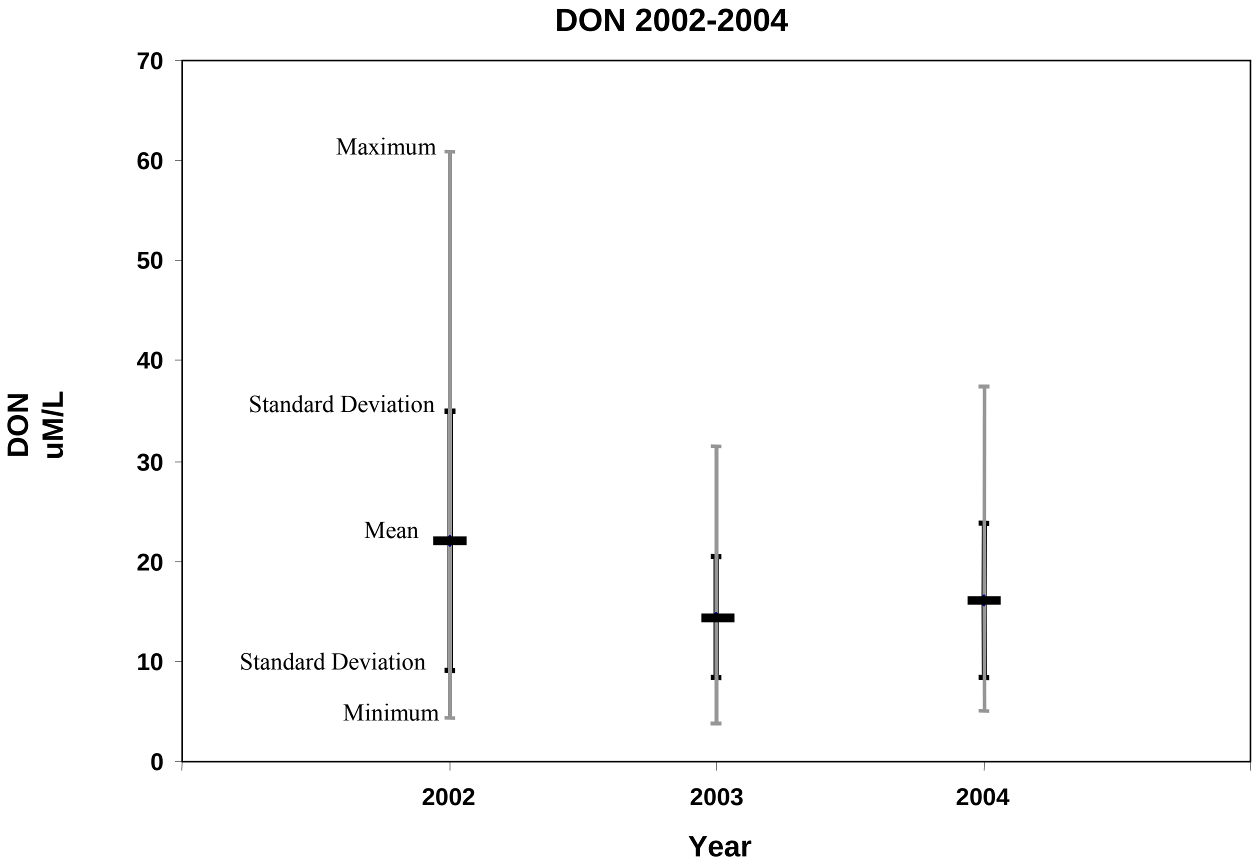

Figure 9. Dissolved Organic Nitrogen (DON; uM/L) for the years 2002-2004: overall mean, standard deviation, minimum and maximum.

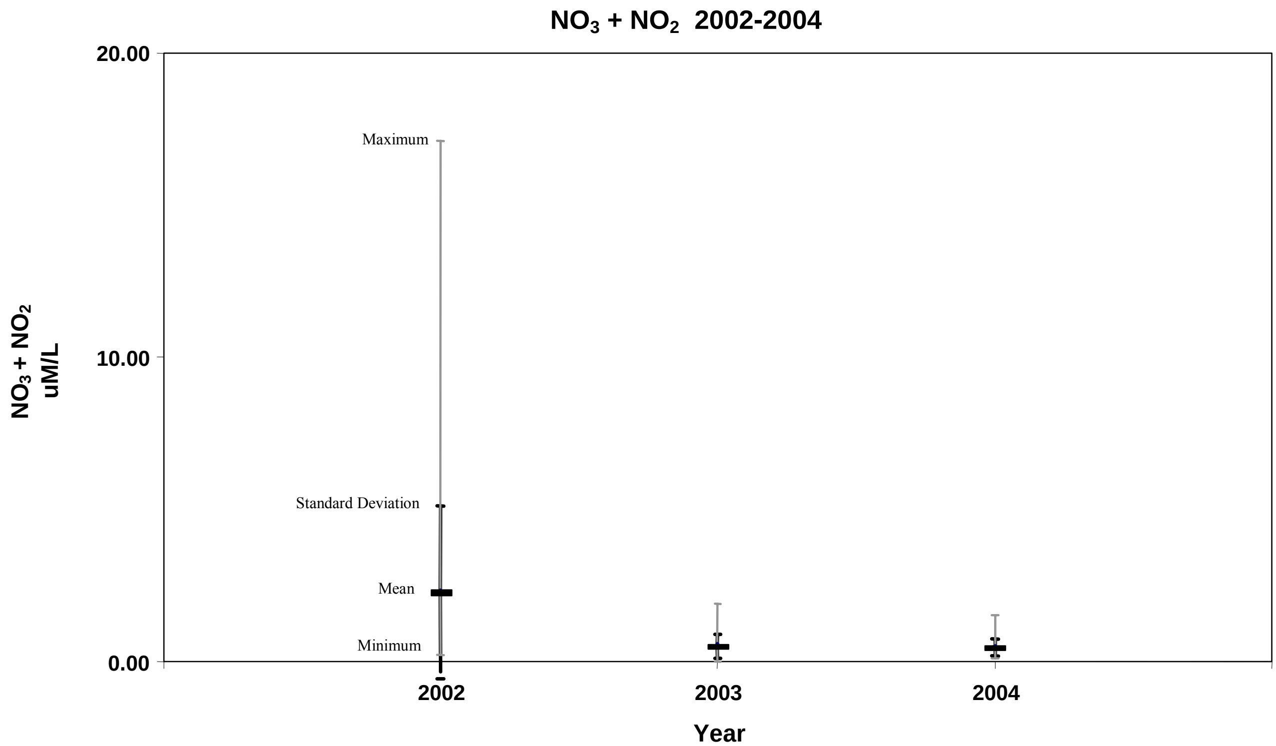

Figure 10. Nitrate+Nitrite (NO_3+$NO_{2;}$ uM/L) for the years 2002-2004: overall mean, standard deviation, minimum and maximum.

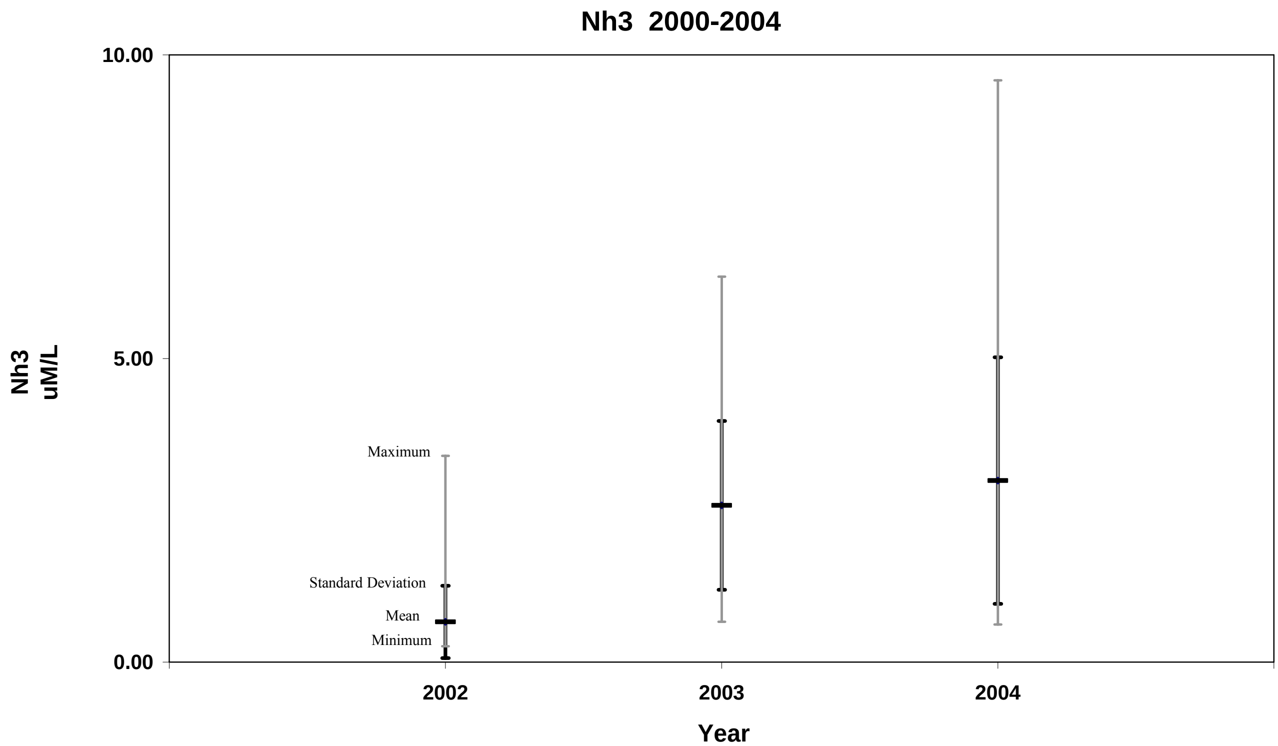

Figure 11. Ammonia ($NH_{3;}$ uM/L) for the years 2002-2004: overall mean, standard deviation, minimum and maximum.

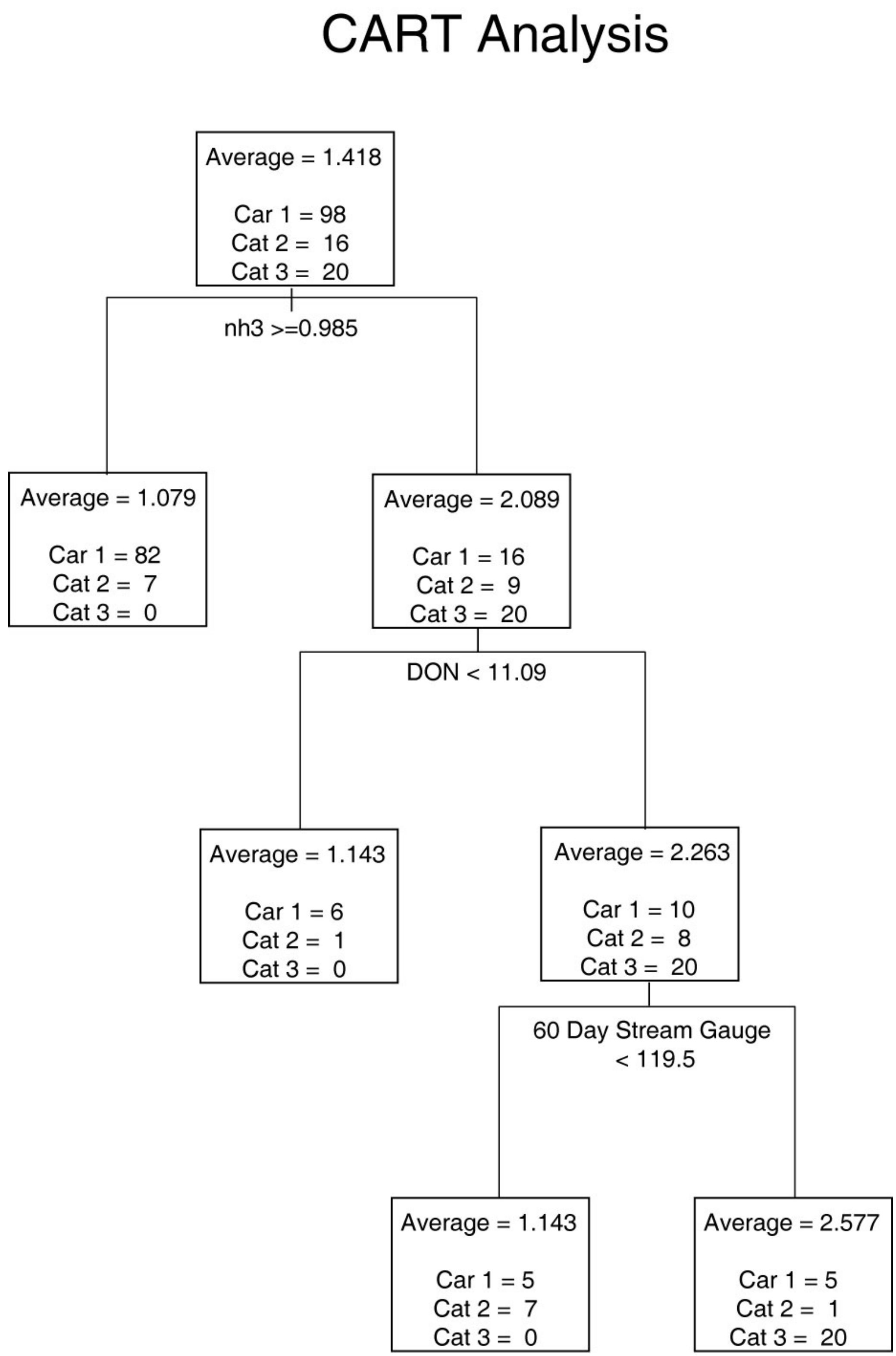

Figure 12. Cartographic and Regression Tree Analysis (CART)

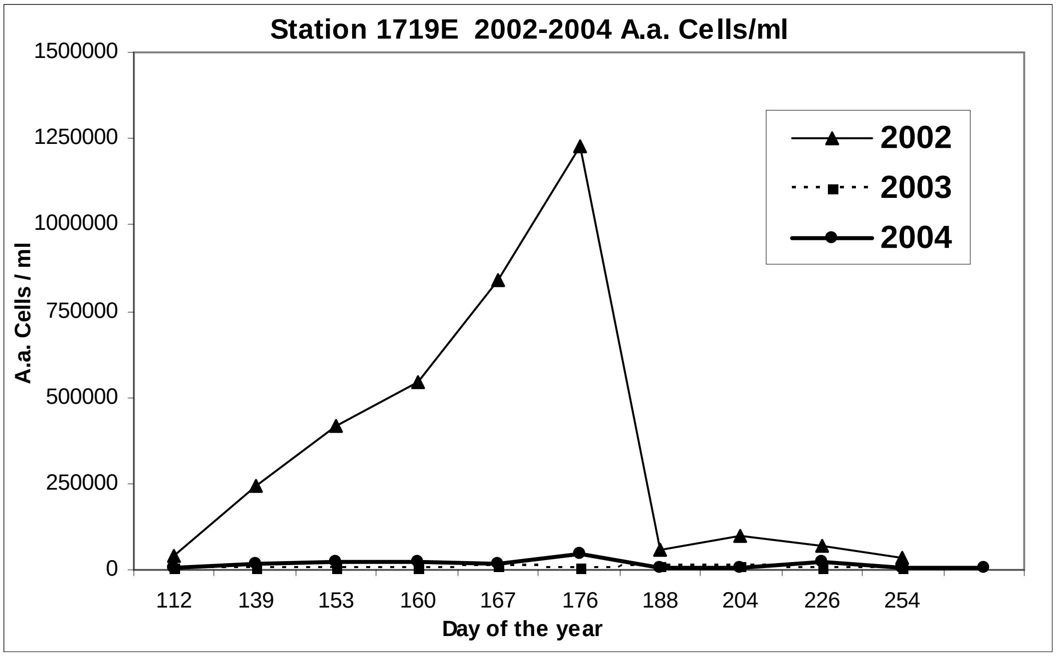

Figure 13. Individual Station Analysis (1719E) 2002-2004 *A. anophagefferens* abundance (cells ml^{-1})

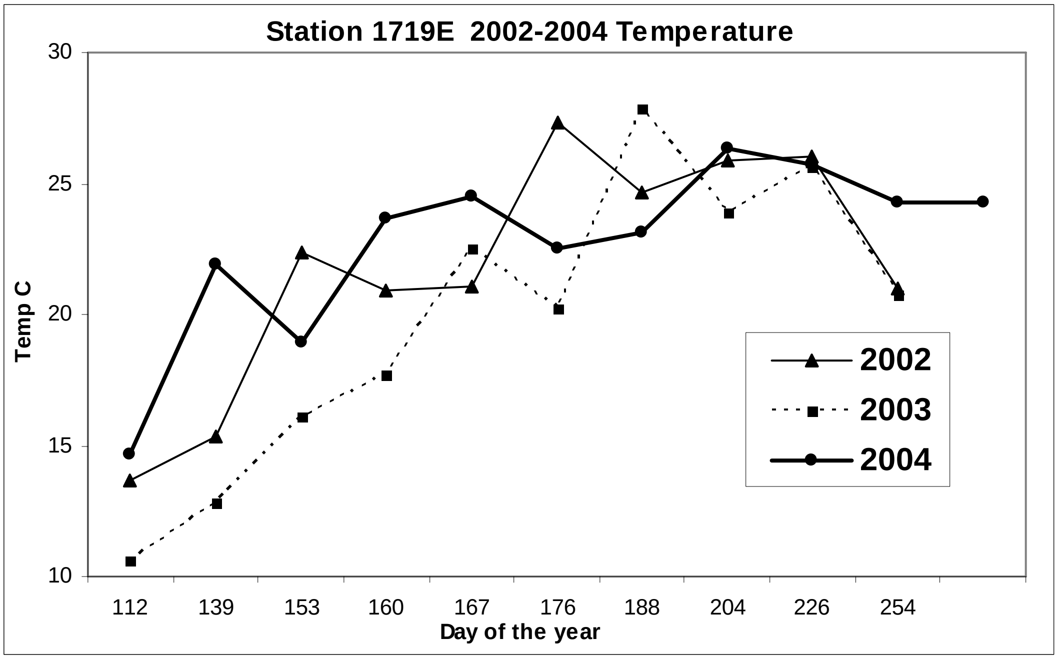

Figure 14. Individual Station Analysis (1719E) 2002-2004 Water Temperature (C)

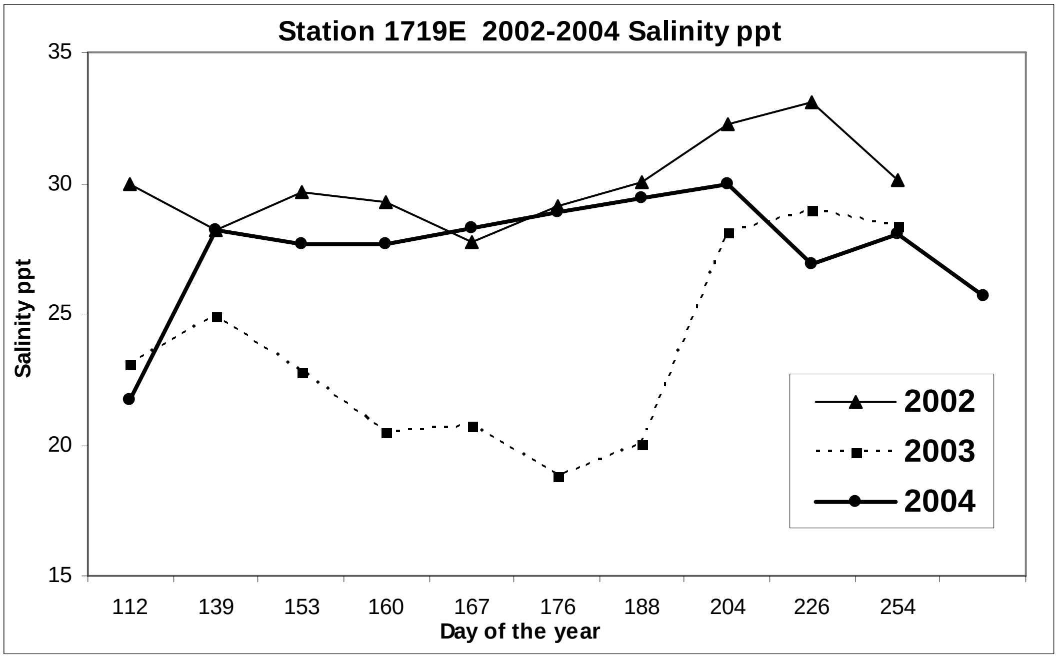

Figure 15. Individual Station Analysis (1719E) 2002-2004 Salinity (ppt)

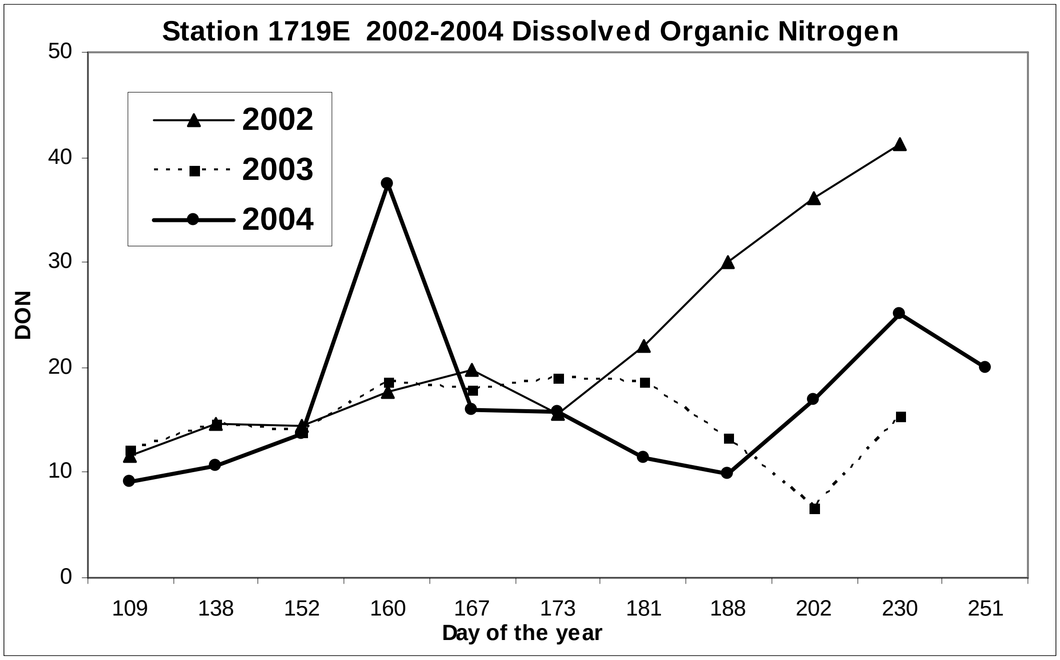

Figure 16. Individual Station Analysis (1719E) 2002-2004 Dissolved Organic Nitrogen (uM/L)

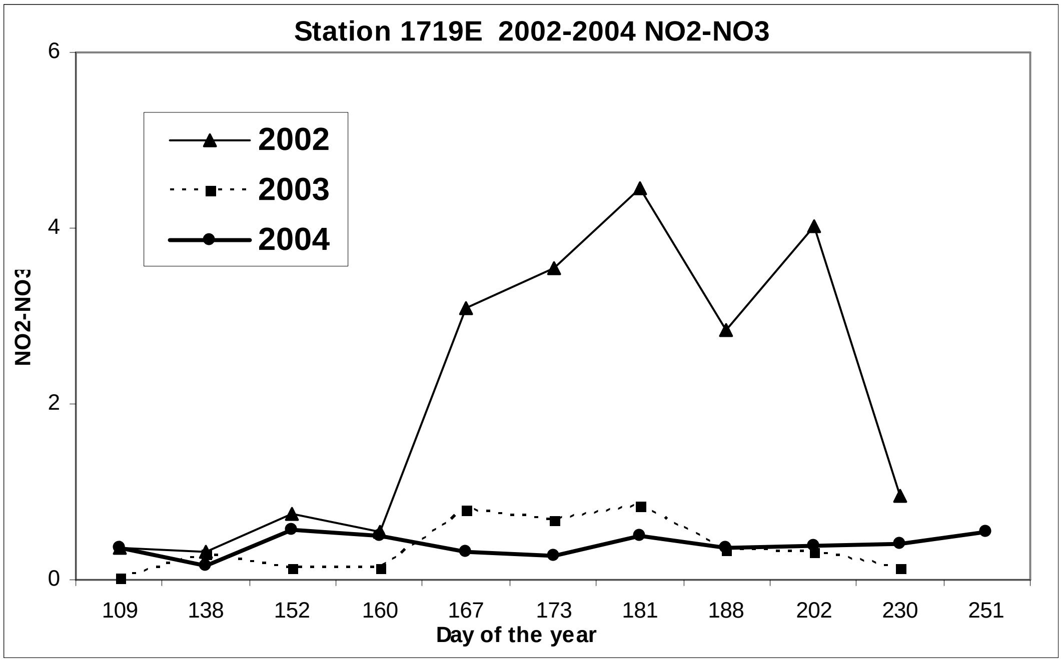

Figure 17. Individual Station Analysis (1719E) 2002-2004 Nitrite + Nitrate (uM/L)

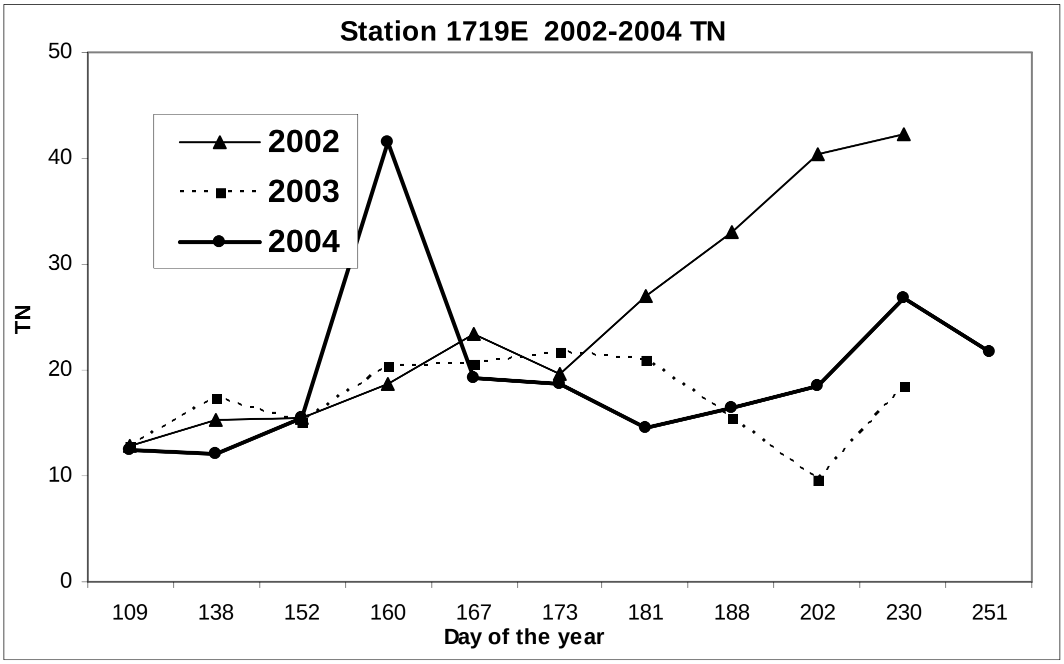

Figure 18. Individual Station Analysis (1719E) 2002-2004 Total Nitrogen (uM/L)

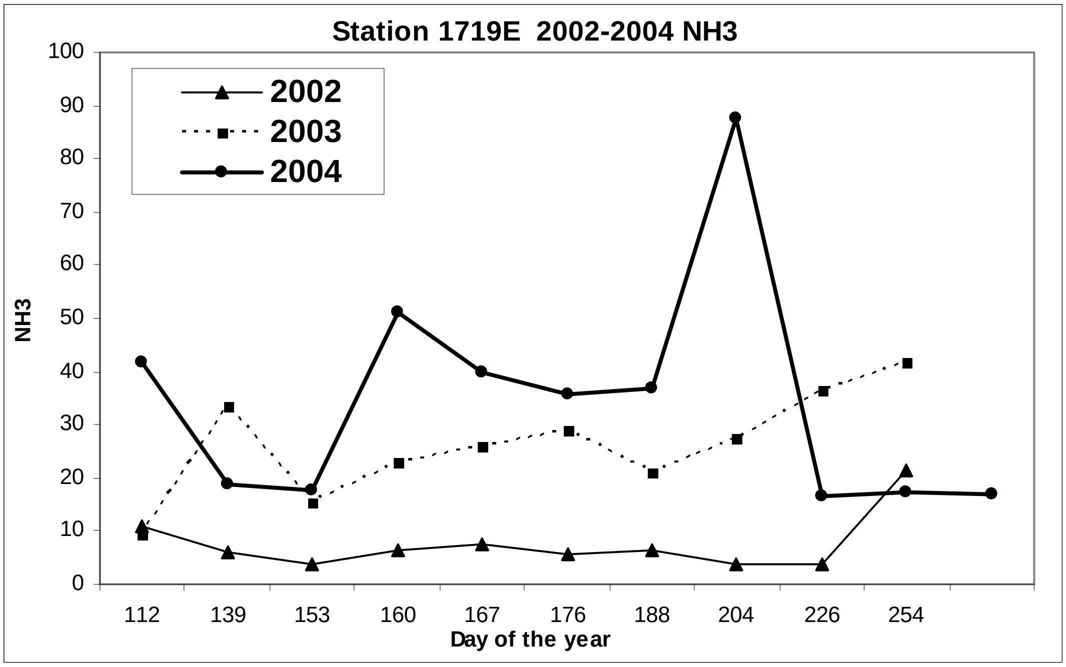

Figure 19. Individual Station Analysis (1719E) 2002-2004 Ammonium (uM/L)

Appendix I   Sampling Data

Table 1. Sampling dates for 2000-2004 brown tide (*A. anophagefferens)* counts and other environmental factors.

Table 1A. Number of Samples Collected for Brown Tide - Year, Date, # of Samples Collected, Collection Method (B = Boat, H = Helicopter), Total Number of *A. anophagefferens* samples.

Year	**Date**	**# of Samples**	**B/H**	**Bt**
2000	24,27,28-April	42	B	42
2000	5-Jun	1	B	1
2000	6,7,8,9-Jun	20	B	20
2000	13,14,15-Jun	13	B/H	13
2000	19-Jun	3	B	3
2000	20-Jun	1	B	1
2000	23-Jun	2	B	2
2000	28-29-Jun	10	B/H	10
2000	6-Jul	2	B	2
2000	12-Jul	8	H	8
2000	27-Jul	8	H	8
2000	3-Aug	1	B	1
2000	7,8,9-Aug	22	B/H	22
2000	10-Aug	1	B	1
2000	14-Aug	3	B	3
2000	15-Aug	5	B	5
2000	17-Aug	3	B	3
2000	18-Aug	2	B	2
2000	23-Aug	8	H	8
2000	29-Aug	12	B	12
2000	31-Aug	4	B	4

2000	6-Sep	4	B	4
2000	7,12-Sep	10	B	10
2000	15-Sep	4	B	4
2000	19-Sep	5	B	5
2000	20-Sep	2	B	2
2000	28-Sep	5	B	5
2000	29-Sep	7	B	7
2000	1-Nov	3	B	3
2000	6-Nov	5	B	5
2000	8-Nov	3	B	3
2000	20-Nov	1	B	1
2000	21-Nov	5	B	5
2000	27-Nov	5	B	5
2000	28-Nov	3	B	3
2000	1-Dec	1	B	1
2000	6-Dec	2	B	2
2000	11-Dec	1	B	1
2000	15-Dec	6	B	6
2000	19-Dec	1	B	1
2000	21-Dec	1	B	1
Totals		**245**	**n/a**	**245**
Year	**Date**	**# of Samples**	**B/H**	**Bt**
2001	16-Apr	10	B	10
2001	20-Apr	7	B	7
2001	25-May	10	B	10
2001	30-May	6	H	6
2001	4-Jun	11	B	11
2001	11-Jun	11	B	11
2001	18-Jun	11	B	11
2001	20-Jun	6	H	6
2001	25-Jun	11	B	10
2001	5-Jul	6	H	6
2001	11-Jul	11	B	11
2001	18-Jul	5	H	5

2001	27-Jul	11	B	11
2001	8-Aug	5	H	5
2001	10-Aug	11	B	11
2001	22-Aug	6	H	6
2001	7-Sep	11	B	11
Total		**149**	**n/a**	**148**

Year	**Date**	**# of Samples**	**B/H**	**Bt**
2002	23-Apr	11	B	11
2002	5-May	1	B	1
2002	14-May	1	B	1
2002	20-May	11	B	11
2002	3-Jun	11	B	10
2002	10-Jun	11	B	11
2002	12-Jun	5	H	5
2002	17-Jun	12	B	12
2002	20-Jun	6	H	6
2002	26-Jun	11	B	11
2002	3-Jul	5	H	5
2002	8-Jul	11	B	11
2002	24-Jul	11	B	11
2002	15-Aug	11	B	11
2002	12-Sep	11	B	11
Total		**129**	**n/a**	**128**

Year	**Date**	**# of Samples**	**B/H**	**Bt**
2003	21-Apr	11	B	11
2003	19-May	11	B	11
2003	2-Jun	11	B	11
2003	9-Jun	11	B	11
2003	16-Jun	11	B	11
2003	17-Jun	6	H	6
2003	23-Jun	11	B	11
2003	25-Jun	6	H	6
2003	7-Jul	11	B	11

2003	9-Jul	6	H	6
2003	24-Jul	11	B	11
2003	31-Jul	5	H	5
2003	13-Aug	11	B	11
2003	20-Aug	3	H	3
2003	10-Sep	11	B	11
TOTAL		**136**		**136**

Year	**Date**	**# of Samples**	**B/H**	**Bt**
2004	19-Apr	11	B	11
2004	18-May	11	B	11
2004	1-Jun	11	B	11
2004	2-Jun	4	B	4
2004	9-Jun	16	B/H	16
2004	16-Jun	6	H	6
2004	22-Jun	11	B	11
2004	23-Jun	5	H	5
2004	30-Jun	11	B	11
2004	7-Jul	16	B/H	16
2004	21-Jul	11	B	11
2004	4-Aug	6	H	6
2004	18-Aug	16	B/H	16
2004	1-Sep	4	H	4
2004	8-Sep	11	B	11
TOTAL		**150**		**150**

Table 1B. Nutrient Monitoring Dates 2002 – 2004: Year, Date, # of Samples, NH3, NO3 + NO2, Dissolved Organic Nitrogen, Total Nitrogen.

Year	Date	# of Samples	NH3	NO3 + NO2	DIS Organic Nitrogen	Total Nitrogen
2002	23-Apr	6	6	6	6	6
2002	20-May	5	5	5	5	5
2002	3-Jun	5	5	5	5	5
2002	10-Jun	5	5	5	5	5
2002	17-Jun	5	5	5	5	5
2002	26-Jun	5	5	5	5	5
2002	8-Jul	5	5	5	5	5
2002	24-Jul	5	5	5	5	5
2002	15-Aug	5	5	5	5	5
2002	12-Sep	5	5	5	5	5
Total 2002	**n/a**	**51**	**51**	**51**	**51**	**51**
2003	21-Apr	5	5	5	5	5
2003	19-May	5	5	5	5	5
2003	2-Jun	5	5	5	5	5
2003	9-Jun	5	5	5	5	5
2003	12-Jun	1	1	1	1	1
2003	16-Jun	5	5	5	5	5
2003	23-Jun	5	5	5	5	5
2003	7-Jul	5	5	5	5	5
2003	24-Jul	5	5	5	5	5
2003	13-Aug	5	5	5	5	5
2003	10-Sep	5	5	5	5	5
Total 2003	**n/a**	**51**	**51**	**51**	**51**	**51**
2004	19-Apr	5	5	5	5	5
2004	18-May	5	5	5	5	5
2004	1-Jun	5	5	5	5	5
2004	09-Jun	5	5	5	5	5
2004	16-Jun	5	5	5	5	5
2004	22-Jun	5	5	5	5	5
2004	30-Jun	5	5	5	5	5
2004	7-Jul	5	5	5	5	5
2004	21-Jul	5	5	5	5	5
2004	18-Aug	5	5	5	5	5
2004	8-Sept	5	5	5	5	5
Total 2004	**n/a**	**55**	**55**	**55**	**55**	**55**

Appendix II Statistical Outputs

Wilcoxon test between bloom and non-bloom years environmental data

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The NPAR1WAY Procedure

Analysis of Variance for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Mean
yes	260	21.290346
no	231	20.472814

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	81.754878	81.754878	3.8319	0.0509
Within	489	10433.021140	21.335422		

Average scores were used for ties.

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	260	67067.0	63960.0	1569.21753	257.950000
no	231	53719.0	56826.0	1569.21753	232.549784

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	53719.0000
Normal Approximation	
Z	-1.9796
One-Sided Pr < Z	0.0239
Two-Sided Pr > |Z|	0.0477
t Approximation	
One-Sided Pr < Z	0.0242
Two-Sided Pr > |Z|	0.0483

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	3.9203
DF	1
Pr > Chi-Square	0.0477

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	260	139.0	129.735234	5.535588	0.534615
no	231	106.0	115.264766	5.535588	0.458874

Average scores were used for ties.

Median Two-Sample Test

Statistic	106.0000
Z	-1.6737
One-Sided Pr < Z	0.0471
Two-Sided Pr > |Z|	0.0942

Median One-Way Analysis

Chi-Square	2.8012
DF	1
Pr > Chi-Square	0.0942

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	260	25.759299	0.0	10.950482	0.099074
no	231	-25.759299	0.0	10.950482	-0.111512

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	-25.7593
Z	-2.3523
One-Sided Pr < Z	0.0093
Two-Sided Pr > |Z|	0.0187

Van der Waerden One-Way Analysis

Chi-Square	5.5335
DF	1
Pr > Chi-Square	0.0187

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	260	26.393021	0.0	10.993991	0.101512
no	231	-26.393021	0.0	10.993991	-0.114256

Average scores were used for ties.

Savage Two-Sample Test

Statistic	-26.3930
Z	-2.4007
One-Sided Pr < Z	0.0082
Two-Sided Pr > |Z|	0.0164

Savage One-Way Analysis

Chi-Square	5.7633
DF	1
Pr > Chi-Square	0.0164

The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
yes	260	0.330769	-0.774775
no	231	0.432900	0.821971
Total	491	0.378819	

Maximum Deviation Occurred at Observation 417
Value of Temp_C at Maximum = 20.610

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)

KS	0.050976	D	0.102131
KSa	1.129563	Pr > KSa	0.1558

Cramer-von Mises Test for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
yes	260	0.187728
no	231	0.211295

Cramer-von Mises Statistics (Asymptotic)
CM 0.000813 CMa 0.399023

Kuiper Test for Variable Temp_C
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
yes	260	0.006660
no	231	0.102131

Kuiper Two-Sample Test (Asymptotic)
K 0.108791 Ka 1.203222 Pr > Ka 0.5300

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The NPAR1WAY Procedure

Analysis of Variance for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Mean
no	231	25.937056
yes	226	28.068009

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	518.742448	518.742448	29.8361	<.0001
Within	455	7910.818602	17.386415		

Average scores were used for ties.

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	231	44495.0	52899.0	1411.56481	192.619048
yes	226	60158.0	51754.0	1411.56481	266.185841

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	60158.0000
Normal Approximation	
Z	5.9533
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	35.4463
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	231	89.0	115.247265	5.349913	0.385281
yes	226	139.0	112.752735	5.349913	0.615044

Average scores were used for ties.

Median Two-Sample Test

Statistic	139.0000
Z	4.9061
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Median One-Way Analysis

Chi-Square	24.0699
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	231	-64.367747	0.0	10.576098	-0.278648
yes	226	64.367747	0.0	10.576098	0.284813

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	64.3677
Z	6.0862
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Van der Waerden One-Way Analysis

Chi-Square	37.0413
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	231	-63.589062	0.0	10.621028	-0.275277
yes	226	63.589062	0.0	10.621028	0.281368

Average scores were used for ties.

Savage Two-Sample Test

Statistic	63.5891
Z	5.9871
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Savage One-Way Analysis

Chi-Square	35.8453
DF	1
Pr > Chi-Square	<.0001

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The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
no	231	0.554113	1.936566
yes	226	0.296460	-1.957871
Total	457	0.426696	

Maximum Deviation Occurred at Observation 377
Value of Salinity_PPT at Maximum = 27.30

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)

KS 0.128818 D 0.257652
KSa 2.753825 Pr > KSa <.0001

Cramer-von Mises Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
no	231	1.717323
yes	226	1.755317

Cramer-von Mises Statistics (Asymptotic)

CM 0.007599 CMa 3.472639

Kuiper Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
no	231	0.257652
yes	226	0.004425

Kuiper Two-Sample Test (Asymptotic)

K 0.262077 Ka 2.801117 Pr > Ka <.0001

The NPAR1WAY Procedure

Analysis of Variance for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Mean
no	22	23.933636
yes	28	25.118214

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	17.287730	17.287730	0.5497	0.4621
Within	48	1509.621720	31.450452		

Average scores were used for ties.

```
              The NPAR1WAY Procedure

  Wilcoxon Scores (Rank Sums) for Variable Salinity_PPT
           Classified by Variable bloomyears

                 Sum of     Expected      Std Dev        Mean
bloomyears    N     Scores     Under H0     Under H0       Score
ƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒ
no           22     475.50        561.0    51.162710    21.613636
yes          28     799.50        714.0    51.162710    28.553571

           Average scores were used for ties.


              Wilcoxon Two-Sample Test

            Statistic           475.5000

            Normal Approximation
            Z                    -1.6614
            One-Sided Pr <  Z     0.0483
            Two-Sided Pr > |Z|    0.0966

            t Approximation
            One-Sided Pr <  Z     0.0515
            Two-Sided Pr > |Z|    0.1030

       Z includes a continuity correction of 0.5.


              Kruskal-Wallis Test

            Chi-Square          2.7927
            DF                  1
            Pr > Chi-Square     0.0947
```

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	22	8.0	11.0	1.772811	0.363636
yes	28	17.0	14.0	1.772811	0.607143

Average scores were used for ties.

Median Two-Sample Test

Statistic	8.0000
Z	-1.6922
One-Sided Pr < Z	0.0453
Two-Sided Pr > |Z|	0.0906

Median One-Way Analysis

Chi-Square	2.8636
DF	1
Pr > Chi-Square	0.0906

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	22	-5.394810	0.0	3.307446	-0.245219
yes	28	5.394810	0.0	3.307446	0.192672

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	-5.3948
Z	-1.6311
One-Sided Pr < Z	0.0514
Two-Sided Pr > |Z|	0.1029

Van der Waerden One-Way Analysis

Chi-Square	2.6605
DF	1
Pr > Chi-Square	0.1029

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	22	-7.172575	0.0	3.382255	-0.326026
yes	28	7.172575	0.0	3.382255	0.256163

Average scores were used for ties.

Savage Two-Sample Test

Statistic	-7.1726
Z	-2.1206
One-Sided Pr < Z	0.0170
Two-Sided Pr > |Z|	0.0340

Savage One-Way Analysis

Chi-Square	4.4972
DF	1
Pr > Chi-Square	0.0340

The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
no	22	0.772727	0.810163
yes	28	0.464286	-0.718132
Total	50	0.600000	

Maximum Deviation Occurred at Observation 47
Value of Salinity_PPT at Maximum = 25.860

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)
KS 0.153106 D 0.308442
KSa 1.082625 Pr > KSa 0.1917

Cramer-von Mises Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
no	22	0.206049
yes	28	0.161896

Cramer-von Mises Statistics (Asymptotic)
CM 0.007359 CMa 0.367945

Kuiper Test for Variable Salinity_PPT
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
no	22	0.308442
yes	28	0.051948

Kuiper Two-Sample Test (Asymptotic)
K 0.360390 Ka 1.264962 Pr > Ka 0.4403

The NPAR1WAY Procedure

Analysis of Variance for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Mean
no	237	1.187764
yes	218	0.823394

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	15.075676	15.075676	55.2374	<.0001
Within	453	123.635203	0.272925		

Average scores were used for ties.

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	65777.0	54036.0	1396.18794	277.540084
yes	218	37963.0	49704.0	1396.18794	174.142202

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	37963.0000
Normal Approximation	
Z	-8.4090
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	70.7168
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	158.0	118.239560	5.026067	0.666667
yes	218	69.0	108.760440	5.026067	0.316514

Average scores were used for ties.

Median Two-Sample Test

Statistic	69.0000
Z	-7.9108
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Median One-Way Analysis

Chi-Square	62.5815
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	81.324604	0.0	10.504820	0.343142
yes	218	-81.324604	0.0	10.504820	-0.373049

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	-81.3246
Z	-7.7416
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Van der Waerden One-Way Analysis

Chi-Square	59.9331
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	66.834437	0.0	10.560485	0.282002
yes	218	-66.834437	0.0	10.560485	-0.306580

Average scores were used for ties.

Savage Two-Sample Test

Statistic	-66.8344
Z	-6.3287
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Savage One-Way Analysis

Chi-Square	40.0528
DF	1
Pr > Chi-Square	<.0001

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The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
no	237	0.434599	-2.749322
yes	218	0.807339	2.866629
Total	455	0.613187	

Maximum Deviation Occurred at Observation 239
Value of Secchi at Maximum = 1.0

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)
KS 0.186208 D 0.372740
KSa 3.971944 Pr > KSa <.0001

Cramer-von Mises Test for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
no	237	3.764769
yes	218	4.092891

Cramer-von Mises Statistics (Asymptotic)
CM 0.017270 CMa 7.857660

Kuiper Test for Variable Secchi
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
no	237	0.001471
yes	218	0.372740

Kuiper Two-Sample Test (Asymptotic)
K 0.374211 Ka 3.987618 Pr > Ka <.0001

The NPAR1WAY Procedure

Analysis of Variance for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Mean
no	237	741.113924
yes	212	983.462264

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	6572308.8656	6572308.866	21.7687	<.0001
Within	447	134956258.6222	301915.567		

Average scores were used for ties.

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	47604.50	53325.0	1372.64025	200.862869
yes	212	53420.50	47700.0	1372.64025	251.983491

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	53420.5000
Normal Approximation	
Z	4.1672
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	17.3682
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	98.0	118.236080	5.295074	0.413502
yes	212	126.0	105.763920	5.295074	0.594340

Average scores were used for ties.

Median Two-Sample Test

Statistic	126.0000
Z	3.8217
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	0.0001

Median One-Way Analysis

Chi-Square	14.6052
DF	1
Pr > Chi-Square	0.0001

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	-38.341182	0.0	10.465875	-0.161777
yes	212	38.341182	0.0	10.465875	0.180855

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	38.3412
Z	3.6634
One-Sided Pr > Z	0.0001
Two-Sided Pr > |Z|	0.0002

Van der Waerden One-Way Analysis

Chi-Square	13.4208
DF	1
Pr > Chi-Square	0.0002

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	237	-51.549616	0.0	10.511019	-0.217509
yes	212	51.549616	0.0	10.511019	0.243159

Average scores were used for ties.

Savage Two-Sample Test

Statistic	51.5496
Z	4.9043
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Savage One-Way Analysis

Chi-Square	24.0526
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable PAR
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
no	237	0.801688	1.850044
yes	212	0.547170	-1.956088
Total	449	0.681514	

Maximum Deviation Occurred at Observation 28
Value of PAR at Maximum = 1099.0

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)

KS	0.127062	D	0.254518
KSa	2.692386	Pr > KSa	<.0001

Cramer-von Mises Test for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
no	237	1.127284
yes	212	1.260218

Cramer-von Mises Statistics (Asymptotic)
CM 0.005317 CMa 2.387502

Kuiper Test for Variable PAR
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
no	237	0.254518
yes	212	0.052643

Kuiper Two-Sample Test (Asymptotic)
K 0.307161 Ka 3.249265 Pr > Ka <.0001

The NPAR1WAY Procedure

Analysis of Variance for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Mean
yes	4757	262.728505
no	2351	200.284432

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Among	1	6135088.18750	6135088.187	821.8463	<.0001
Within	7106	53046340.02489	7465.007		

Average scores were used for ties.

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	4757	19010005.0	16908756.5	81394.8722	3996.21715
no	2351	6255381.0	8356629.5	81394.8722	2660.73203

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	6255381.0000
Normal Approximation	
Z	-25.8155
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	666.4395
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Median Scores (Number of Points Above Median) for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	4757	2773.0	2378.50	19.815237	0.582930
no	2351	781.0	1175.50	19.815237	0.332199

Average scores were used for ties.

Median Two-Sample Test

Statistic	781.0000
Z	-19.9089
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Median One-Way Analysis

Chi-Square	396.3652
DF	1
Pr > Chi-Square	<.000

The NPAR1WAY Procedure

Van der Waerden Scores (Normal) for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	4757	1046.9559	0.0	39.609030	0.220087
no	2351	-1046.9559	0.0	39.609030	-0.445324

Average scores were used for ties.

Van der Waerden Two-Sample Test

Statistic	-1046.9559
Z	-26.4323
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Van der Waerden One-Way Analysis

Chi-Square	698.6639
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Savage Scores (Exponential) for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
yes	4757	861.42472	0.0	39.502650	0.181086
no	2351	-861.42472	0.0	39.502650	-0.366408

Average scores were used for ties.

Savage Two-Sample Test

Statistic	-861.4247
Z	-21.8068
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Savage One-Way Analysis

Chi-Square	475.5347
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Kolmogorov-Smirnov Test for Variable Sol
Classified by Variable bloomyears

bloomyears	N	EDF at Maximum	Deviation from Mean at Maximum
yes	4757	0.323733	-6.655515
no	2351	0.615483	9.467208
Total	7108	0.420231	

Maximum Deviation Occurred at Observation 710
Value of Sol at Maximum = 246.30

Kolmogorov-Smirnov Two-Sample Test (Asymptotic)

KS	0.137264	D	0.291749
KSa	11.572549	Pr > KSa	<.0001

Cramer-von Mises Test for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Summed Deviation from Mean
yes	4757	21.822991
no	2351	44.156515

Cramer-von Mises Statistics (Asymptotic)

CM	0.009282	CMa	65.979506

Kuiper Test for Variable Sol
Classified by Variable bloomyears

bloomyears	N	Deviation from Mean
yes	4757	0.000000
no	2351	0.291749

Kuiper Two-Sample Test (Asymptotic)

K	0.291749	Ka	11.572549	Pr > Ka	<.0001

The UNIVARIATE Procedure
Variable: AvgOfNO3_NO2 (AvgOfNO3+NO2)

Moments

N	46	Sum Weights	46
Mean	46.6267391	Sum Observations	2144.83
Std Deviation	109.86887	Variance	12071.1685
Skewness	5.61600401	Kurtosis	34.2917301
Uncorrected SS	643209.011	Corrected SS	543202.582
Coeff Variation	235.634899	Std Error Mean	16.199281

Basic Statistical Measures

Location		Variability	
Mean	46.62674	Std Deviation	109.86887
Median	13.00000	Variance	12071
Mode	.	Range	723.46000
		Interquartile Range	34.59000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	2.878322	Pr > |t|	0.0061
Sign	M	23	Pr >= |M|	<.0001
Signed Rank	S	540.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	726.56
99%	726.56
95%	119.69
90%	62.48
75% Q3	43.40
50% Median	13.00
25% Q1	8.81
10%	5.12
5%	4.26
1%	3.10
0% Min	3.10

The UNIVARIATE Procedure
Variable: AvgOfNO3_NO2 (AvgOfNO3+NO2)

Extreme Observations

----Lowest----		-----Highest----	
Value	Obs	Value	Obs
3.10	1	62.48	42
4.25	2	85.12	43
4.26	3	119.69	44
4.57	4	239.53	45
5.12	5	726.56	46

Kruskal-Wallis tests comparing years 2002, 2003, and 2004 - nutrient values

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_TN
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2724.0	3174.0	219.406016	59.217391
2004	45	3006.0	3105.0	218.197159	66.800000
2002	46	3723.0	3174.0	219.406016	80.934783

Kruskal-Wallis Test

Chi-Square	7.0912
DF	2
Pr > Chi-Square	0.0289

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DON
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2675.0	3174.0	219.406016	58.152174
2004	45	2949.0	3105.0	218.197159	65.533333
2002	46	3829.0	3174.0	219.406016	83.239130

Kruskal-Wallis Test

Chi-Square	9.6988
DF	2
Pr > Chi-Square	0.0078

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_NO3NO2
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2533.50	3174.0	219.373503	55.076087
2004	45	2381.50	3105.0	218.164824	52.922222
2002	46	4538.00	3174.0	219.373503	98.652174

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	38.7269
DF	2
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_nh3
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	4036.0	3174.0	219.357628	87.739130
2004	45	4123.0	3105.0	218.149037	91.622222
2002	46	1294.0	3174.0	219.357628	28.130435

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	73.6709
DF	2
Pr > Chi-Square	<.0001

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DIN
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	3315.0	3174.0	219.405760	72.065217
2004	45	3454.0	3105.0	218.196904	76.755556
2002	46	2684.0	3174.0	219.405760	58.347826

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	5.3053
DF	2
Pr > Chi-Square	0.0705

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_dindon
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	3671.0	3174.0	219.406016	79.804348
2004	45	3586.0	3105.0	218.197159	79.688889
2002	46	2196.0	3174.0	219.406016	47.739130

Kruskal-Wallis Test

Chi-Square	19.8694
DF	2
Pr > Chi-Square	<.000

Wilcoxon tests between bloom and non-bloom years - nutrient values

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_TN
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	5730.0	6279.0	219.406016	62.967033
yes	46	3723.0	3174.0	219.406016	80.934783

Wilcoxon Two-Sample Test

Statistic	3723.0000
Normal Approximation	
Z	2.4999
One-Sided Pr > Z	0.0062
Two-Sided Pr > |Z|	0.0124
t Approximation	
One-Sided Pr > Z	0.0068
Two-Sided Pr > |Z|	0.0136

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	6.2611
DF	1
Pr > Chi-Square	0.0123

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DON
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	5624.0	6279.0	219.406016	61.802198
yes	46	3829.0	3174.0	219.406016	83.239130

Wilcoxon Two-Sample Test

Statistic	3829.0000
Normal Approximation	
Z	2.9831
One-Sided Pr > Z	0.0014
Two-Sided Pr > |Z|	0.0029
t Approximation	
One-Sided Pr > Z	0.0017
Two-Sided Pr > |Z|	0.0034

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	8.9122
DF	1
Pr > Chi-Square	0.0028

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_NO3NO2
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	4915.0	6279.0	219.373503	54.010989
yes	46	4538.0	3174.0	219.373503	98.652174

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	4538.0000
Normal Approximation	
Z	6.2154
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr > Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	38.6599
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_nh3
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	8159.0	6279.0	219.357628	89.659341
yes	46	1294.0	3174.0	219.357628	28.130435

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	1294.0000
Normal Approximation	
Z	-8.5682
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	73.4531
DF	1
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DIN
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	6769.0	6279.0	219.405760	74.384615
yes	46	2684.0	3174.0	219.405760	58.347826

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	2684.0000
Normal Approximation	
Z	-2.2310
One-Sided Pr < Z	0.0128
Two-Sided Pr > |Z|	0.0257
t Approximation	
One-Sided Pr < Z	0.0137
Two-Sided Pr > |Z|	0.0273

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	4.9877
DF	1
Pr > Chi-Square	0.0255

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_dindon
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	91	7257.0	6279.0	219.406016	79.747253
yes	46	2196.0	3174.0	219.406016	47.739130

Wilcoxon Two-Sample Test

Statistic	2196.0000
Normal Approximation	
Z	-4.4552
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001
t Approximation	
One-Sided Pr < Z	<.0001
Two-Sided Pr > |Z|	<.0001

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	19.8692
DF	1
Pr > Chi-Square	<.0001

Kruskal-Wallis tests between 2002, 2003, and 2004 - April nutrient species.

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_TN
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2724.0	3174.0	219.406016	59.217391
2004	45	3006.0	3105.0	218.197159	66.800000
2002	46	3723.0	3174.0	219.406016	80.934783

Kruskal-Wallis Test

Chi-Square	7.0912
DF	2
Pr > Chi-Square	0.0289

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DON
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2675.0	3174.0	219.406016	58.152174
2004	45	2949.0	3105.0	218.197159	65.533333
2002	46	3829.0	3174.0	219.406016	83.239130

Kruskal-Wallis Test

Chi-Square	9.6988
DF	2
Pr > Chi-Square	0.0078

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_NO3NO2
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	2533.50	3174.0	219.373503	55.076087
2004	45	2381.50	3105.0	218.164824	52.922222
2002	46	4538.00	3174.0	219.373503	98.652174

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	38.7269
DF	2
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_nh3
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	4036.0	3174.0	219.357628	87.739130
2004	45	4123.0	3105.0	218.149037	91.622222
2002	46	1294.0	3174.0	219.357628	28.130435

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	73.6709
DF	2
Pr > Chi-Square	<.0001

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DIN
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	3315.0	3174.0	219.405760	72.065217
2004	45	3454.0	3105.0	218.196904	76.755556
2002	46	2684.0	3174.0	219.405760	58.347826

Average scores were used for ties.

Kruskal-Wallis Test

Chi-Square	5.3053
DF	2
Pr > Chi-Square	0.0705

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_dindon
Classified by Variable year

year	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
2003	46	3671.0	3174.0	219.406016	79.804348
2004	45	3586.0	3105.0	218.197159	79.688889
2002	46	2196.0	3174.0	219.406016	47.739130

Kruskal-Wallis Test

Chi-Square	19.8694
DF	2
Pr > Chi-Square	<.000

Wilcoxon test between bloom and non-bloom years - April

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_TN
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	78.0	85.0	9.219544	7.800000
yes	6	58.0	51.0	9.219544	9.666667

Wilcoxon Two-Sample Test

Statistic	58.0000
Normal Approximation	
Z	0.7050
One-Sided Pr > Z	0.2404
Two-Sided Pr > |Z|	0.4808
t Approximation	
One-Sided Pr > Z	0.2458
Two-Sided Pr > |Z|	0.4916

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	0.5765
DF	1
Pr > Chi-Square	0.4477

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DON
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	72.0	85.0	9.219544	7.200000
yes	6	64.0	51.0	9.219544	10.666667

Wilcoxon Two-Sample Test

Statistic	64.0000
Normal Approximation	
Z	1.3558
One-Sided Pr > Z	0.0876
Two-Sided Pr > |Z|	0.1752
t Approximation	
One-Sided Pr > Z	0.0976
Two-Sided Pr > |Z|	0.1952

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	1.9882
DF	1
Pr > Chi-Square	0.1585

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_NO3NO2
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	73.0	85.0	9.219544	7.30
yes	6	63.0	51.0	9.219544	10.50

Wilcoxon Two-Sample Test

Statistic	63.0000
Normal Approximation	
Z	1.2474
One-Sided Pr > Z	0.1061
Two-Sided Pr > |Z|	0.2123
t Approximation	
One-Sided Pr > Z	0.1157
Two-Sided Pr > |Z|	0.2314

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	1.6941
DF	1
Pr > Chi-Square	0.1931

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_nh3
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	104.0	85.0	9.192388	10.400000
yes	6	32.0	51.0	9.192388	5.333333

Average scores were used for ties.

Wilcoxon Two-Sample Test

Statistic	32.0000
Normal Approximation	
Z	-2.0125
One-Sided Pr < Z	0.0221
Two-Sided Pr > |Z|	0.0442
t Approximation	
One-Sided Pr < Z	0.0312
Two-Sided Pr > |Z|	0.0625

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	4.2722
DF	1
Pr > Chi-Square	0.0387

The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_DIN
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	96.0	85.0	9.219544	9.600000
yes	6	40.0	51.0	9.219544	6.666667

Wilcoxon Two-Sample Test

Statistic	40.0000
Normal Approximation	
Z	-1.1389
One-Sided Pr < Z	0.1274
Two-Sided Pr > |Z|	0.2548
t Approximation	
One-Sided Pr < Z	0.1363
Two-Sided Pr > |Z|	0.2726

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square	1.4235
DF	1
Pr > Chi-Square	0.2328

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The NPAR1WAY Procedure

Wilcoxon Scores (Rank Sums) for Variable mol_dindon
Classified by Variable bloom_years

bloom_ years	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
no	10	101.0	85.0	9.219544	10.100000
yes	6	35.0	51.0	9.219544	5.833333

Wilcoxon Two-Sample Test

Statistic 35.0000

Normal Approximation
Z -1.6812
One-Sided Pr < Z 0.0464
Two-Sided Pr > |Z| 0.0927

t Approximation
One-Sided Pr < Z 0.0567
Two-Sided Pr > |Z| 0.1134

Z includes a continuity correction of 0.5.

Kruskal-Wallis Test

Chi-Square 3.0118
DF 1
Pr > Chi-Square 0.0827