

# Pleasant Bay Alliance Water Quality Monitoring Program: Statistical Analysis of Multi-year Water Quality Monitoring Data

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## Executive Summary

Pleasant Bay is an estuarine system located on Cape Cod in the Towns of Orleans, Chatham, Harwich and Brewster, Massachusetts. It was designated as an Area of Critical Environmental Concern (ACEC) by the Massachusetts Executive Office of Environmental Affairs in 1987. The Pleasant Bay Alliance was formed in 1998 to oversee the implementation of a resource management program developed by the four towns, which includes a bay-wide water quality monitoring program. In 2007, the Massachusetts Department of Environmental Protection established Total Maximum Daily Loads (TMDLs) for Pleasant Bay, based on threshold concentrations for bioactive nitrogen established in the 2006 Massachusetts Estuaries Project (MEP) technical report for Pleasant Bay. The TMDLs and MEP report utilized much of the data collected by the Pleasant Bay Alliance and established water quality targets for designated “sentinel” stations.

Ten consecutive years of water quality data have now been collected at sites throughout Pleasant Bay (years of data collected vary by site). In an effort to better understand the trends in these data, a statistical analysis was conducted on the 10-year dataset. The Alliance is particularly interested in the effects of the Patriots Day storm of 2007, and the resulting “break” in Nauset Beach, on trends in water quality. This storm caused the formation of a second inlet, resulting in an increased tidal range and volume of water exchanged with the Atlantic Ocean. This increase in the rate and volume of water exchange between the bay and the ocean is expected to have an influence on water quality.

Statistical analysis of the data included a bay-wide trend analysis, as well as site-specific analyses. A class of statistical methods, called mixed effects models, was used to evaluate bay-wide trends. Multiple linear regression was used to evaluate site-specific trends. Both methods allow for the inclusion of multiple explanatory variables, which helps isolate trends over time from other influences on water quality.

Results of the site-specific analysis demonstrate that water quality is improving at some sites, but declining at others. However, most of the sites do not demonstrate any statistically significant trends. In general, those sites showing improvement in water quality tend to be located in the open water areas of the bay, while those sites showing declining water quality tend to be located in the sub-embayments of the system. Results of the bay-wide analysis demonstrate that water quality was declining for some parameters prior to the 2007 break in Nauset Beach, but that it has been improving for these same parameters since that time. Other parameters remain unchanged.

These results suggest that the increased exchange of water between the Atlantic Ocean and Pleasant Bay (as a result of the 2007 inlet formation) may be responsible for limited improvements in water quality in some open areas of the bay. Even with limited improvement in these areas, bioactive nitrogen concentrations continue to exceed MEP modeled restoration values for estuarine health. Inlet formation in the Pleasant Bay system is thought to be “quasi-cyclical,” with new inlets typically migrating south along Nauset Beach. As the new inlet migrates southward, tidal flushing of the bay may decrease to previous levels and nutrient concentrations may return to pre-inlet concentrations. However, it is important to note that the analyses reported here are not predictive models and should not be extrapolated into the future.



## Introduction

Pleasant Bay is an estuarine system located on Cape Cod in the Towns of Orleans, Chatham, Harwich and Brewster, Massachusetts. It was designated as an Area of Critical Environmental Concern (ACEC) by the Massachusetts Executive Office of Environmental Affairs in 1987. The Pleasant Bay Alliance was formed in 1998 to oversee the implementation of a resource management program developed by the four towns, which includes a bay-wide water quality monitoring program. In 2007, the Massachusetts Department of Environmental Protection established Total Maximum Daily Loads (TMDLs) for Pleasant Bay, based on threshold concentrations for bioactive nitrogen established in the 2006 Massachusetts Estuaries Project (MEP) technical report for Pleasant Bay. The TMDLs and MEP report utilized much of the data collected by the Pleasant Bay Alliance and established water quality targets for designated “sentinel” stations.

Ten consecutive years of water quality data have now been collected at sites throughout Pleasant Bay (years of data collected vary by site). In an effort to better understand the trends in these data, the Alliance hired The Cadmus Group, Inc. in May of 2010 to perform a statistical analysis on the 10-year dataset. The Alliance is particularly interested in the effects of the Patriots Day storm of 2007, and the resulting “break” in Nauset Beach, on trends in water quality. This storm caused the formation of a second inlet, resulting in an increased tidal range of 7/10 of a foot and increased volume of water exchanged with the Atlantic Ocean of 14 percent (Applied Coastal Research and Engineering, Inc., 2008). This increase in the rate and volume of water exchange between the bay and the ocean is expected to have an influence on water quality. Statistical analysis of the data includes a bay-wide trend analysis, as well as site-specific analyses. A class of statistical methods, called mixed effects models, was used to evaluate bay-wide trends. Multiple linear regression was used to evaluate site-specific trends. Both methods allow for the inclusion of multiple explanatory variables, which helps isolate trends over time from other influences on water quality.

This report is intended for a broad audience. As such, the main body of the report provides a general description of the methods, followed by presentation of the results in the form of graphs and maps. A discussion of the results is also included. The appendices to the report provide additional information for those readers who desire more discussion of the methods used and the results of the analyses. Appendix A describes the statistical methods in much more detail than the main report. Appendix B contains the plots of the multiple linear regression analyses for each water quality sampling station where a significant trend was detected. Appendices C and D contain bar graphs of the average concentrations of total nitrogen and total pigments at each sampling station. Appendix E contains tables of summary statistics (means and confidence intervals) for dissolved inorganic nitrogen (DIN), bioactive nitrogen (DIN plus particulate organic nitrogen), total nitrogen, total algal pigments, phosphate, and dissolved oxygen. Finally, Appendix F contains tables showing the percentage of samples that do not meet water quality targets at each station and for each year. Water quality targets have been established for bioactive nitrogen, dissolved oxygen, and total pigments.

## Methods

The objective of the statistical analysis was to evaluate trends in water quality parameters that are associated with nutrient loading and eutrophication in Pleasant Bay. These parameters included concentrations of dissolved inorganic nitrogen (DIN), bioactive nitrogen (DIN plus particulate organic nitrogen), total nitrogen, total algal pigments, phosphate, and dissolved oxygen. A total of 2,334 total nitrogen samples, collected at 33 sites over ten years, were used in the analysis (Table 1); a similar number of samples were collected for each of the other parameters. Water quality samples were collected by members of the Pleasant Bay Alliance using methods described in the *QAPP for the Pleasant Bay Citizen Water Quality Monitoring Program* (Pleasant Bay Resource Management Alliance, 2001). Laboratory analyses were conducted at the School for Marine Science and Technology (SMAST) Laboratory at the University of Massachusetts-Dartmouth campus.

**Table 1** Number of total nitrogen samples collected at each site during each year.

Station ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
PBA-1	20	15	14	11	12	14	10				96
PBA-2	10	8	7	5	6						36
PBA-3	19	16	13	13	14	14	7	10	9	7	122
CM-13	19	16	13	12	14	11	12	10	10	10	127
CM-14	9	6	7	7	7	6					42
PBA-4	20	16	14	10	13	14	10	10	10	8	125
PBA-5	9	8	5	6	6	7	5	4	5	4	59
PBA-5A			6	7	7	7	6	5	5	5	48
PBA-6	9	10	10	12	12	14					67
PBA-7	12	12	14	14	14	12					78
PBA-8	9	12	14	14	14	14	12	8	9	10	116
PBA-9	12	12	12	14	14	13	12	10	10	10	119
PBA-10	12	12	14	14	14	14	12	8	10	10	120
PBA-11	12	11	14	12	12	14	12	6	8	10	111
PBA-12	12	12	14	12	14	14	8	10	10	10	116
PBA-13	11	12	14	12	10	13	12	10	10	10	114
PBA-14	12	12	13	14	13	14	6				84
PBA-15	12	12	12	13	14	14	10	10	10	10	117
PBA-16	12	12	13	13	13	14	6				83
PBA-18			9	10	10	14					43
PBA-19			8	10	11	10					39
PBA-20			10	12	11	14					47
PBA-21			10	12	12	14					48
WMO-3		12	8	12	6		6	5	5	4	58
WMO-5		6	4	6	6	6	6	5	5	5	49
WMO-6		6	6	5	6		6	4	5	5	43
WMO-10		6	11	6	6		12	8	10	10	69
WMO-2		11	10	9	6						36
WMO-4		6	6	6	6						24
WMO-7		6	6	5	5						22
WMO-8		6	6	6	5						23
WMO-9		6	6	5	6	6					29
WMO-12		6	6	6	6						24
<b>Total</b>	<b>231</b>	<b>285</b>	<b>329</b>	<b>325</b>	<b>325</b>	<b>287</b>	<b>170</b>	<b>123</b>	<b>131</b>	<b>128</b>	<b>2334</b>

## Basic Statistical Concepts

Coastal and embayment water quality is influenced by a large number of variables, such as rainfall, temperature, salinity, ocean currents, etc. Since these variables are constantly changing, so too is water quality. When a water quality sample is taken, it represents water quality conditions at one specific location at a particular moment in time. It is not uncommon to take a sample immediately adjacent to, or immediately following, another and obtain different results. This inherent quality of nature (not just water quality) is referred to as “variability” and, though it can be minimized, it cannot be eliminated. However, the field of statistics provides a set of analytical tools that allow this variability to be accurately described and sometimes even explained. One of the simplest statistics is the “average”. The average concentration of ten total nitrogen samples collected in a particular year, for example, is an estimate of the true average concentration throughout that year. Since it is just an estimate, it is important to also state the level of confidence in that estimate. A “confidence interval” represents the amount of variability in the data (the differences between individual samples) and its influence on the estimate of the average. A 90% confidence interval of 6 around an average of 20, for example, means that we are 90% confident that the true average is somewhere between 17 and 23, with its most likely value at 20. The primary way to reduce variability, and thus decrease the width of the confidence interval, is to increase the number of samples collected.

Statistical methods, such as regression, can be used to evaluate trends in water quality over time (but should not be used to predict trends into the future). Simple linear regression could be used to examine the influence of time on the concentration of a particular water quality parameter. The resulting trend line could be plotted on a graph and the confidence interval could also be plotted to illustrate the amount of confidence in the slope of that line (Figure 1). Although the trend line may slope upwards or downwards, if a horizontal line could fit between the confidence interval, then the trend is not “statistically significant” (Figure 2). Statistical significance is related to confidence intervals (though they are not the same) and refers to the likelihood that a result is due to chance alone. A 95% level of statistical significance signifies that there is a 5% chance that the result of the statistical analysis is due to chance alone. A simple linear regression analysis, for example, may result in a trend line sloping downwards. However, if it is not statistically significant, then the slope of that line could simply be due to chance (because of the underlying variability in the data), meaning that you cannot say with any certainty that there really is a trend. In order to increase the chance of finding a trend that actually exists, the variability in the data needs to be decreased through collection of additional samples or explained through the inclusion of additional explanatory variables in the analysis.

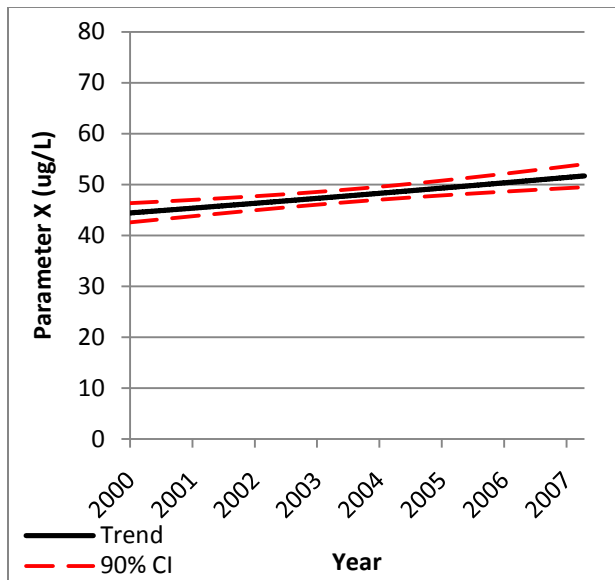


Figure 1 Statistically significant trend.

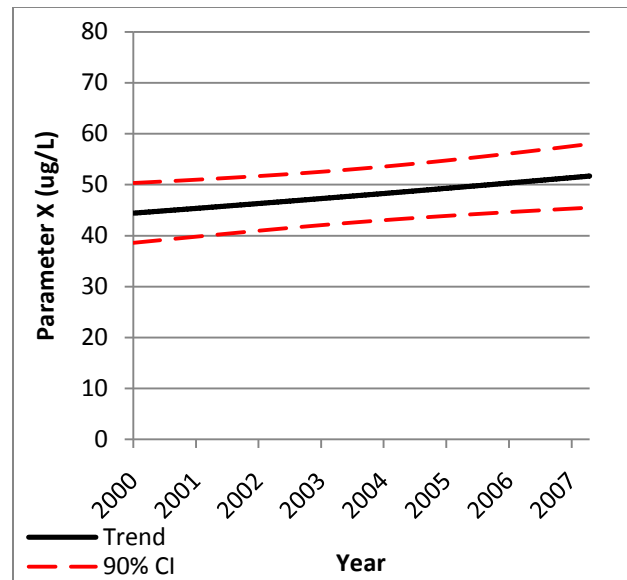


Figure 2 Statistically non-significant trend.

### Multiple Linear Regression

Multiple linear regression is an extension of simple linear regression that allows for the inclusion of multiple explanatory variables in the analysis. This can be advantageous in complex situations where multiple effects are influencing the behavior of the variable of interest. For example, dissolved oxygen concentration is a variable of interest in Pleasant Bay because it is an indicator of nutrient enrichment. However, dissolved oxygen concentrations are also influenced by water temperature, atmospheric pressure, and salinity. A simple regression analysis to examine trends over time would evaluate the effect of time on dissolved oxygen concentrations. Since it only considers one of the many variables that influence dissolved oxygen concentrations, a certain amount of the variance will be left unexplained. If data also exist for temperature and salinity, multiple linear regression can be used to evaluate the effects of all three variables (time, temperature, and salinity) on dissolved oxygen concentrations. This approach may allow more of the variance to be explained and increase the chances of finding a statistically significant trend if it actually exists. However, including additional variables in a regression analysis also decreases the degrees of freedom in the analysis, which can decrease the chance of finding a statistically significant trend. Therefore, an additional variable should only be included when the explanatory power of that variable outweighs the increase in model<sup>1</sup> complexity.

Multiple linear regression was used to evaluate trends at individual monitoring sites in Pleasant Bay. Sixty-four separate models (see Appendix A) were created in the “R” programming language for each site/parameter combination (33 sites and 6 parameters). This resulted in 12,672 separate models that were evaluated using Akaike’s Information Criterion (AIC) (Hirotsugu, 1974) to find the model that provides the most explanatory power, while minimizing the number of variables in the model. Thus, the simplest possible model is preferred unless the inclusion of an additional variable provides significantly more explanatory power. The model with the lowest AIC is most likely to be the correct model. AIC

<sup>1</sup> A statistical model is a mathematical expression that describes the relationships between two or more variables.

values were converted into probabilities (see Appendix A for formula) so that the relative likelihoods of each model could be compared. The best model was identified for each site/parameter combination (198 models). Identification of the best models also considered the number of data points used in the analysis. The rule of thumb in multiple linear regression is that only one parameter per 30 samples should be included in the model. The plots of the statistically significant models are presented in Appendix B.

### Mixed Effects Model

A mixed effects model is an extension of multiple linear regression where groups of observations have some factor in common. The model is considered “mixed” because it includes both fixed effects (the typical explanatory variables that would be found in a multiple linear regression equation) and random effects (the effect of an observation being made on a specific unit, such as a sampling station). The random effects (e.g., site ID) are used to explain some of the variance in the average value of the response, which factors out consistent differences among stations, making overall trends easier to detect.

A series of mixed effects models were created in the “R” programming language to evaluate bay-wide trends in Pleasant Bay water quality data for dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, total pigments, phosphate, and dissolved oxygen. Eight candidate models were created for each of these six parameters. The primary difference among the candidate models is how they represent the shape of the water quality trend over time. The eight candidate models include four different trend shapes, both with and without other covariates, including salinity, temperature, and cumulative rainfall in the week prior to the sample. Salinity indicates the relative influence of relatively low-nutrient marine water versus relatively high-nutrient fresh water in the sample. Temperature affects the growth of algae and other processes that partition nutrients among their chemical forms. Rain events transport nitrogen and phosphorus from land to water and increase the influence of freshwater in the bay. The four trend shapes include:

1. Linear (date)
2. Linear with a change in intercept at date of 2007 break (date, break)
3. Linear with a change in intercept and slope at date of 2007 break (date, break, date:break)
4. Curved (date, date<sup>2</sup>)

All models include sample depth (surface, middle, or bottom) as a covariate, and include station ID, the interaction of depth and station ID, and the interaction of date and station ID as random effects. A model with a linear trend shape suggests that average concentrations have either continuously increased or continuously decreased over time. A curved trend shape suggests a non-linear response in the average concentration over time (average concentrations have increased and decreased at different times during the period of analysis). A model with a break term suggests that average concentrations have either continuously increased or continuously decreased over time, but that the Nauset Beach break event caused a sudden change in average concentrations (i.e., a change in where the trend line intercepts the vertical axis of the plot). A model with the date:break interaction term suggests that average concentrations have either continuously increased or continuously decreased until the Nauset Beach break event, after which the direction of the trend has reversed (i.e., a change in slope).

The eight candidate models (the four models described above, each with and without covariates) were evaluated against each other using the AIC method (see Figure 10 through Figure 15 in the Results & Discussion section). For all six parameters, one model was clearly more likely than the others to be the correct model. After selecting the best model for each of the six parameters of interest, the statistical significance of the trend over time was evaluated and the trend was plotted (see Results & Discussion for plots).

## Results & Discussion

### Site-specific Trends

Most of the individual stations did not show significant trends in water quality over time (Figure 3). In general, those sites showing improvements in water quality (green sites in Figure 4 through Figure 9) tend to be located in the open water areas of the bay, while those sites showing declining water quality tend to be located in the sub-embayments of the system. This suggests that the increased exchange of water between the Atlantic Ocean and Pleasant Bay (as a result of the 2007 inlet formation) may be responsible for improving water quality in some open areas of the bay. However, it should be noted that 17 of the 33 sites (about half) do not have data beyond 2006 (Table 1). Therefore, any trends at these sites are completely independent of the 2007 inlet formation and cannot be used to forecast conditions beyond the dates of sample collection. Figure 4 through Figure 9 indicate which sites do not have data collected after the 2007 break. Appendix B contains the plots of the regression output for each station with a significant trend. Appendix F reports the percentage of samples at each station in each year that exceeded water quality targets. At many stations, these percentages may appear to trend up or down. However, the regression results are the most reliable way to determine trends that are unlikely to be due to random chance.

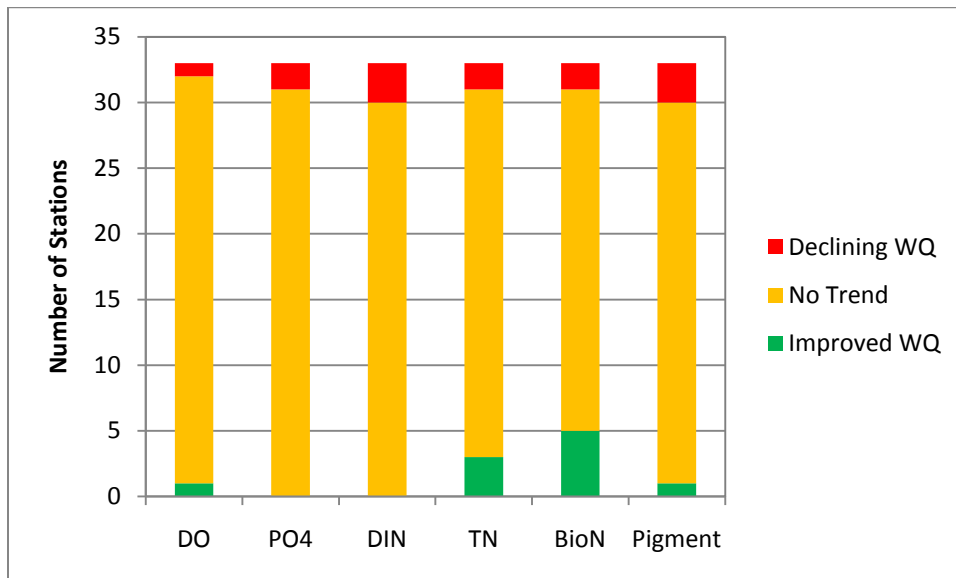


Figure 3 Trends in water quality (WQ) at individual stations.

Table 2 Statistically significant trends in water quality at individual stations. ▲ = improved water quality. ▼ = declining water quality. ■ = no statistically significant trend. DO=dissolved oxygen, PO4=phosphate, DIN=dissolved inorganic nitrogen, TN=total nitrogen, BioN=bioactive nitrogen. While the colors of the arrows indicate improving or declining water quality, the directions of the arrows indicate the direction of the concentration trend. Note that about half of the stations do not have data after the 2007 break.

Station	DO	PO4	DIN	TN	BioN	Pigment	Post Break Data
Chatham Harbor (PBA-1)	■	■	■	▼	▼	▼	No
Bassing Harbor (PBA-2)	■	■	■	■	■	■	No
Inner Ryders Cove (PBA-3)	■	■	▲	▲	▲	▲	Yes
Outer Ryder's Cove (CM-13)	■	■	▲	■	■	■	Yes
Frost Fish Creek (CM-14)	■	■	■	■	■	■	No
Crow's Pond (PBA-4)	■	■	■	■	■	■	Yes
Muddy Creek (PBA-5)	■	■	■	■	■	■	Yes
Muddy Creek-Upper (PBA-5A)	■	■	■	■	■	■	Yes
Big Bay-SW (PBA-6)	■	■	■	▼	■	■	No
Big Bay-Mid (PBA-7)	■	■	■	■	■	■	No
Big Bay-NE (PBA-8)	▲	■	■	■	■	■	Yes
Round Cove (PBA-9)	■	■	■	■	■	■	Yes
Quanset Pond (PBA-10)	■	■	▲	▲	■	■	Yes
Paw Wah Pond (PBA-11)	■	■	■	■	■	■	Yes
Namequoit-South (PBA-12)	■	■	■	■	▼	■	Yes
Namequoit-North (PBA-13)	■	■	■	■	■	■	Yes
Arey's Pond (PBA-14)	■	■	■	■	■	■	No
Kescayogansett Pond (PBA-15)	■	▲	■	■	■	■	Yes
Meetinghouse Pond (PBA-16)	■	■	■	■	■	■	No
Allen's/Ministers Point (PBA-18)	■	■	■	▼	▼	■	No
Nickersons Neck (PBA-19)	■	■	■	■	■	■	No
Strong Island (PBA-20)	■	■	■	■	▼	■	No
Little Pleasant Bay (PBA-21)	■	■	■	■	▼	■	No
Pochet Mouth (WMO-3)	■	■	■	■	■	■	Yes
Pochet Upper (WMO-5)	■	■	■	■	■	▲	Yes
Namequoit River Mid (WMO-6)	■	■	■	■	■	■	Yes
River at Rattles Dock (WMO-10)	▼	▲	■	■	▲	▲	Yes
Pleasant Bay off Quanset (WMO-2)	■	■	■	■	■	■	No
Pochet-Mid (WMO-4)	■	■	■	■	■	■	No
Namequoit River-Mouth (WMO-7)	■	■	■	■	■	■	No
Lower River (WMO-8)	■	■	■	■	■	■	No
Mid River (WMO-9)	■	■	■	■	■	■	No
Little Quanset Pond (WMO-12)	■	■	■	■	■	■	No



Figure 4 Direction of trends in bioactive nitrogen (BioN) concentrations at each water quality monitoring site in Pleasant Bay.



Figure 5 Direction of trends in dissolved inorganic nitrogen (DIN) concentrations at each water quality monitoring site in Pleasant Bay.



Figure 6 Direction of trends in dissolved oxygen (DO) concentrations at each water quality monitoring site in Pleasant Bay.



Figure 7 Direction of trends in total pigment concentrations at each water quality monitoring site in Pleasant Bay.



Figure 8 Direction of trends in phosphate (PO<sub>4</sub>) concentrations at each water quality monitoring site in Pleasant Bay.



Figure 9 Direction of trends in total nitrogen (TN) concentrations at each water quality monitoring site in Pleasant Bay.

## Bay-Wide Trends

Figure 10 through Figure 15 show the relative likelihood of each bay-wide model being correct. For each parameter, one model is clearly more likely than the others to be the correct model. Models 1 through 4 represent each of the four trend shapes mentioned above. A “C” indicates that the covariates of salinity, temperature, and cumulative rainfall in the week prior to the sample were included in the model.

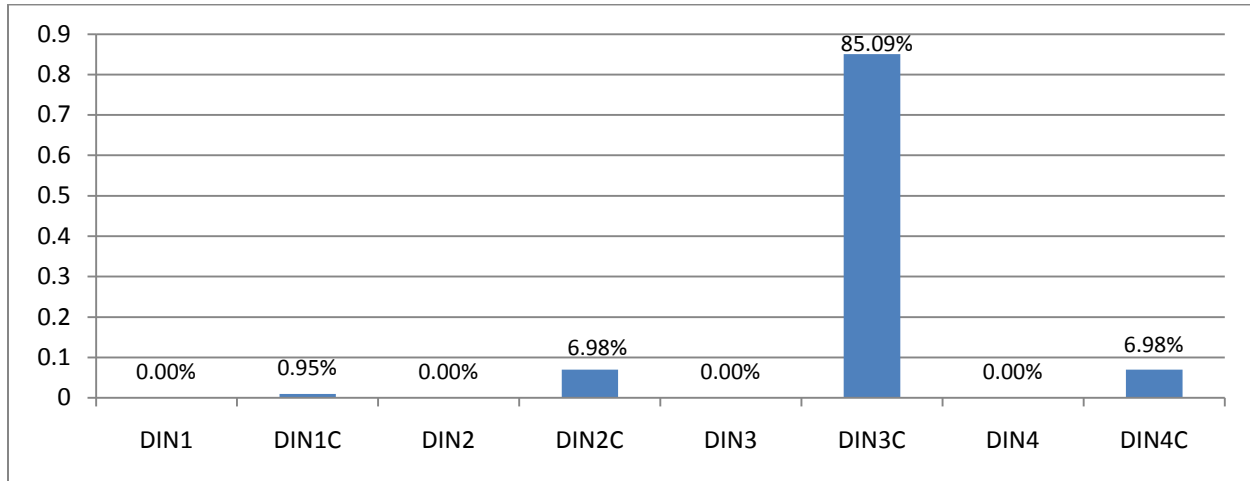


Figure 10 Probabilities of each of the eight dissolved inorganic nitrogen (DIN) models being correct. “C” indicates covariates.

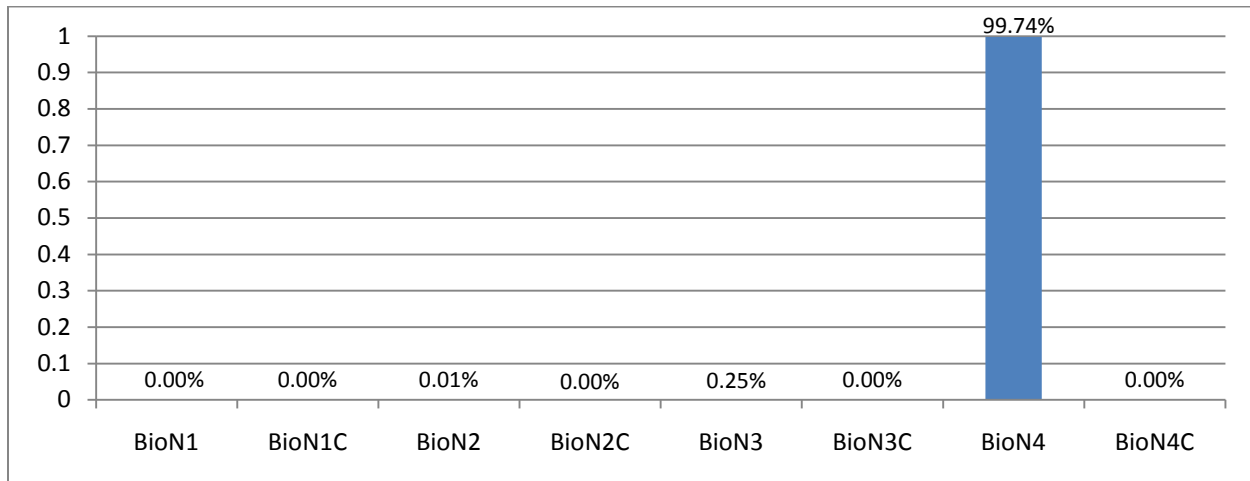


Figure 11 Probabilities of each of the eight bioactive nitrogen (BioN) models being correct. “C” indicates covariates.

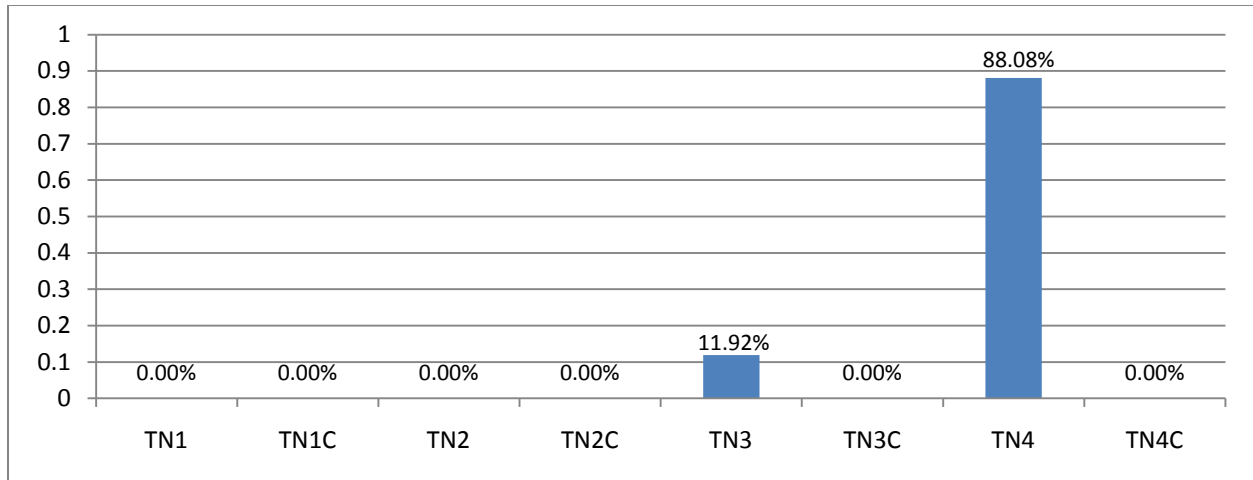


Figure 12 Probabilities of each of the eight total nitrogen (TN) models being correct. "C" indicates covariates.

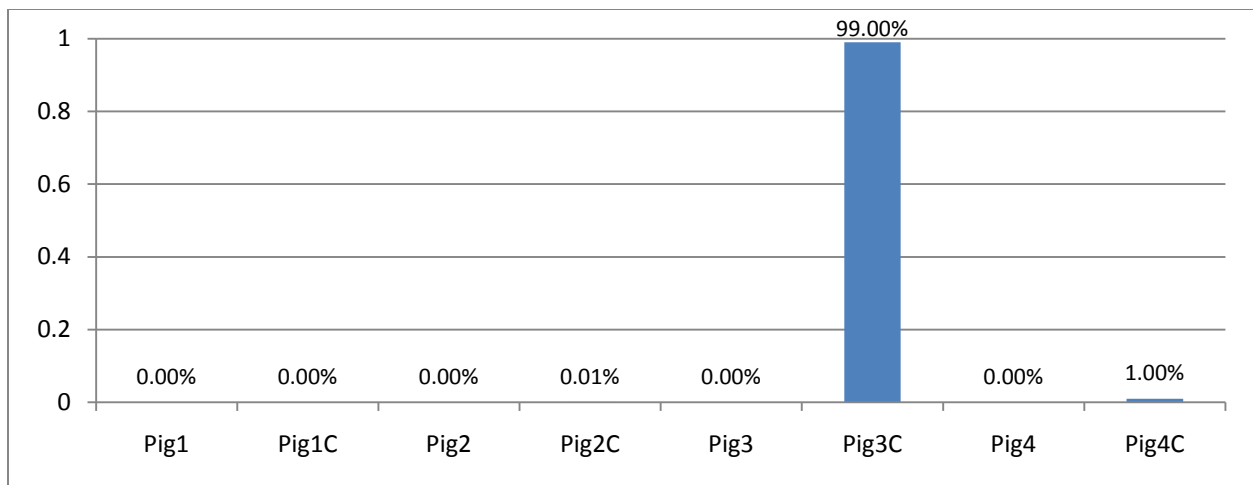


Figure 13 Probabilities of each of the eight total pigment (Pig) models being correct. "C" indicates covariates.

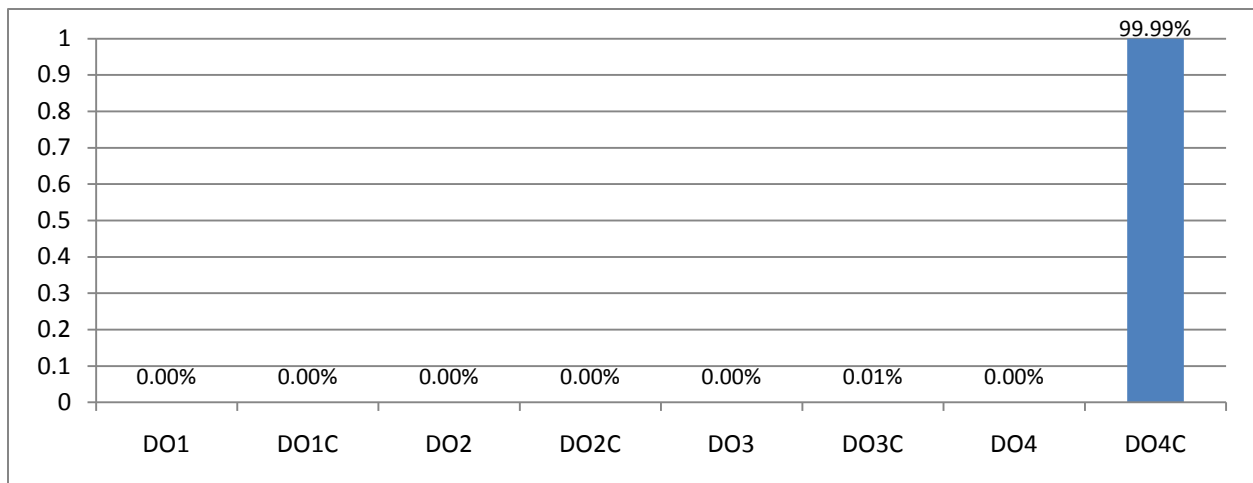
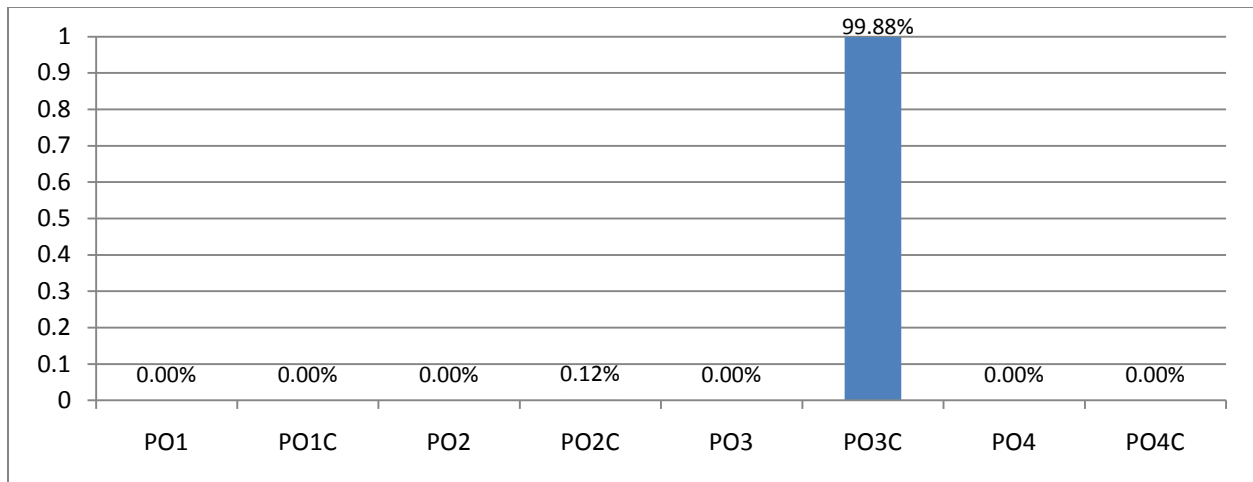


Figure 14 Probabilities of each of the eight dissolved oxygen (DO) models being correct. "C" indicates covariates.



**Figure 15 Probabilities of each of the eight phosphate (PO) models being correct. “C” indicates covariates.**

Of the six water quality parameters evaluated with mixed effects models, three have statistically significant trends over time across the bay as a whole. Both dissolved inorganic nitrogen (DIN) and phosphate were increasing prior to the 2007 Nauset Beach break; following the break, DIN and phosphate decreased (Figure 16 through Figure 19). There was no significant trend in total pigments (chlorophyll a and phaeophytin) prior to the 2007 Nauset Beach break, but total pigments did decrease after the break (Figure 20 and Figure 21). There were no significant trends in bioactive nitrogen, total nitrogen, and dissolved oxygen.

Other environmental variables had strong influences on some of the water quality parameters (Appendix A, Table 5). Higher salinity was associated with lower bioactive nitrogen, pigments, and dissolved oxygen, but higher phosphate. Higher temperature was associated with higher bioactive nitrogen, total nitrogen, pigments, and phosphate, but lower dissolved oxygen. Samples collected after significant rainfall tended to have higher dissolved inorganic nitrogen, bioactive nitrogen, and phosphate. In many cases, the effects of these variables were statistically much stronger than the trends over time.

The bay-wide mixed effects model analysis shows a decrease in the concentrations of some of the water quality parameters in the Bay after the formation of the 2007 inlet. However, other parameters remain unchanged. It is important to note that dissolved inorganic nitrogen and phosphate levels were increasing prior to formation of the new inlet, and their current declining trend may be temporary. Inlet formation in the Pleasant Bay system is thought to be “quasi-cyclical,” with new inlets typically migrating south along Nauset Beach (Giese, 2009). As the inlet migrates southward, tidal flushing of the bay may decrease to previous levels and nutrient concentrations may return to pre-inlet concentrations. However, it is important to note that the analyses reported here are not predictive models and should not be extrapolated into the future.

As mentioned in the Methods section, a larger sample size increases the chances of finding a statistically significant trend where one actually exists. This is the primary reason why the results of the bay-wide analysis show an increasing trend in dissolved inorganic nitrogen concentrations followed by a decreasing trend after the break (Figure 16 and Figure 17), while the site-specific analysis only shows

increasing trends at three sites and no decreasing trends at any site (Figure 5). The same is true for phosphate and total pigments. The water quality data in this study exhibit very high variance, which can mask modest trends that may have occurred at individual stations. When data from multiple stations are combined, they are said to “borrow strength” from one another, making the overall picture more clear. A significant trend in a combined model does not imply that all the individual stations also had trends, but that they belong to a common population of stations which, on average, had a trend. The maximum number of samples available at any one of the monitoring stations is 130. The bay-wide analysis included all of the samples from all of the sites, bringing the sample size up to 2,364. This large increase in sample size gives the bay-wide analysis much more statistical power to find a trend that is otherwise difficult to detect. Increasing the sample size at each of the individual sample stations would increase the chances of finding trends where they actually exist. The sample size necessary to detect a statistically significant trend can be determined through a statistical power analysis.

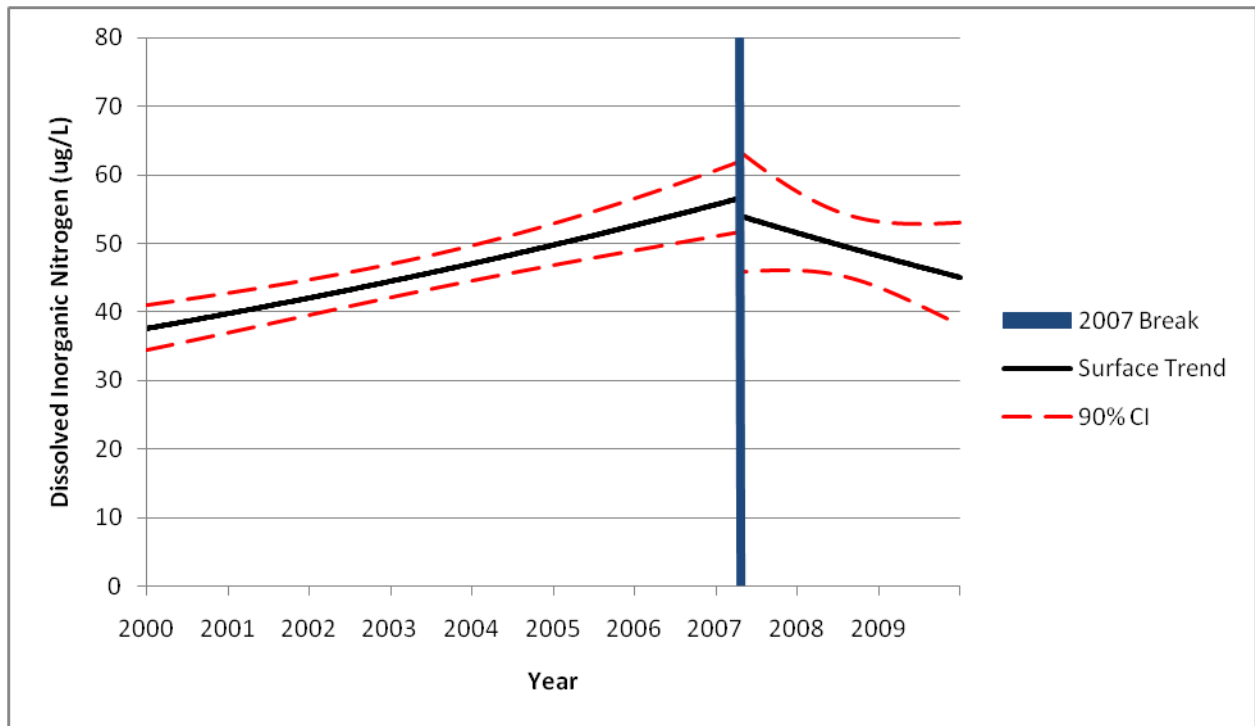


Figure 16 Bay-wide trends in dissolved inorganic nitrogen (DIN) surface concentrations over the 2000-2009 period. Dashed lines indicate approximate 90% confidence intervals (CI). Both pre-break and post-break trends are statistically significant.

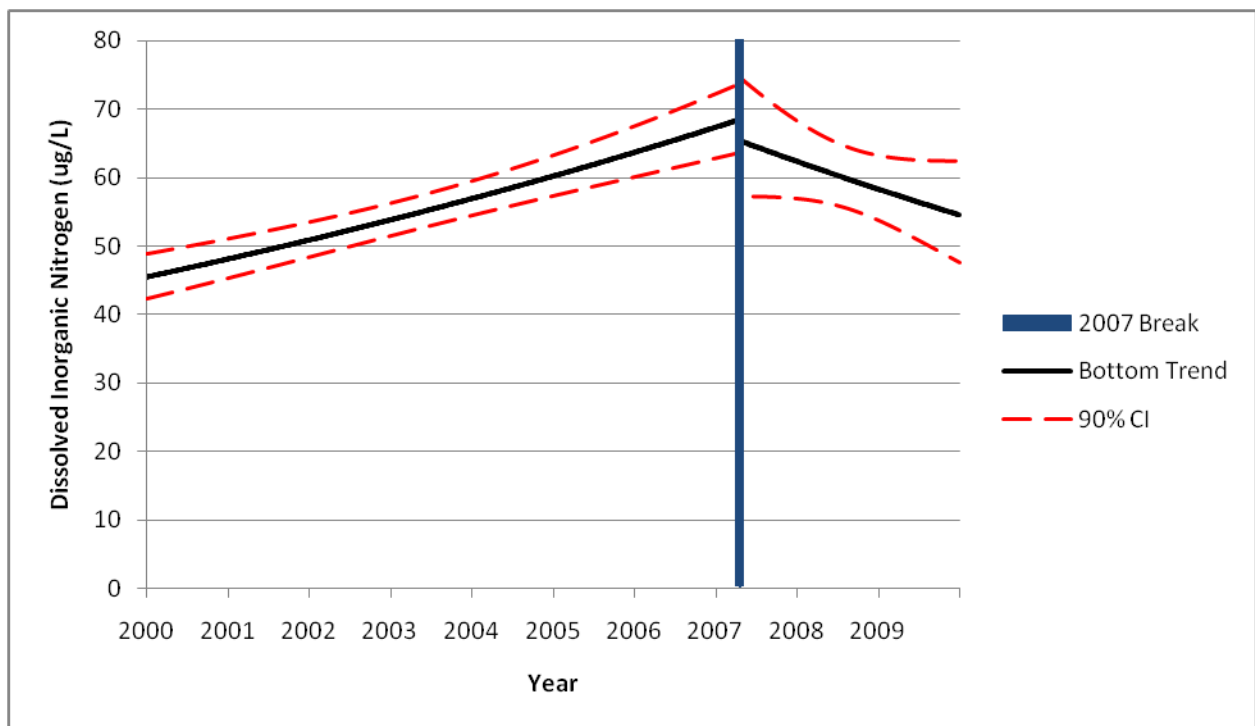


Figure 17 Bay-wide trends in dissolved inorganic nitrogen (DIN) bottom/middle concentrations over the 2000-2009 period. Bottom and middle concentrations are not statistically different. Dashed lines indicate approximate 90% confidence intervals (CI). Both pre-break and post-break trends are statistically significant.

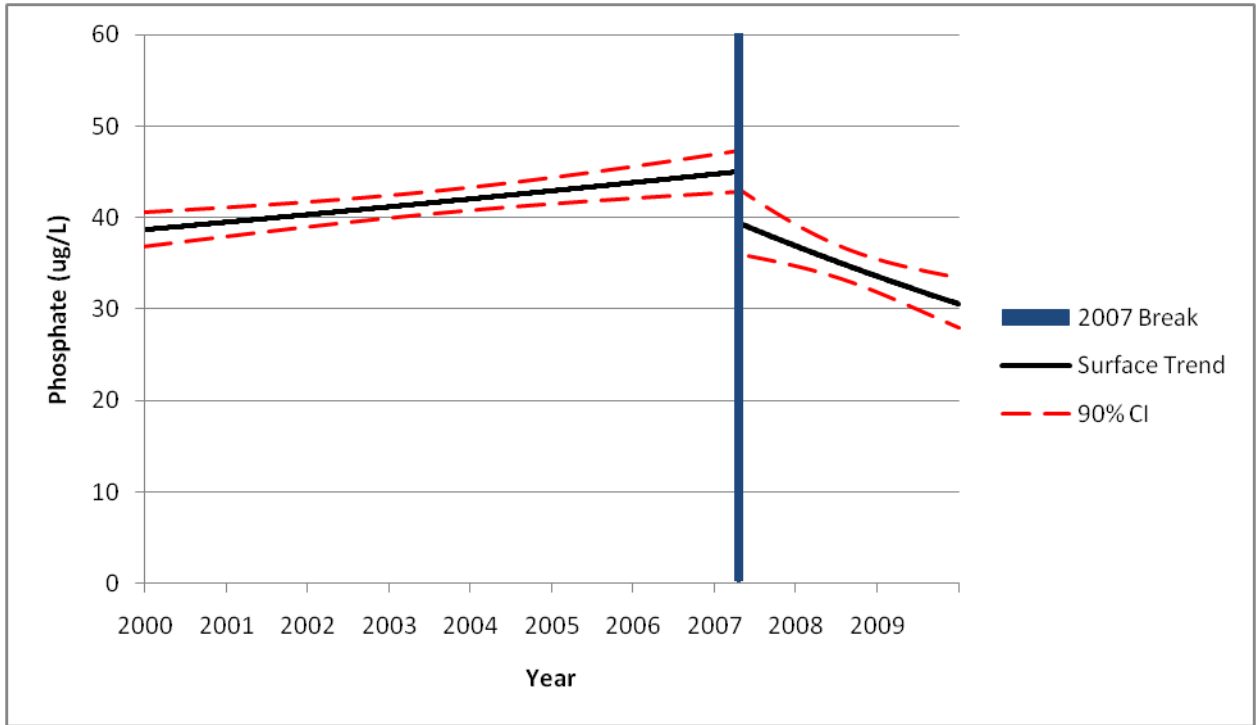


Figure 18 Bay-wide trends in phosphate (PO<sub>4</sub>) surface concentrations over the 2000-2009 period. Dashed lines indicate approximate 90% confidence intervals (CI). Both pre-break and post-break trends are statistically significant.

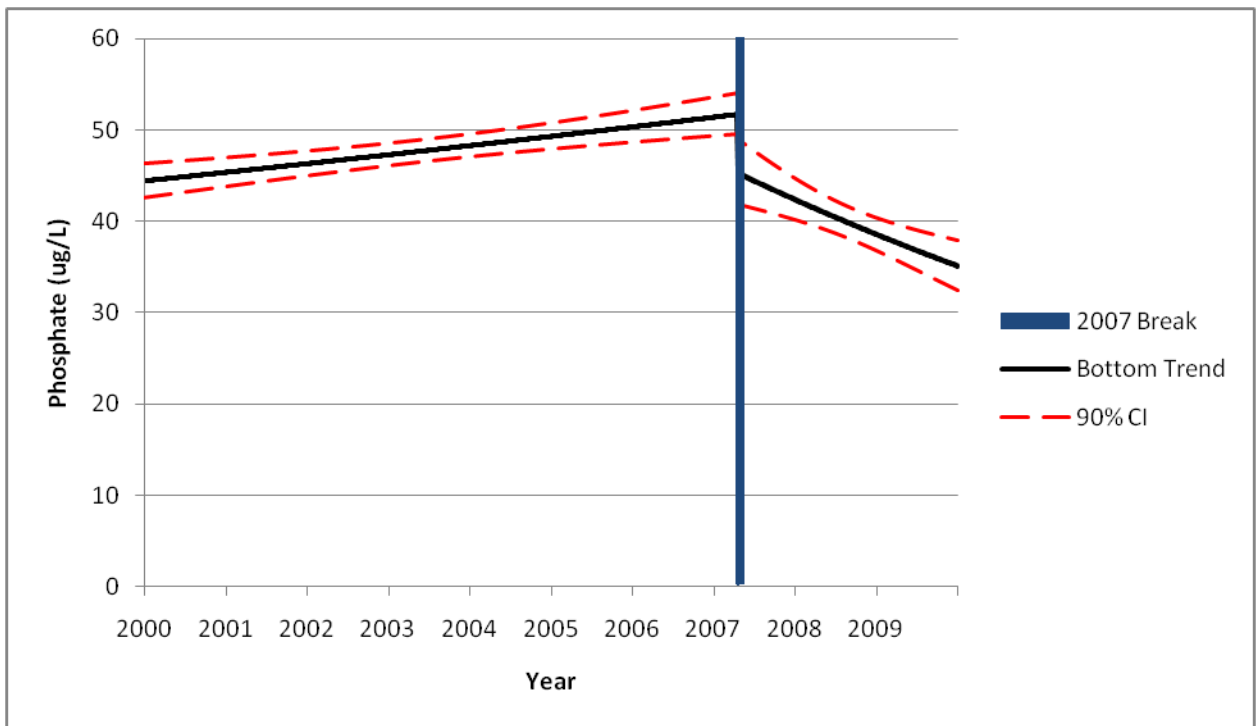


Figure 19 Bay-wide trends in phosphate (PO<sub>4</sub>) bottom/middle concentrations over the 2000-2009 period. Bottom and middle concentrations are not statistically different. Dashed lines indicate approximate 90% confidence intervals (CI). Both pre-break and post-break trends are statistically significant.

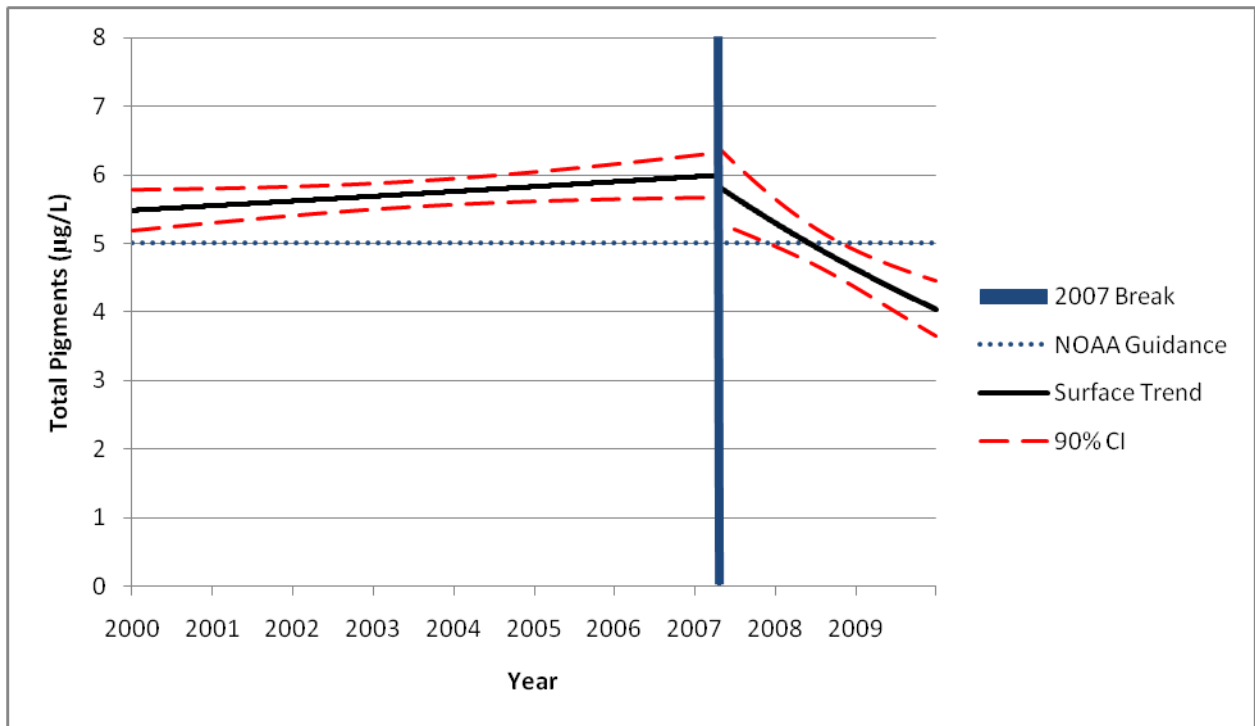


Figure 20 Bay-wide trends in total pigment surface concentrations over the 2000-2009 period. Dashed lines indicate approximate 90% confidence intervals (CI). The pre-break trend is not statistically significant, but the post-break trend is statistically significant.

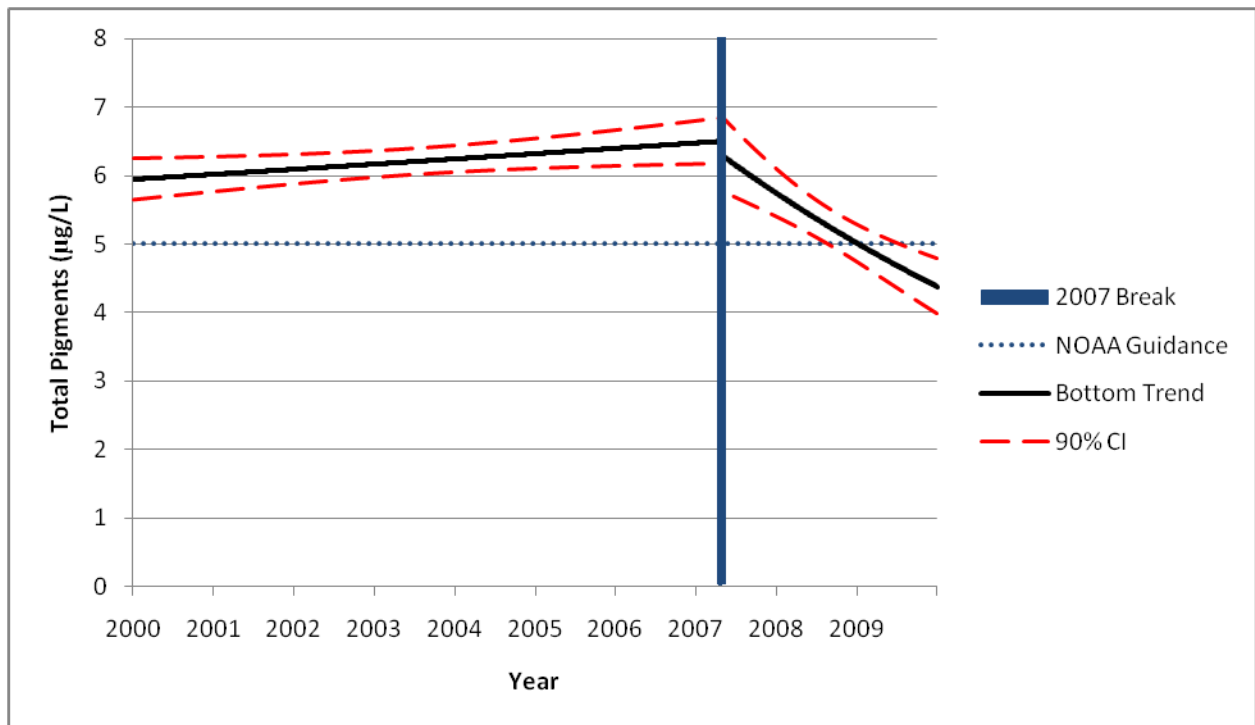


Figure 21 Bay-wide trends in total pigment bottom/middle concentrations over the 2000-2009 period. Bottom and middle concentrations are not statistically different. Dashed lines indicate approximate 90% confidence intervals (CI). The pre-break trend is not statistically significant, but the post-break trend is statistically significant.

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## Appendix A. Detailed Methods

### Data preparation

Original data files from the laboratory at the School of Marine Science and Technology at the University of Massachusetts, Dartmouth were provided to Cadmus by the Pleasant Bay Alliance. These data were imported into a Microsoft Access database. The database stores all data in a single table, called All\_data. The original spreadsheets were edited so that field names were all in the top row and matched field names in the database. Notes fields were added to store non-numeric cell contents in fields that should only contain numeric contents. Spreadsheets were then imported into Access and appended to the All\_data table. Access generates a list of import errors that primarily indicate data type mismatches between the spreadsheet and the destination table. These errors were reviewed to confirm that they only occurred when a non-numeric value could not be imported into a numeric field in the database. The notes fields contain these non-numeric values, so all information (including error flags) in the spreadsheets was imported to the database.

Sample ID information, including station, depth, and duplicate fields, were cleaned to create consistent formats (e.g., Dup, FD, FieldDup were converted to Duplicate). Queries were used to concatenate sample information into new sample IDs to facilitate further data evaluation (SDDID is Station-Date-Depth and SDID is Station-Date). Because the data spreadsheets provided by the PBA contain a lot of data from areas outside of Pleasant Bay, the Analysis\_site field was created to note stations that will be used in the statistical analyses.

### Identifying potentially erroneous data points

The database import procedure described above eliminated data points that were flagged in the spreadsheets or contained non-numeric values. Most of the non-numeric values indicate missing data (NS, ND, NDS, NC, N/A, NES, Lost, Machine Error) and it is appropriate to leave these cells blank when formatting data for statistical analysis because linear models can accommodate missing data.

Many samples were reported as BDL (below detection limit) or <X, where X is the detection limit for that parameter. These values were replaced with half the detection limit ( $0.5 \times X$ ). This is a common method for accommodating BDL results and is appropriate for trend analysis (<http://www.epa.gov/reg3hwmd/risk/human/info/guide3.htm>).

Two approaches were used to identify potential outliers in numeric fields. Box plots were used to identify values that fall outside of the possible range for each parameter. For example, because most temperature values were recorded in degrees Celsius, a box plot would identify a temperature value of 70, which was probably recorded in degrees Fahrenheit. In addition, modified z-scores (Iglewicz & Hoaglin, 1993) were calculated for log transformations of each variable. Absolute values of modified z-scores >3.5 are considered potential outliers. This procedure only identifies potential outliers, and unless there is other evidence to indicate that a value is suspect, it should not be discarded (Iglewicz & Hoaglin, 1993). Because all data points with flags from the lab were already discarded, the remaining data were considered valid and included in the analysis. The influence of very high values on the evaluation of temporal trends is moderated by the log transformation approach.

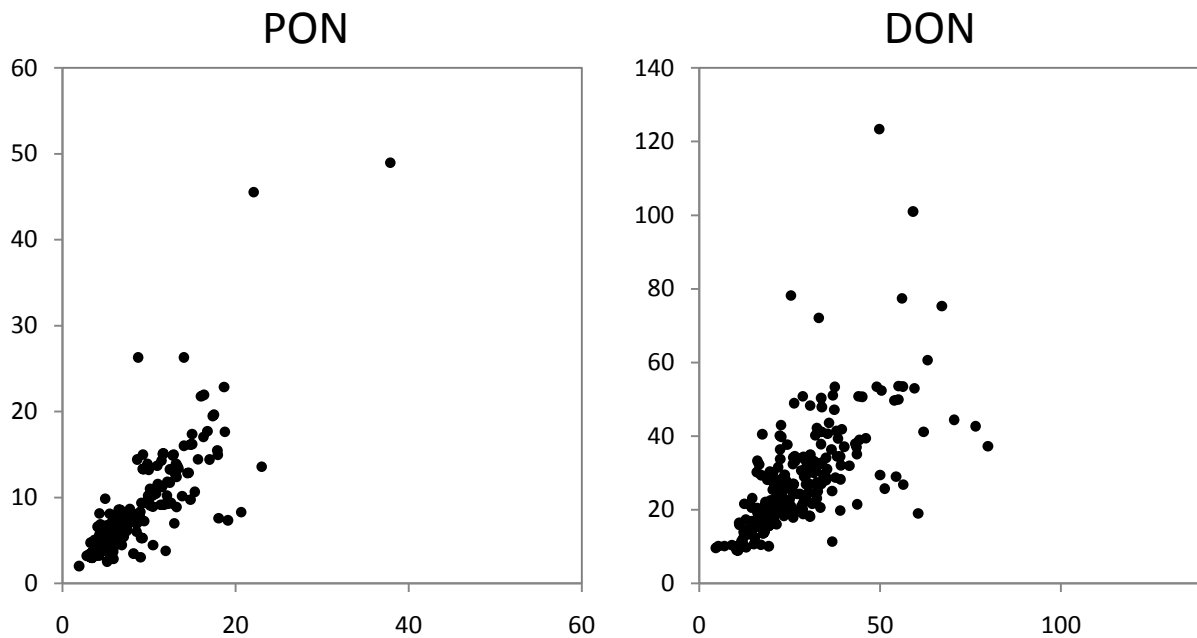
**Table 3** Number of potential outliers for each variable based on modified z-scores.

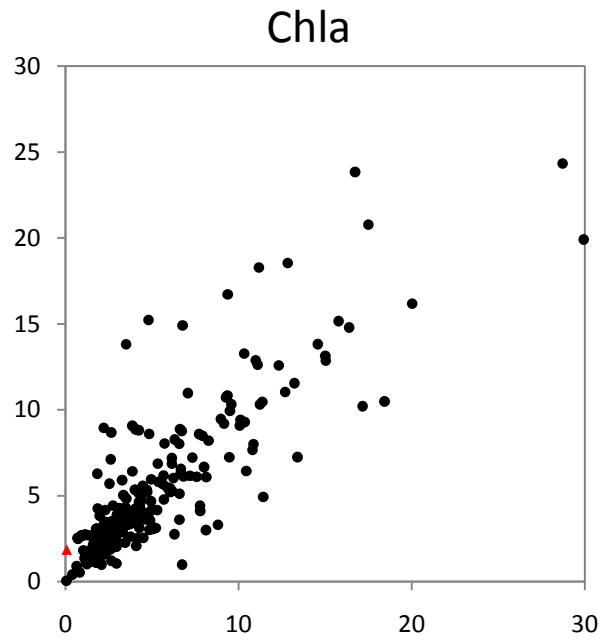
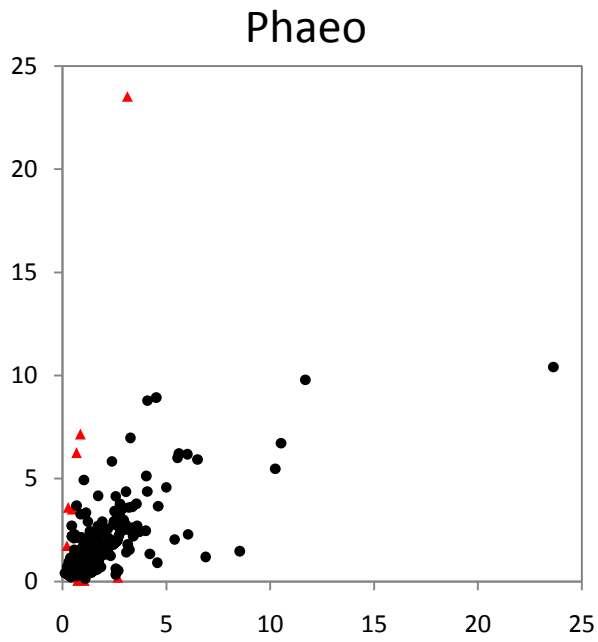
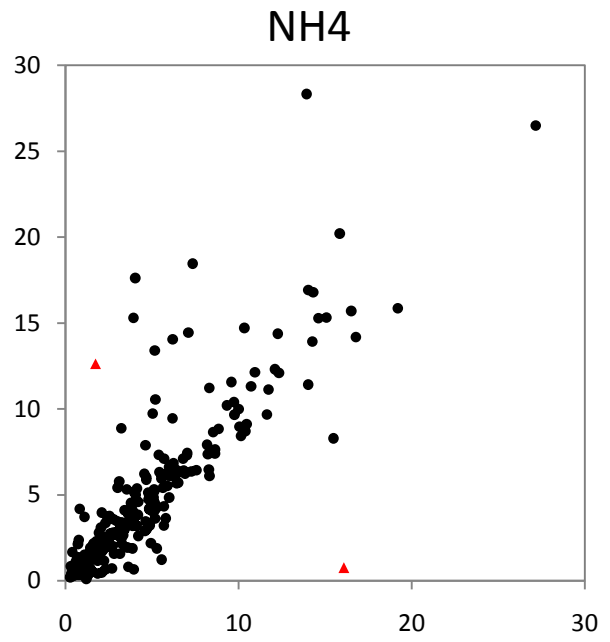
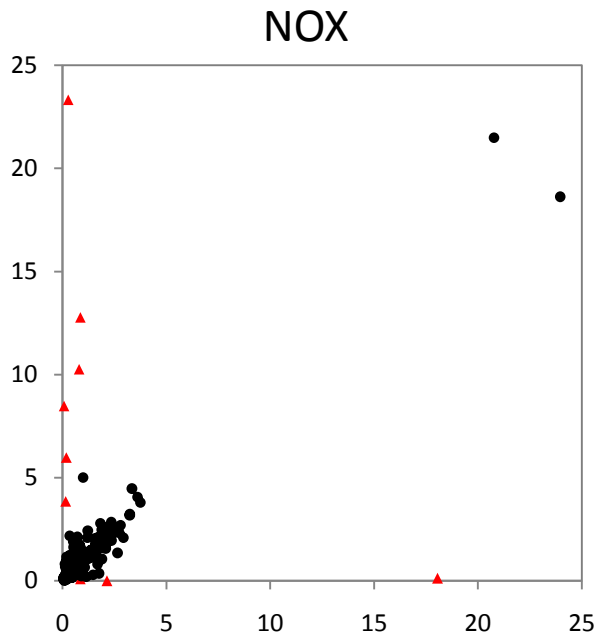
Parameter	Number of potential outliers	Number of observations
NOX	34	2482
NH4	10	2520
PON	19	2280
DON	9	2520
Chla	28	2532
Phaeo	24	2285
PO4	16	2538
POC	35	2517

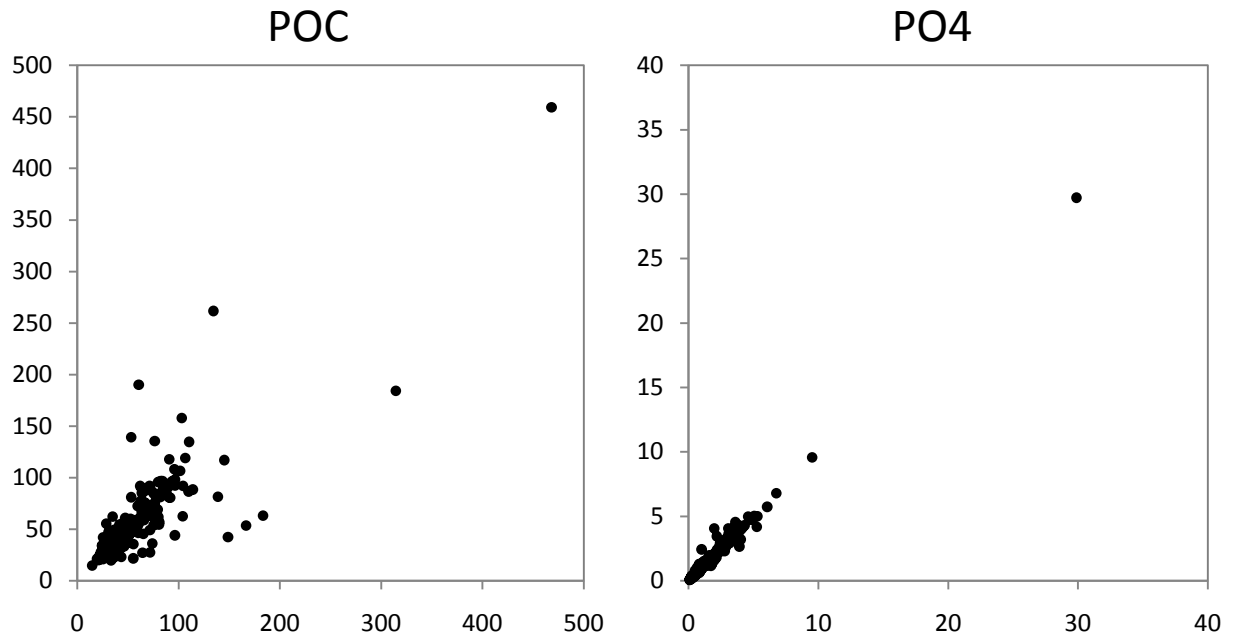
### Duplicate Samples

Duplicate samples were plotted on an x-y plot to evaluate their correlation and identify duplicates that differ substantially. The correlation between duplicates varied substantially among parameters. PO4 duplicates were the most consistent and phaeophytin duplicates were the most variable.

For statistical analysis, duplicate samples were averaged except where they differed by more than 150% of the average of the two values (red triangles in the below plots). In these cases, both samples were excluded from analysis.







### Surface/Bottom Comparison

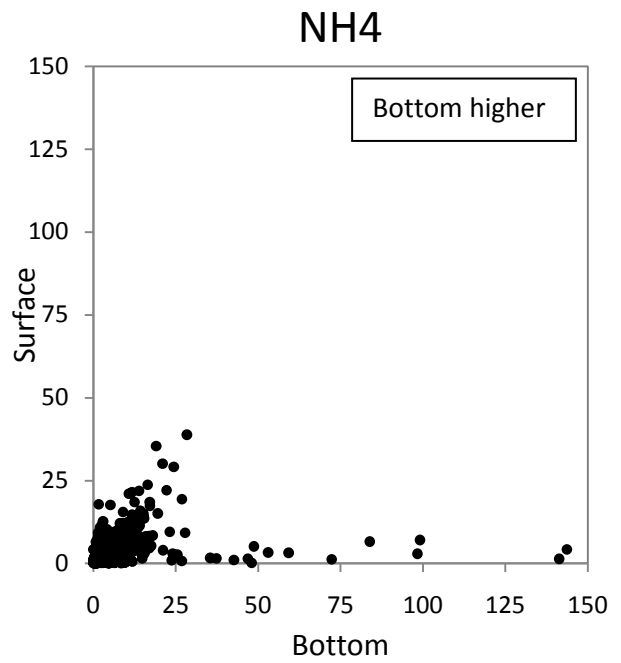
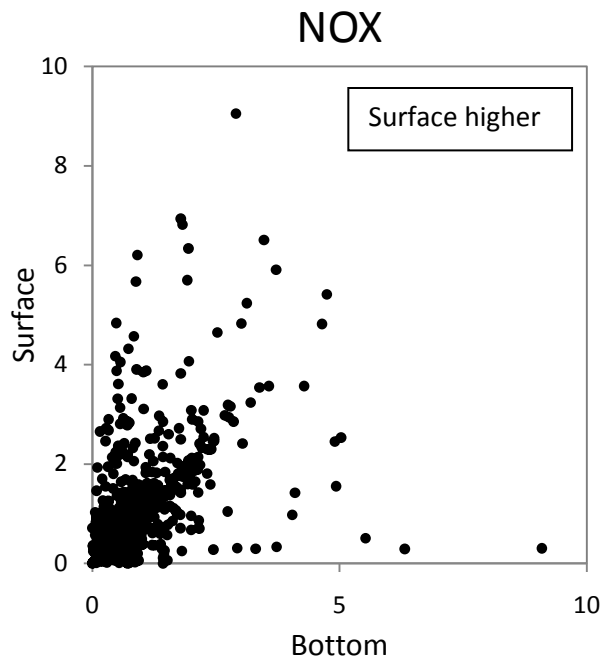
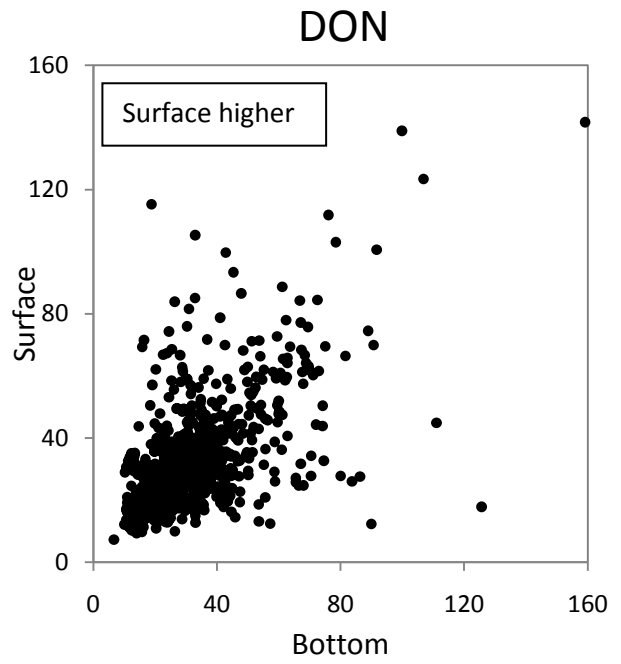
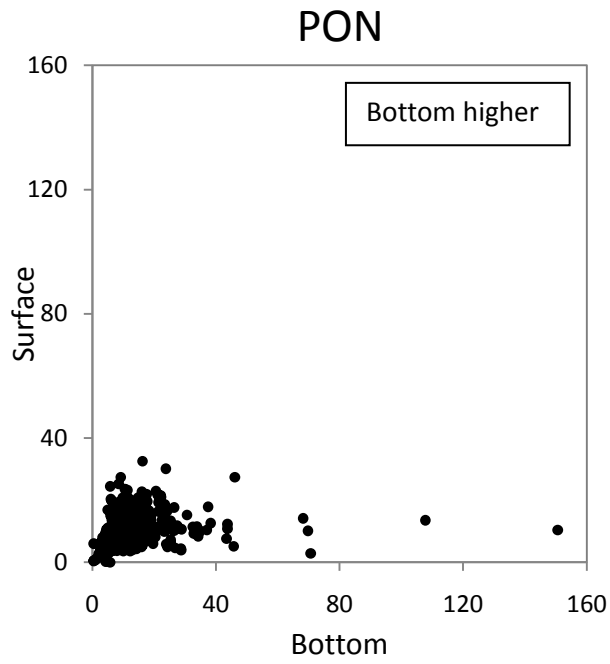
Surface and bottom samples from the same location were compared to determine whether there are consistent differences in eleven water quality parameters across the water column (Table 4). Six of the parameters are generally higher in bottom samples, four of the parameters are generally higher in surface samples, and one parameter (Chla) does not consistently differ with depth.

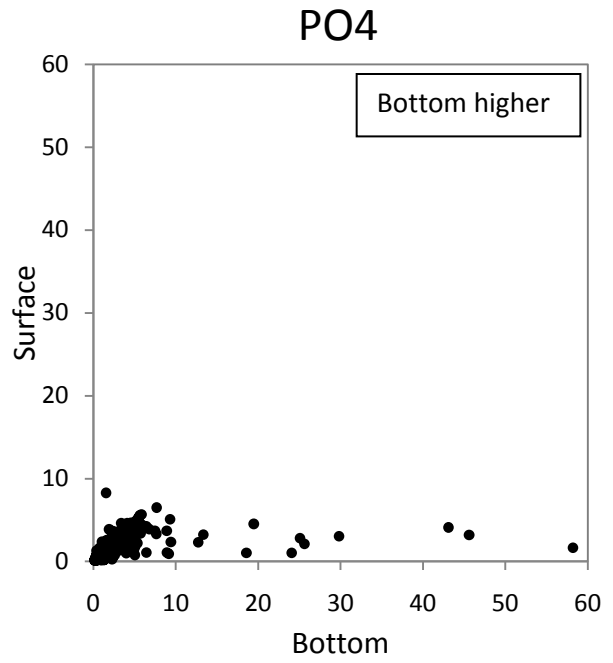
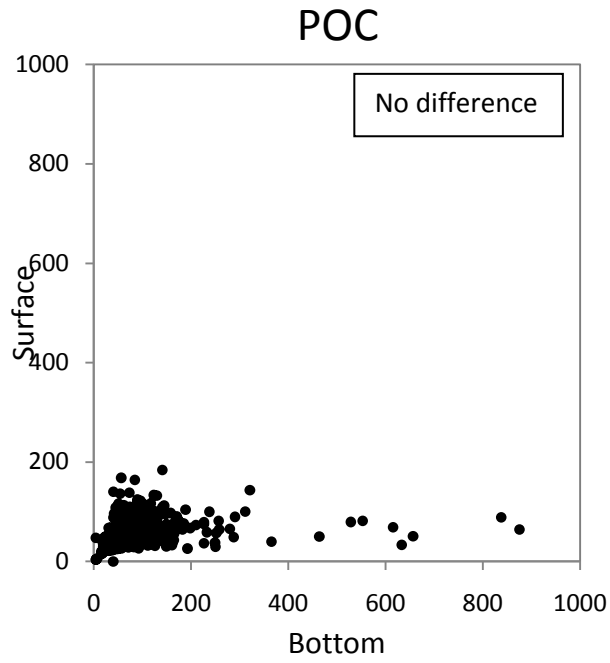
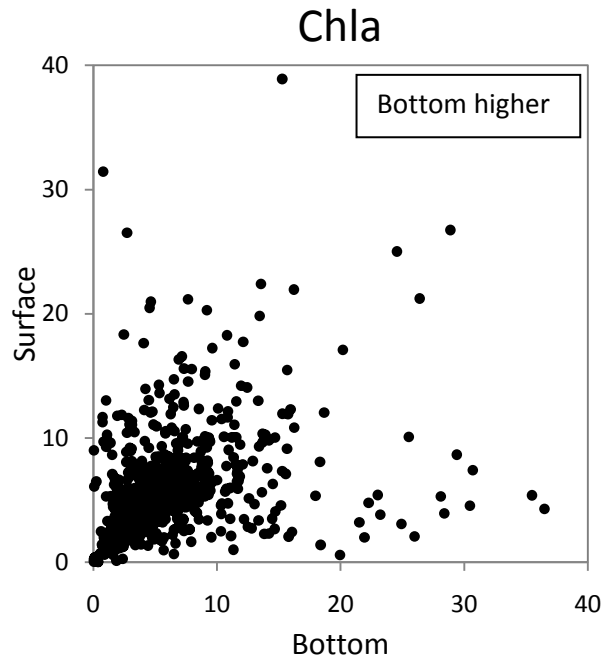
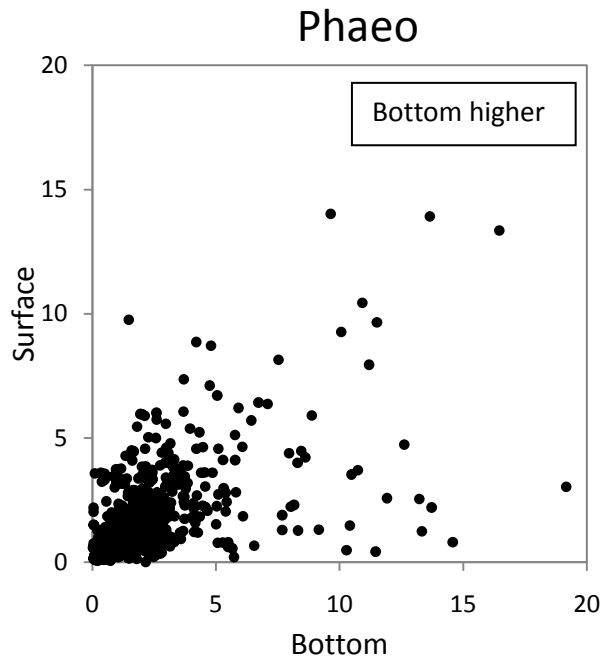
One way to account for these differences is to analyze surface and bottom data separately. However, this approach has less power to evaluate trends because there are fewer samples in each analysis. A more powerful approach is to analyze all samples together with depth as a categorical variable.

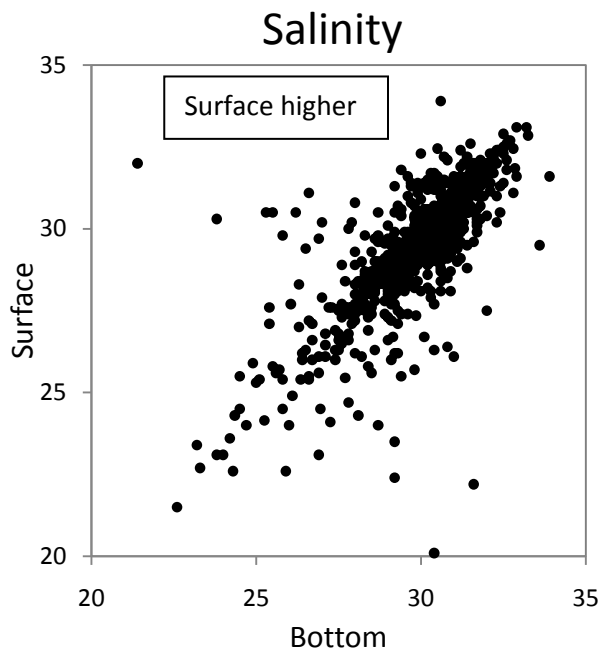
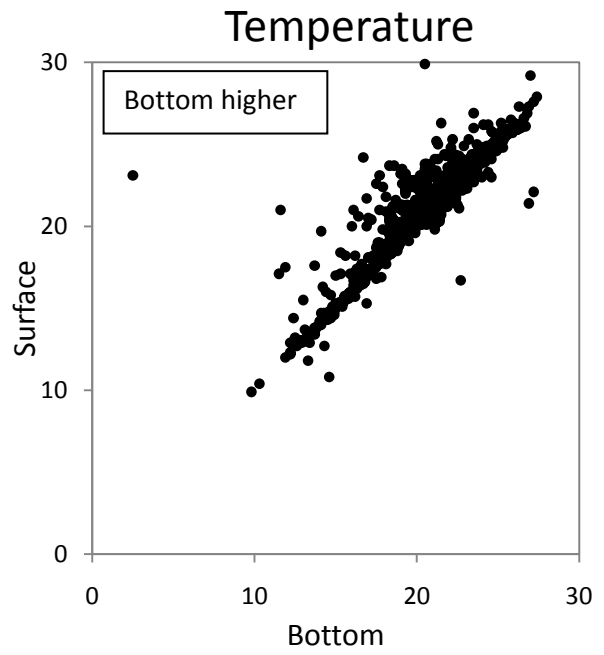
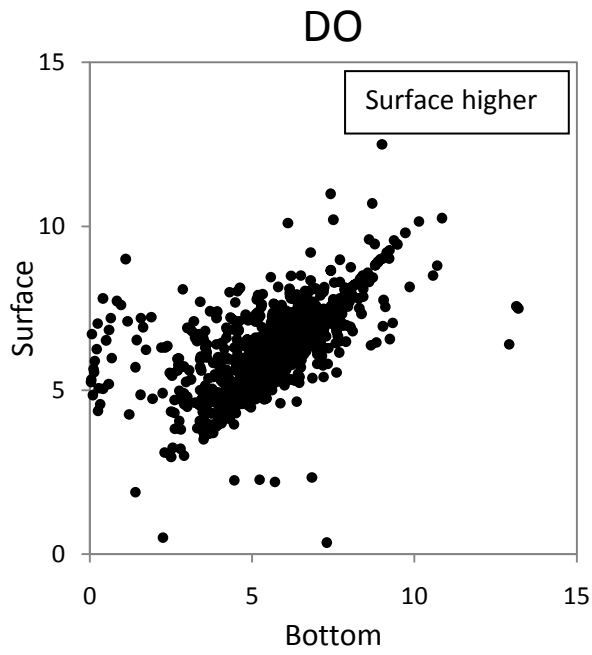
**Table 4 Results of paired t-tests comparing surface and bottom water quality samples.**

Parameter	Paired sample count	Pearson correlation	Mean bottom	Mean surface	T statistic for paired difference	P-value for paired difference
DO	932	0.58	5.57	6.20	-13.51	4.0E-38
Temp	943	0.90	20.83	21.40	-13.04	7.1E-36
Salinity	908	0.74	29.93	29.58	8.21	7.6E-16
PON	811	0.60	0.94*	0.90*	4.90	1.2E-06
POC	910	0.58	1.77*	1.72*	8.19	8.9E-16
PO4	910	0.83	0.12*	0.07*	7.87	1.0E-14
Phaeo	771	0.62	0.14*	0.08*	4.77	2.2E-06
NOX	874	0.64	-0.29*	-0.22*	-5.03	5.9E-07
NH4	903	0.62	0.47*	0.36*	8.12	1.5E-15
DON	921	0.62	1.43*	1.45*	-2.71	0.007
Chla	915	0.56	0.62*	0.62*	-0.05	0.96

\* indicates log transformed values







## Summary Statistics

Summary statistics were calculated by year and across the range of available data for the following water quality parameters:

- **Dissolved Inorganic Nitrogen ( $\text{NH}_4+\text{NO}_x$ )**
- **Bioactive Nitrogen (DIN+PON)**
- **Total Nitrogen (DIN+PON+DON)**
- **Total Phytopigments (Chla+Phaeo)**
- **Dissolved Oxygen (DO)**
- **Phosphate (PO4)**

The geometric mean (mean of log-transformed values, back-transformed to original scale) was used for dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, phosphate, and pigments because these variables are log-normally distributed. The arithmetic mean was used for DO because it is normally distributed. Confidence intervals for these parameters are based on the mean and sample size. The percentage of samples that do not meet water quality standards (6 mg/L DO), NOAA thresholds (5 mg/L total pigments), and MEP restoration targets for bioactive nitrogen (varies by station) were also calculated.

## Evaluation of Water Quality Trends

A series of mixed effects models were created in the R programming language to evaluate bay-wide trends in Pleasant Bay water quality data for dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, total pigments, phosphate, and dissolved oxygen. Mixed effects models were fit with the lmer function in the lme4 R package (Bates & Maechler, 2010). Eight candidate models were created for each of these six parameters. The primary difference among the candidate models is how they represent the shape of the water quality trend over time. The eight candidate models include four different trend shapes, both with and without other covariates, including salinity, temperature, and cumulative rainfall in the week prior to the sample. Salinity indicates the relative influence of relatively low-nutrient marine water versus relatively high nutrient fresh water in the sample. Temperature affects growth of algae and other processes that partition nutrients among their chemical forms. Rain events transport nitrogen and phosphorus from land to water and increase the influence of freshwater in the bay. The variables in the models are defined as:

- Intercept (DepthB) – Bottom depth
- DepthM – Middle depth
- DepthS – Surface depth
- DateN – Normalized date
- DateN2 – Normalized date squared
- Break – Categorical variable representing the 2007 break in Nauset Beach
- DateN:Break – Interaction term representing the combined effect of date and break
- Salinity – Salinity
- Temp – Temperature
- LogRain7 – Logarithm of the previous 7 days rainfall (as recorded at Chatham Municipal Airport)

Models with a statistically significant DateN, Break, or DateN:Break term have significant trends over time. The four trend shapes include:

1. Linear (date)
2. Linear with a change in intercept at date of 2007 break (date, break)
3. Linear with a change in intercept and slope at date of 2007 break (date, break, date:break)
4. Curved (date, date<sup>2</sup>)

All models include sample depth (surface, middle, or bottom) as a covariate. All models include station ID, the interaction of depth and station ID, and the interaction of date and station ID as random effects. A model with a linear trend shape suggests that average concentrations have either continuously increased or continuously decreased over time. A curved trend shape suggests a non-linear response in the average concentration over time (average concentrations have increased and decreased at different times during the period of analysis). A model with a break term suggests that average concentrations have either continuously increased or continuously decreased over time, but that the Nauset Beach break event caused a sudden change in average concentrations (i.e., a change in intercept). A model with the date:break interaction term suggests that average concentrations have either continuously increased or continuously decreased until the Nauset Beach break event, after which the direction of the trend has reversed (i.e., a change in slope).

The eight candidate models (the four models described above, each with and without covariates) were evaluated against each other using Akaike's Information Criterion (AIC) (Hirotsugu, 1974) to find the model that provides the most explanatory power, while minimizing the number of variables in the model. Table 5 displays the AIC values and t-values for each parameter within the 48 mixed effects models evaluated for the bay-wide trend analysis. Table 6 displays the model coefficients. The model with the lowest AIC value (highlighted in yellow) is the one with the most statistical support and was chosen as the best model for each response variable. The following equations were used to convert the AIC values to probabilities as presented in the Results & Discussion section (Burnham & Anderson, 2002):

The raw weight for model  $i$  among  $M$  models is  $w_i = \frac{\exp\left(-\frac{1}{2}AIC_i\right)}{\sum_{i=1}^M \exp\left(-\frac{1}{2}AIC_i\right)}$

The normalized weight (i.e., the model probability) for model  $i$  is  $w_{in} = \frac{w_i}{\sum_{i=1}^M w_i}$

Mixed effects models do not lend themselves to the calculation of accurate p-values for evaluating the statistical significance of a parameter within a model. Instead, a t-value greater than |1.961| (based on the degrees of freedom in these particular models) indicates a statistically significant parameter (see Table 5). Similarly, an exact confidence interval cannot be calculated for a mixed effects model. Therefore, the confidence intervals from reduced versions of the mixed effects models (equivalent to multiple regression) were calculated for the plots in Figure 16 through Figure 21. Confidence intervals for all model results were calculated as follows (Draper & Smith, 1998):

$$\hat{y}_i \pm t_{\alpha/2, n-(k+1)} \sqrt{\hat{\sigma}^2 x_i' (X'X)^{-1} x_i}$$

$$\text{Where: } x_i = \begin{bmatrix} 1 \\ x_{i1} \\ \cdot \\ \cdot \\ x_{ik} \end{bmatrix}$$

Multiple linear regression was used to evaluate trends at individual monitoring sites. Multiple linear regression models were fit with the lm function in R. Sixty-four separate models (see Appendix A) were created in the R programming language for each site/parameter combination (33 sites and 6 parameters). This resulted in 12,672 separate models that were also evaluated using the AIC method. The best model was identified for each site/parameter combination (198 models). Identification of the best models also considered the number of data points used in the analysis. The rule of thumb in multiple linear regression is that only one parameter per 30 samples should be included in the model. The plots of the statistically significant models are presented in Appendix B. Multiple linear regression models do allow the calculation of p-values and these are listed along with the model coefficients for the statistically significant models in Table 8. Since there are 33 sites in the analysis, the Bonferroni correction must be applied to determine statistical significance. The typical  $\alpha$ -level of 0.05 is thus divided by 33 to obtain the 0.0015 level used to test for statistical significance.

Table 5 AIC values and t-values for each of the candidate mixed effects models. The best models (lowest AIC) are highlighted in yellow.

Model	AIC	T Value									
		Intercept	DepthM	DepthS	DateN	DateN2	Break	DateN:Break	Salinity	Temp	LogRain7
DIN1	1679	29.417	1.504	-2.139	2.379						
DIN1C	1576	13.062	1.552	-2.384	2.911				0.01	0.992	8.485
DIN2	1676	29.409	1.534	-2.115	3.038		-2.261				
DIN2C	1572	12.867	1.422	-2.212	3.669		-2.57		0.367	0.792	8.558
DIN3	1667	31.237	1.336	-2.144	3.407		2.598	-3.393			
DIN3C	1567	12.971	1.501	-2.348	3.931		1.663	-2.51	0.302	0.645	8.241
DIN4	1674	29.483	1.477	-2.118	3.081	-2.714					
DIN4C	1572	13.164	1.531	-2.342	3.507	-2.358			0.09	0.735	8.329
BioN1	-2160	65.07	-2.11	-3.4	-3.51						
BioN1C	-2103	40.66	-2.17	-3.62	-3.8				-5.14	2.65	3.03
BioN2	-2165	65.33	-2.13	-3.42	-2.35		-2.68				
BioN2C	-2104	40.46	-2.17	-3.62	-2.72		-1.9		-4.82	2.47	3.06
BioN3	-2172	65.08	-2.14	-3.41	-2.01		2.07	-2.99			
BioN3C	-2108	40.51	-2.16	-3.61	-2.42		1.79	-2.45	-4.9	2.32	2.77
BioN4	-2184	65.29	-2.14	-3.4	-1.9	-5.2					
BioN4C	-2120	40.87	-2.15	-3.59	-2.14	-4.44			-5	2.1	2.7
TN1	-2304	130.42	0.81	-1.26	-3.53						
TN1C	-2267	47.15	0.89	-1.49	-3.87				1.16	5.49	1.86
TN2	-2309	130.76	0.75	-1.26	-2.49		-2.6				
TN2C	-2271	46.92	0.83	-1.46	-2.79		-2.34		1.49	5.26	1.9
TN3	-2337	129.36	0.72	-1.27	-1.93		4.49	-5.51			
TN3C	-2294	47.26	0.82	-1.46	-2.25		4.1	-5.02	1.36	4.97	1.33
TN4	-2341	130.31	0.68	-1.24	-1.79	-6.32					
TN4C	-2297	47.61	0.78	-1.42	-2.08	-5.74			1.37	4.77	1.43
Pig1	-288.6	23.426	0.066	-0.801	-0.646						
Pig1C	-346.3	10.097	-1.141	-1.435	-0.948				-5.123	8.182	0.89
Pig2	-311.5	23.632	0.024	-0.807	1.021		-5.072				
Pig2C	-360.2	9.839	-1.046	-1.411	0.643		-4.016		-4.533	7.829	0.95
Pig3	-336.8	23.389	0.018	-0.817	1.447		3.495	-5.218			
Pig3C	-379.3	10.044	-1.069	-1.4	1.102		3.234	-4.617	-4.647	7.545	0.418
Pig4	-322.7	23.649	-0.019	-0.791	0.896	-6.105					
Pig4C	-370.1	10.375	-1.111	-1.394	0.636	-5.14			-4.942	7.539	0.518
DO1	8063	29.208	2.548	3.826	-2.897						
DO1C	7028	20.94	2.16	4.148	-2.765				-2.871	-15.837	-1.582
DO2	8047	29.308	2.535	3.834	-1.761		-4.31				
DO2C	6999	20.792	2.096	4.159	-0.923		-5.588		-2.265	-16.363	-1.522
DO3	8018	29.364	2.426	3.83	-1.219		4.042	-5.575			
DO3C	6954	21.335	1.978	4.166	-0.069		4.955	-6.927	-2.581	-16.946	-2.33
DO4	8006	29.904	2.388	3.813	-1.359	-7.811					
DO4C	6935	22.174	1.952	4.202	-0.122	-9.921			-2.935	-17.284	-2.377
PO1	-293.2	33.63	-0.3	-2.2	0.29						
PO1C	-735.7	6.663	-0.434	-2.863	-1.054				5.825	21.99	5.886
PO2	-328.9	33.89	-0.2	-2.2	3.43		-6.22				
PO2C	-770.7	6.285	-0.257	-2.811	1.997		-6.148		6.645	21.622	6.043
PO3	-349.6	33.72	-0.35	-2.21	3.98		2.8	-4.78			
PO3C	-784.1	6.472	-0.385	-2.804	2.427		1.997	-3.952	6.544	21.415	5.57
PO4	-314.9	33.82	-0.34	-2.19	2.44	-4.91					
PO4C	-743.8	6.819	-0.427	-2.827	0.378	-3.193			5.923	21.542	5.665

Table 6 AIC values and coefficient estimates for each of the candidate mixed effects models. The best models (lowest AIC) are highlighted in yellow.

Model	AIC	Coefficient Estimate									
		Intercept	DepthM	DepthS	DateN	DateN2	Break	DateN:Break	Salinity	Temp	LogRain7
DIN1	1679	1.746	0.083	-0.078	0.013						
DIN1C	1576	1.733	0.092	-0.084	0.015				0.000	0.003	0.089
DIN2	1676	1.749	0.085	-0.078	0.019		-0.068				
DIN2C	1572	1.713	0.081	-0.080	0.022		-0.078		0.001	0.002	0.089
DIN3	1667	1.746	0.075	-0.077	0.022		0.272	-0.072			
DIN3C	1567	1.726	0.089	-0.083	0.024		0.176	-0.053	0.001	0.002	0.087
DIN4	1674	1.758	0.082	-0.077	0.018	-0.003					
DIN4C	1572	1.749	0.090	-0.082	0.020	-0.003			0.000	0.002	0.087
BioN1	-2160	2.350	-0.065	-0.064	-0.011						
BioN1C	-2103	2.536	-0.066	-0.068	-0.011				-0.008	0.003	0.014
BioN2	-2165	2.352	-0.065	-0.065	-0.008		-0.036				
BioN2C	-2104	2.529	-0.066	-0.068	-0.009		-0.026		-0.008	0.003	0.014
BioN3	-2172	2.353	-0.066	-0.064	-0.007		0.095	-0.028			
BioN3C	-2108	2.536	-0.067	-0.068	-0.008		0.084	-0.023	-0.008	0.003	0.013
BioN4	-2184	2.361	-0.066	-0.064	-0.007	-0.003					
BioN4C	-2120	2.550	-0.066	-0.068	-0.007	-0.002			-0.008	0.003	0.013
TN1	-2304	2.817	0.022	-0.015	-0.011						
TN1C	-2267	2.632	0.024	-0.018	-0.012				0.002	0.006	0.008
TN2	-2309	2.819	0.020	-0.015	-0.009		-0.034				
TN2C	-2271	2.623	0.023	-0.018	-0.009		-0.031		0.002	0.006	0.009
TN3	-2337	2.820	0.020	-0.016	-0.007		0.201	-0.050			
TN3C	-2294	2.637	0.023	-0.018	-0.008		0.186	-0.046	0.002	0.006	0.006
TN4	-2341	2.830	0.018	-0.015	-0.006	-0.003					
TN4C	-2297	2.651	0.021	-0.017	-0.007	-0.003			0.002	0.006	0.006
Pig1	-288.6	0.770	0.003	-0.020	-0.003						
Pig1C	-346.3	0.836	-0.045	-0.036	-0.004				-0.012	0.015	0.006
Pig2	-311.5	0.777	0.001	-0.021	0.005		-0.102				
Pig2C	-360.2	0.814	-0.042	-0.036	0.003		-0.081		-0.011	0.014	0.007
Pig3	-336.8	0.777	0.001	-0.021	0.008		0.238	-0.072			
Pig3C	-379.3	0.831	-0.043	-0.035	0.005		0.223	-0.064	-0.011	0.013	0.003
Pig4	-322.7	0.789	-0.001	-0.020	0.005	-0.004					
Pig4C	-370.1	0.860	-0.045	-0.035	0.003	-0.004			-0.012	0.013	0.004
DO1	8063	5.597	0.346	0.545	-0.084						
DO1C	7028	9.722	0.524	0.712	-0.073				-0.036	-0.152	-0.058
DO2	8047	5.618	0.350	0.545	-0.049		-0.486				
DO2C	6999	9.623	0.515	0.714	-0.023		-0.600		-0.029	-0.157	-0.056
DO3	8018	5.618	0.326	0.544	-0.033		1.534	-0.428			
DO3C	6954	9.806	0.483	0.714	-0.002		1.789	-0.504	-0.032	-0.161	-0.085
DO4	8006	5.718	0.329	0.544	-0.035	-0.031					
DO4C	6935	10.102	0.464	0.724	-0.003	-0.038			-0.036	-0.164	-0.086
PO1	-293.2	1.668	-0.011	-0.047	0.001						
PO1C	-735.7	0.556	-0.015	-0.061	-0.003				0.013	0.036	0.037
PO2	-328.9	1.674	-0.007	-0.047	0.012		-0.120				
PO2C	-770.7	0.523	-0.009	-0.060	0.007		-0.111		0.015	0.035	0.038
PO3	-349.6	1.676	-0.013	-0.048	0.014		0.191	-0.066			
PO3C	-784.1	0.538	-0.014	-0.060	0.009		0.125	-0.050	0.015	0.035	0.035
PO4	-314.9	1.683	-0.012	-0.047	0.008	-0.003					
PO4C	-743.8	0.570	-0.015	-0.061	0.001	-0.002			0.013	0.035	0.036

**Table 7 Sixty-four candidate multiple linear regression models evaluated for each station/parameter combination.**

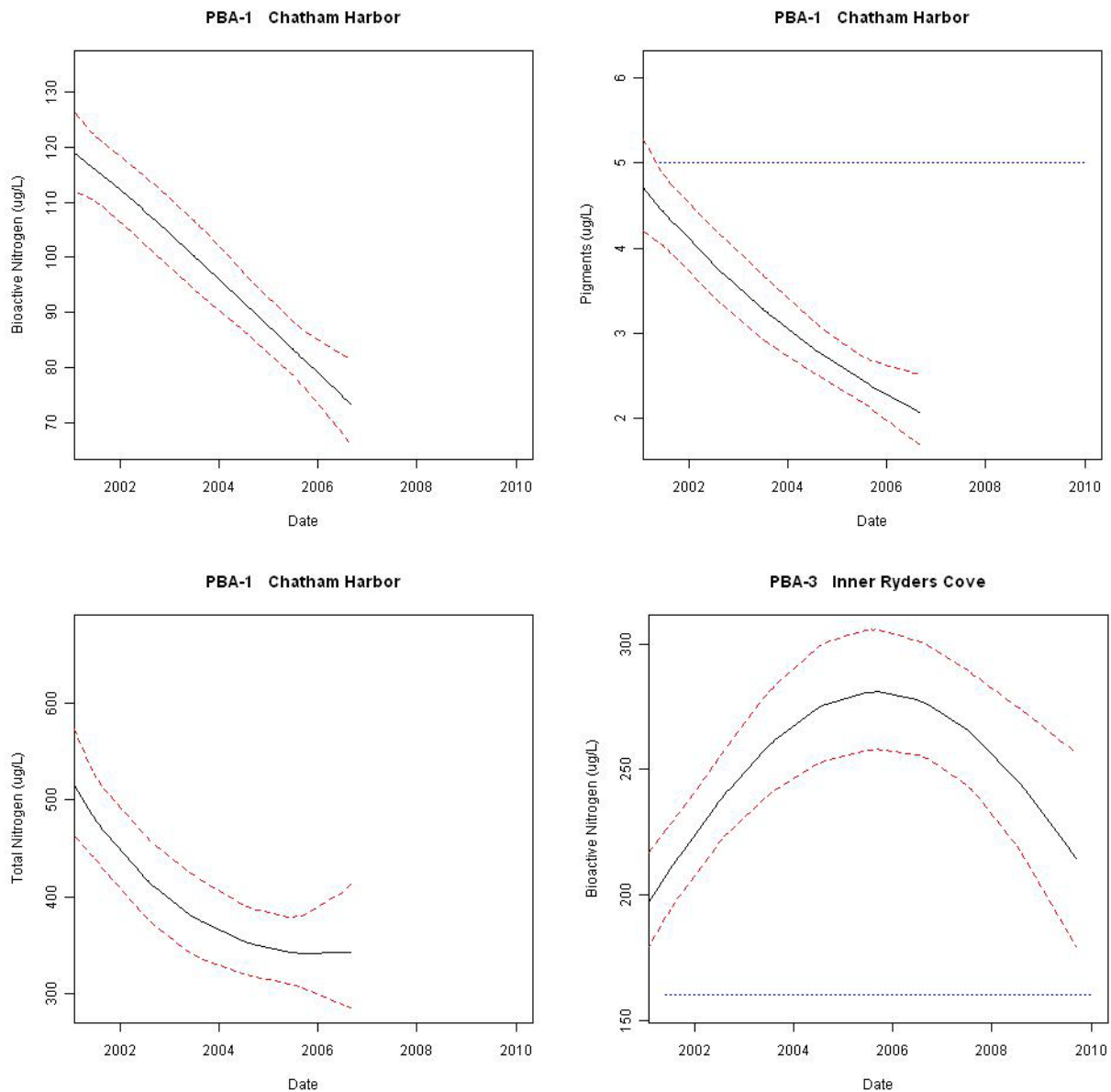
Model Equations	
Response ~ DateN	Response ~ DateN+Depth+Break+Temp+DateN:Break
Response ~ DateN+Break	Response ~ DateN+Depth+Break+Temp+LogRain7
Response ~ DateN+Break+DateN:Break	Response ~ DateN+Depth+Break+Temp+LogRain7+DateN:Break
Response ~ DateN+Break+LogRain7	Response ~ DateN+Depth+DateN2
Response ~ DateN+Break+LogRain7+DateN:Break	Response ~ DateN+Depth+LogRain7
Response ~ DateN+Break+Salinity	Response ~ DateN+Depth+LogRain7+DateN2
Response ~ DateN+Break+Salinity+DateN:Break	Response ~ DateN+Depth+Salinity
Response ~ DateN+Break+Salinity+LogRain7	Response ~ DateN+Depth+Salinity+DateN2
Response ~ DateN+Break+Salinity+LogRain7+DateN:Break	Response ~ DateN+Depth+Salinity+LogRain7
Response ~ DateN+Break+Salinity+Temp	Response ~ DateN+Depth+Salinity+LogRain7+DateN2
Response ~ DateN+Break+Salinity+Temp+DateN:Break	Response ~ DateN+Depth+Salinity+Temp
Response ~ DateN+Break+Salinity+Temp+LogRain7	Response ~ DateN+Depth+Salinity+Temp+DateN2
Response ~ DateN+Break+Salinity+Temp+LogRain7+DateN:Break	Response ~ DateN+Depth+Salinity+Temp+LogRain7
Response ~ DateN+Break+Temp	Response ~ DateN+Depth+Salinity+Temp+LogRain7+DateN2
Response ~ DateN+Break+Temp+DateN:Break	Response ~ DateN+Depth+Temp
Response ~ DateN+Break+Temp+LogRain7	Response ~ DateN+Depth+Temp+DateN2
Response ~ DateN+Break+Temp+LogRain7+DateN:Break	Response ~ DateN+Depth+Temp+LogRain7
Response ~ DateN+DateN2	Response ~ DateN+Depth+Temp+LogRain7+DateN2
Response ~ DateN+Depth	Response ~ DateN+LogRain7
Response ~ DateN+Depth+Break	Response ~ DateN+LogRain7+DateN2
Response ~ DateN+Depth+Break+DateN:Break	Response ~ DateN+Salinity
Response ~ DateN+Depth+Break+LogRain7	Response ~ DateN+Salinity+DateN2
Response ~ DateN+Depth+Break+LogRain7+DateN:Break	Response ~ DateN+Salinity+LogRain7
Response ~ DateN+Depth+Break+Salinity	Response ~ DateN+Salinity+LogRain7+DateN2
Response ~ DateN+Depth+Break+Salinity+DateN:Break	Response ~ DateN+Salinity+Temp
Response ~ DateN+Depth+Break+Salinity+LogRain7	Response ~ DateN+Salinity+Temp+DateN2
Response ~ DateN+Depth+Break+Salinity+LogRain7+DateN:Break	Response ~ DateN+Salinity+Temp+LogRain7
Response ~ DateN+Depth+Break+Salinity+Temp	Response ~ DateN+Salinity+Temp+LogRain7+DateN2
Response ~ DateN+Depth+Break+Salinity+Temp+DateN:Break	Response ~ DateN+Temp
Response ~ DateN+Depth+Break+Salinity+Temp+LogRain7	Response ~ DateN+Temp+DateN2
Response ~ DateN+Depth+Break+Salinity+Temp+LogRain7+DateN:Break	Response ~ DateN+Temp+LogRain7
Response ~ DateN+Depth+Break+Temp	Response ~ DateN+Temp+LogRain7+DateN2

Table 8 Model coefficients and p-values for each of the statistically significant multiple linear regression models.

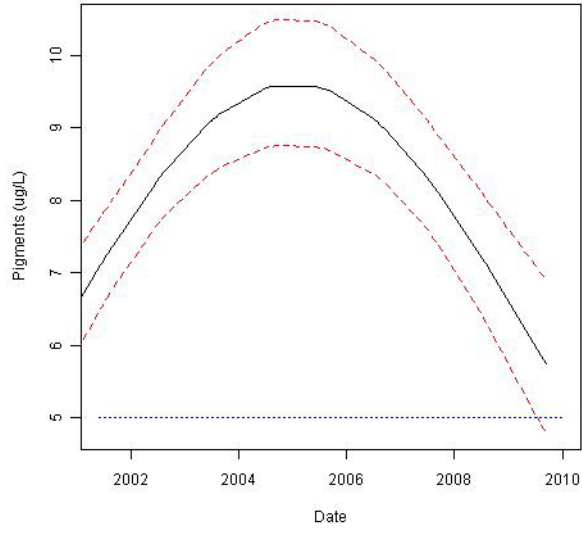
Station	Response	Intercept		DateN		DateN2		Temp	
		Estimate	p-value	Estimate	p-value	Estimate	p-value	Estimate	p-value
CM-13	LogDIN	1.492	5.11E-94	0.043	1.06E-06				
PBA-1	LogBioN	1.996	4.98E-104	-0.037	6.01E-10	-0.002	4.80E-01		
PBA-1	LogPigments	0.509	8.54E-30	-0.064	4.70E-09	0.000	9.76E-01		
PBA-1	LogTN	2.574	9.04E-92	-0.035	2.80E-04	0.007	1.75E-01		
PBA-10	LogDIN	1.597	2.88E-77	0.061	2.39E-05	-0.013	4.98E-04		
PBA-10	LogTN	2.780	3.10E-148	0.020	4.91E-04	-0.007	2.88E-06		
PBA-12	LogBioN	2.220	6.18E-120	-0.027	6.04E-04	0.001	4.71E-01		
PBA-15	LogPO4	1.996	4.09E-107	0.036	1.12E-04	-0.008	6.60E-04		
PBA-18	LogBioN	2.102	6.47E-55	-0.050	3.48E-04				
PBA-18	LogTN	2.696	7.29E-56	-0.086	2.43E-06				
PBA-20	LogBioN	2.118	2.37E-52	-0.108	6.79E-06	0.045	5.90E-03		
PBA-21	LogBioN	2.146	1.98E-54	-0.073	6.80E-04	0.007	6.21E-01		
PBA-3	LogBioN	2.418	2.58E-124	0.030	4.52E-05	-0.007	6.91E-04		
PBA-3	LogDIN	1.782	4.19E-68	0.068	5.95E-05	-0.005	2.84E-01		
PBA-3	LogPigments	0.963	2.61E-76	0.029	2.55E-04	-0.010	7.22E-06		
PBA-3	LogTN	2.906	4.29E-141	0.026	3.17E-05	-0.009	9.86E-07		
PBA-6	LogTN	2.711	7.64E-79	-0.038	3.23E-04	-0.007	1.93E-01		
PBA-8	DO_conc	9.389	1.43E-18	0.212	4.24E-04	-0.077	9.13E-07	-0.116	9.06E-03
WMO-10	DO_conc	6.056	8.24E-18	-0.426	4.95E-05				
WMO-10	LogBioN	2.460	8.70E-85	0.042	2.92E-05	-0.011	8.70E-07		
WMO-10	LogPigments	0.941	5.61E-35	0.099	1.76E-05	-0.025	1.34E-06		
WMO-10	LogPO4	1.989	2.44E-64	0.076	1.21E-05	-0.017	1.37E-05		
WMO-5	LogPigments	0.696	9.22E-26	0.061	1.48E-03	-0.012	5.84E-03		

## Appendix B. Multiple Linear Regression Plots

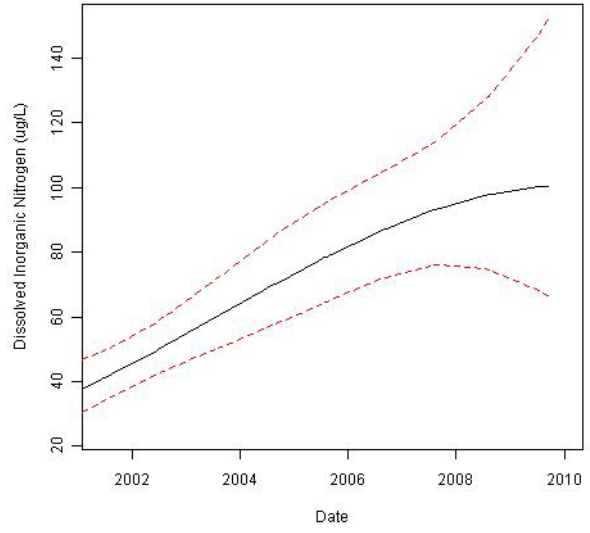
This appendix contains plots of the multiple linear regression models that were determined to have significant trends in water quality during the period of data collection, which varies by station. Red dashed lines indicate 90% confidence intervals. Blue dotted lines indicate water quality targets for those stations and parameters that have targets. Bioactive nitrogen targets were established for “sentinel” stations in the MEP analyses (Howes, Samimy, Schlezinger, Kelley, Ramsey, & Eichner, 2006). The MEP analyses assume that water quality goals for the entire Pleasant Bay system will be met when the targets are met at the sentinel stations. The total pigments target is the guidance value established by the National Oceanic and Atmospheric Administration (NOAA). The plots should not be used to forecast conditions beyond the period of data collection.



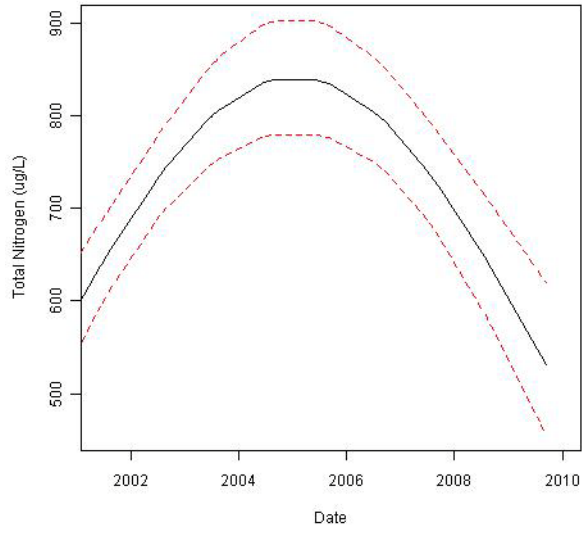
**PBA-3 Inner Ryders Cove**



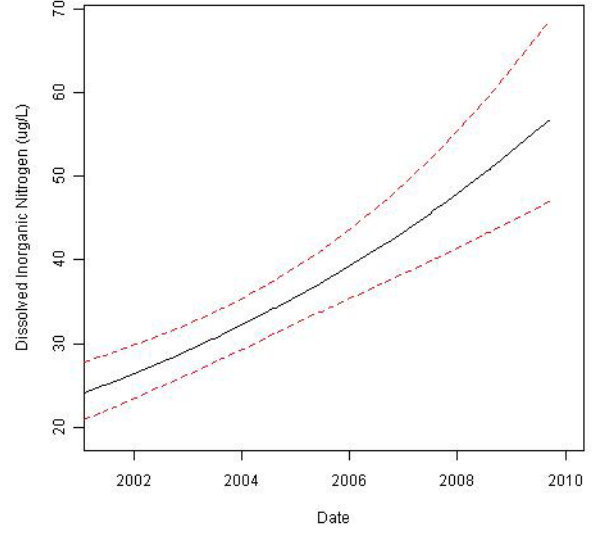
**PBA-3 Inner Ryders Cove**



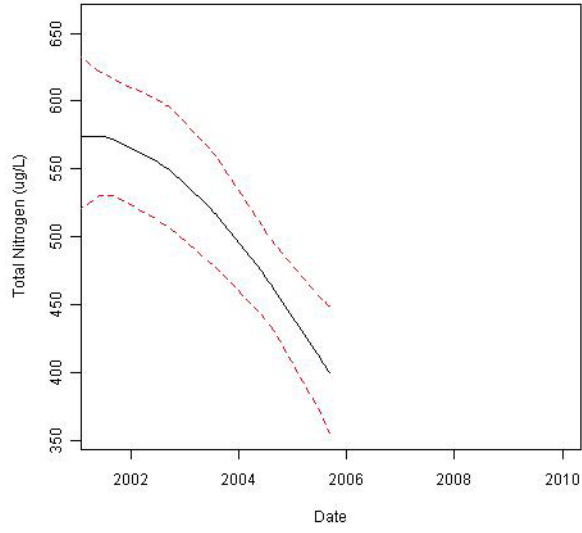
**PBA-3 Inner Ryders Cove**



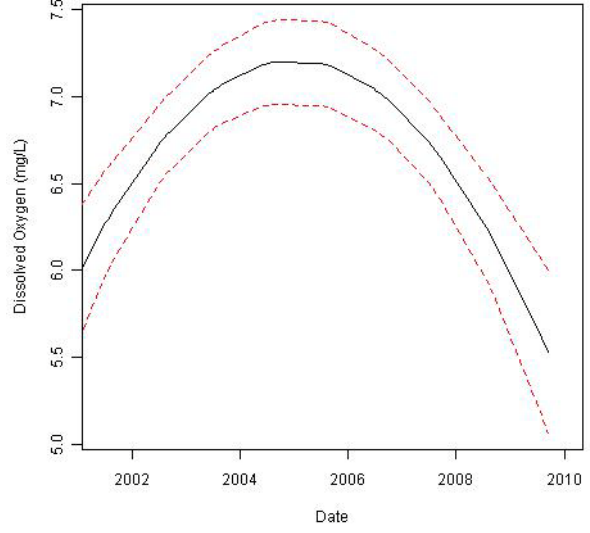
**CM-13 Outer Ryders Cove**



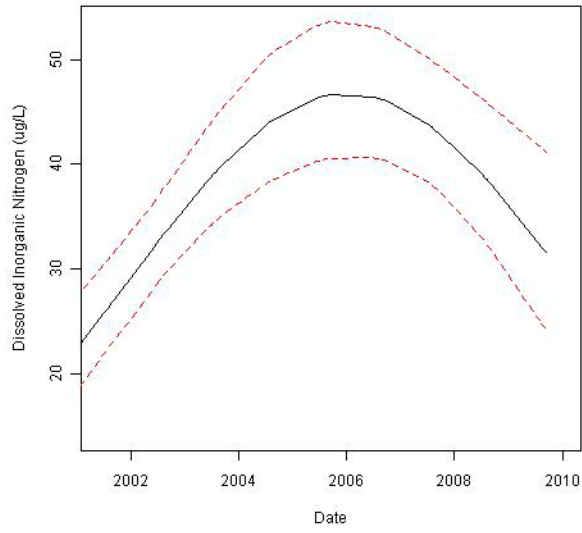
**PBA-6 Big Bay – SW**



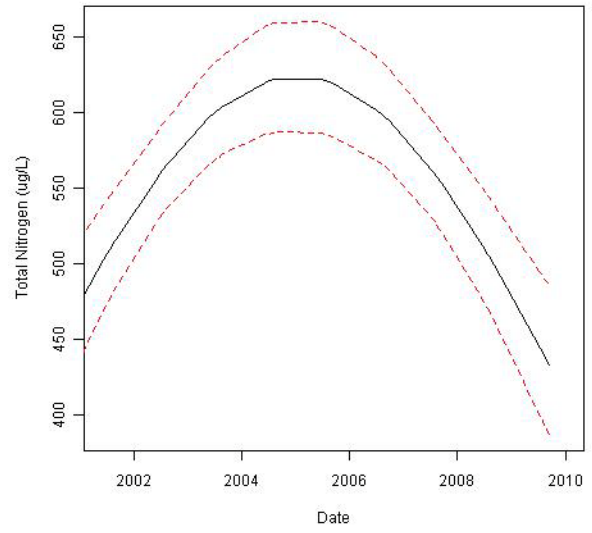
**PBA-8 Big Bay – NE**



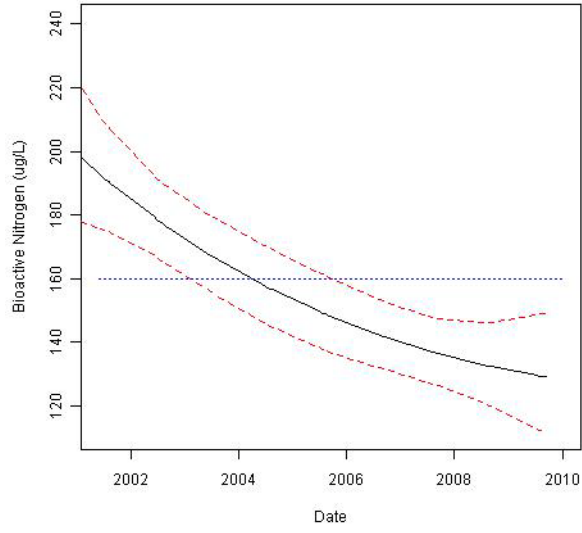
**PBA-10 Quanset Pond**



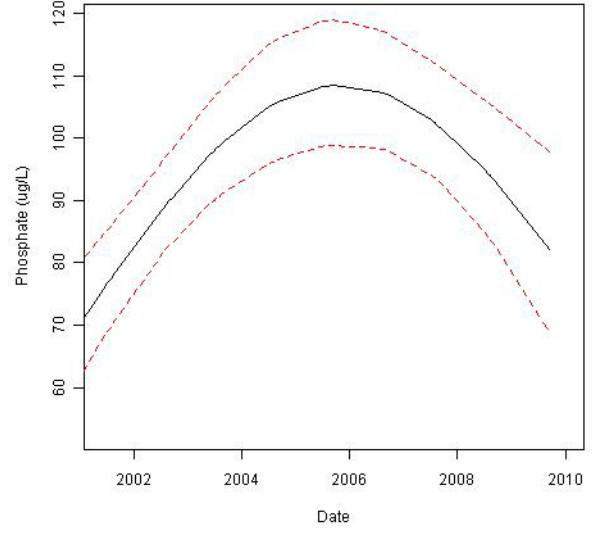
**PBA-10 Quanset Pond**



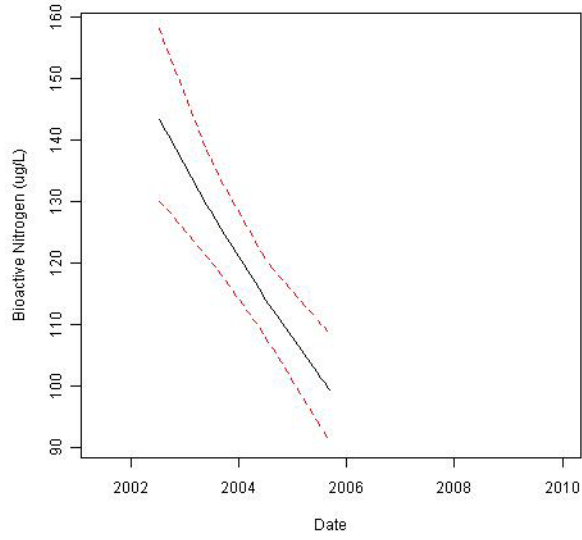
**PBA-12 Namequoit-South**



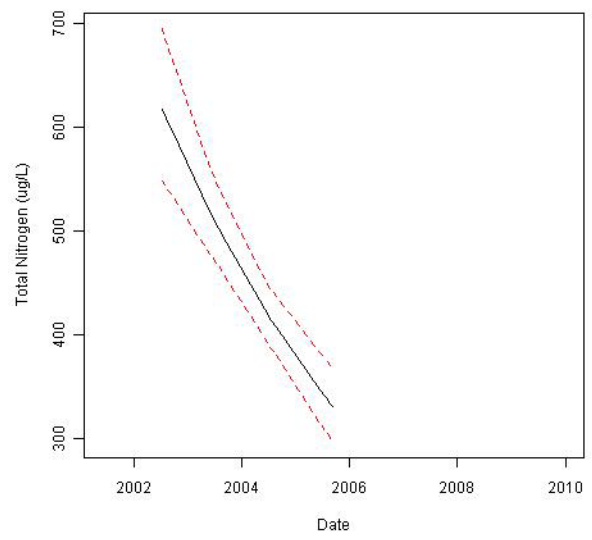
**PBA-15 Kescayogansett Pond**



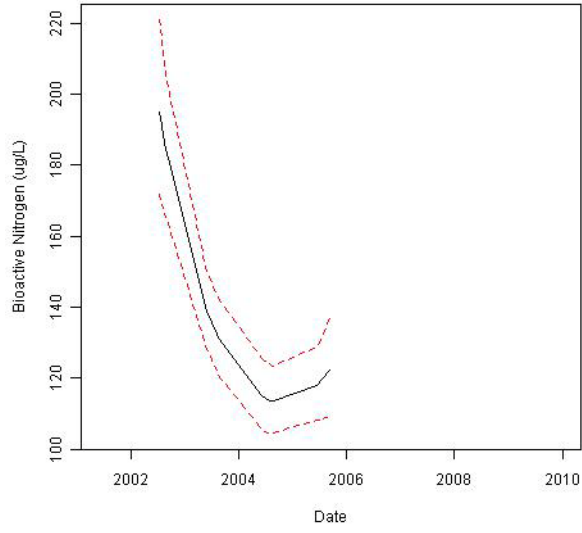
**PBA-18 Allen's/Ministers Point**



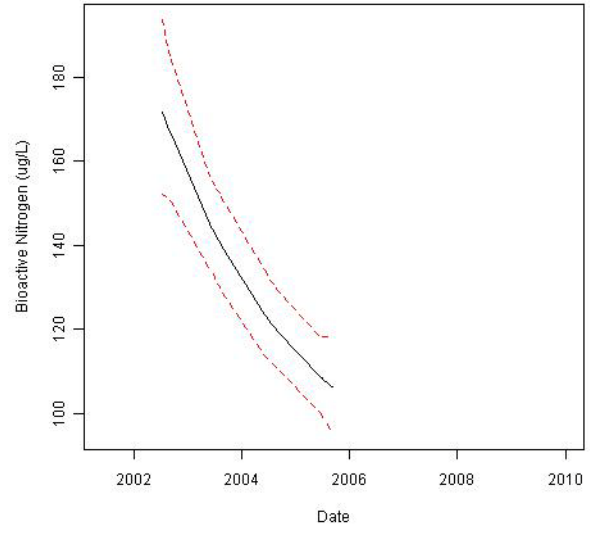
**PBA-18 Allen's/Ministers Point**



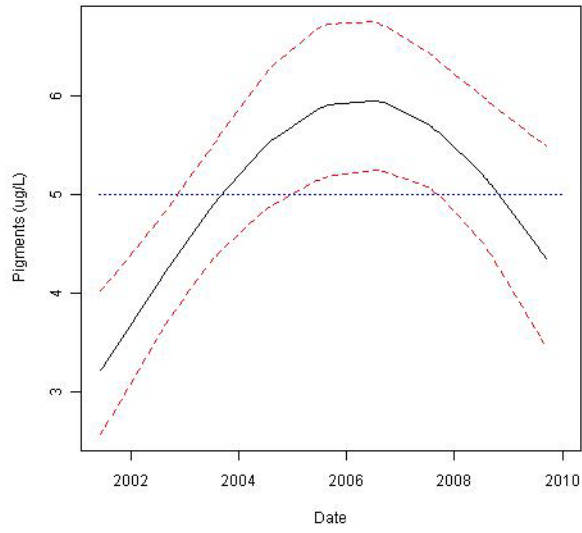
**PBA-20 Strong Island**



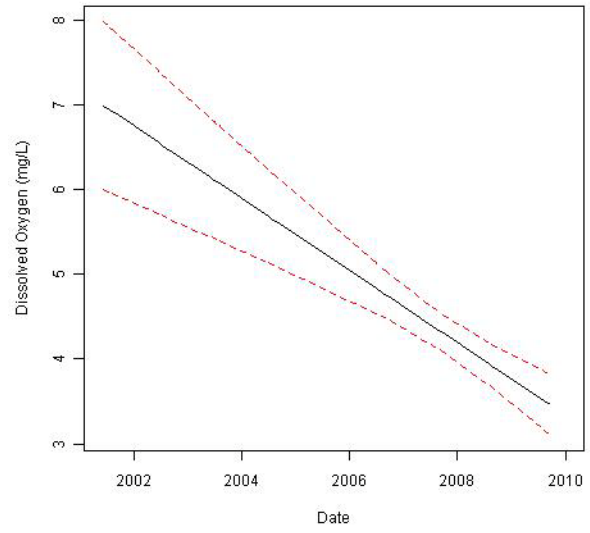
**PBA-21 Little Pleasant Bay**



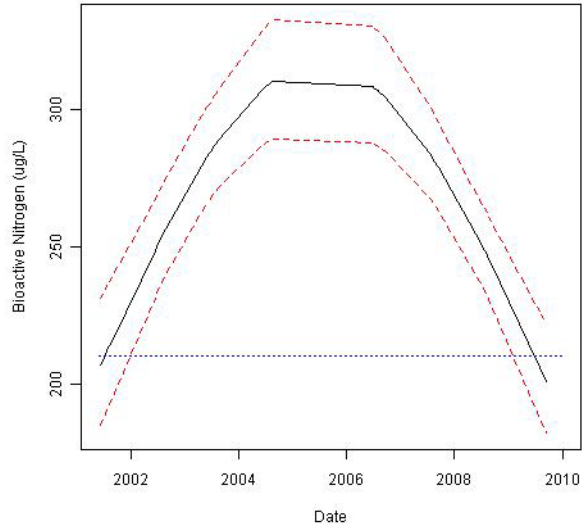
**WMO-5 Pochet Upper**



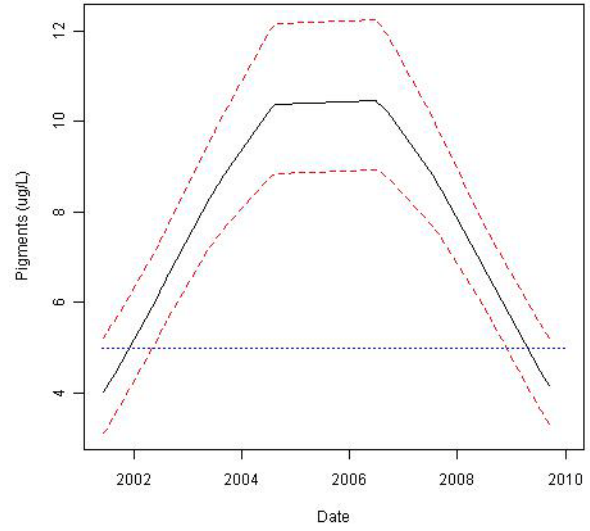
**WMO-10 River at Rattles Dock**



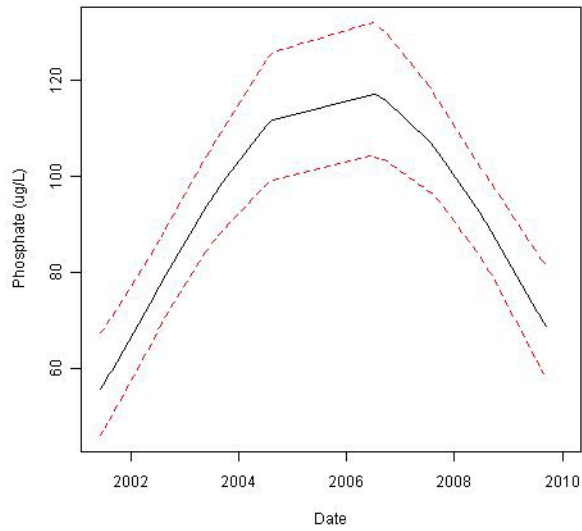
WMO-10 River at Rattles Dock



WMO-10 River at Rattles Dock

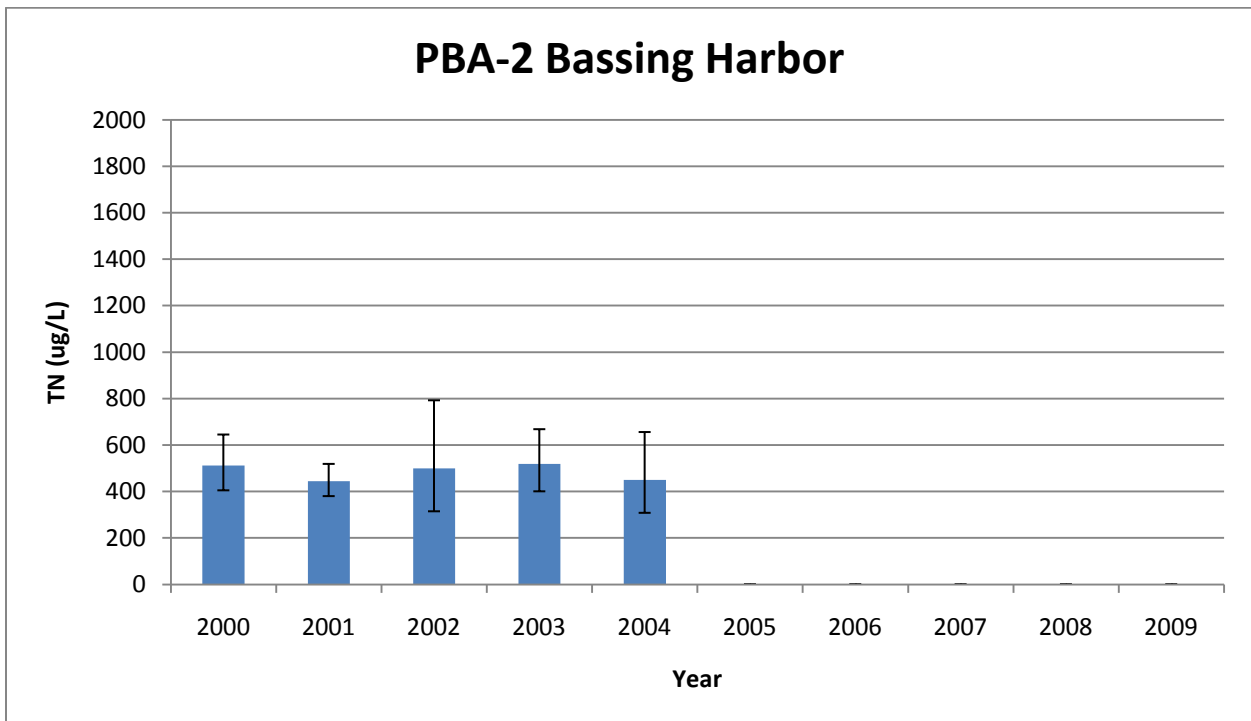
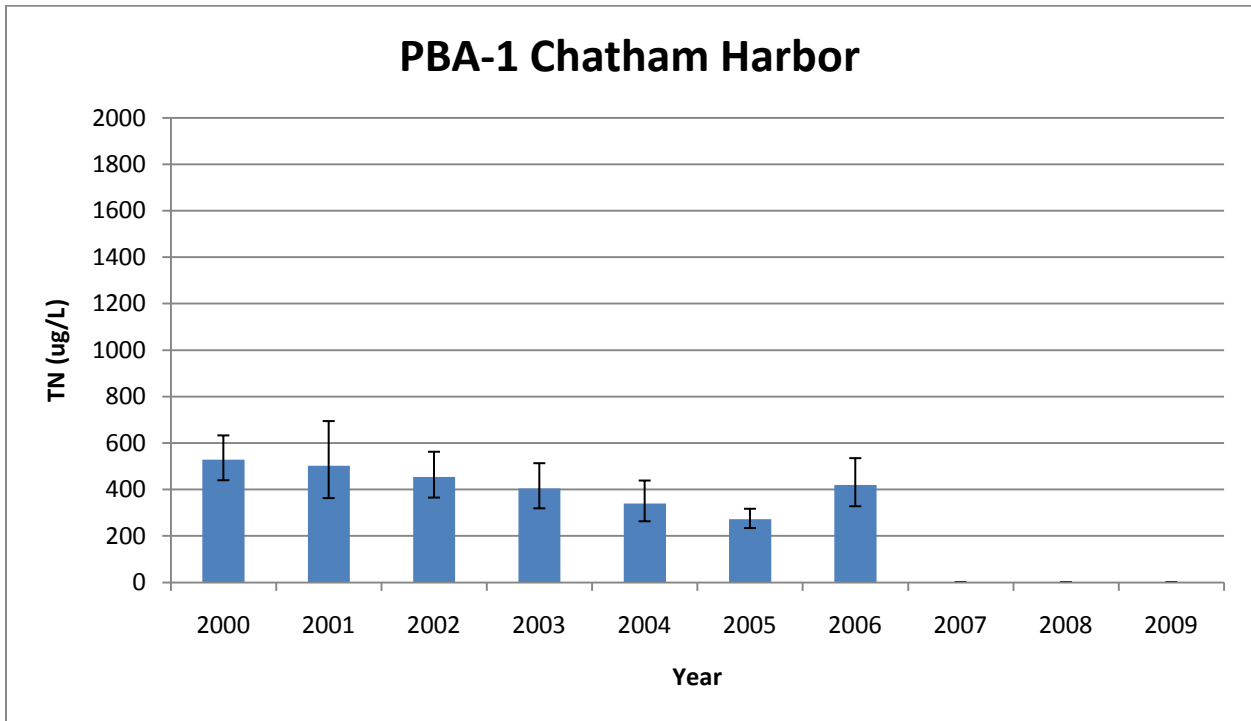


WMO-10 River at Rattles Dock

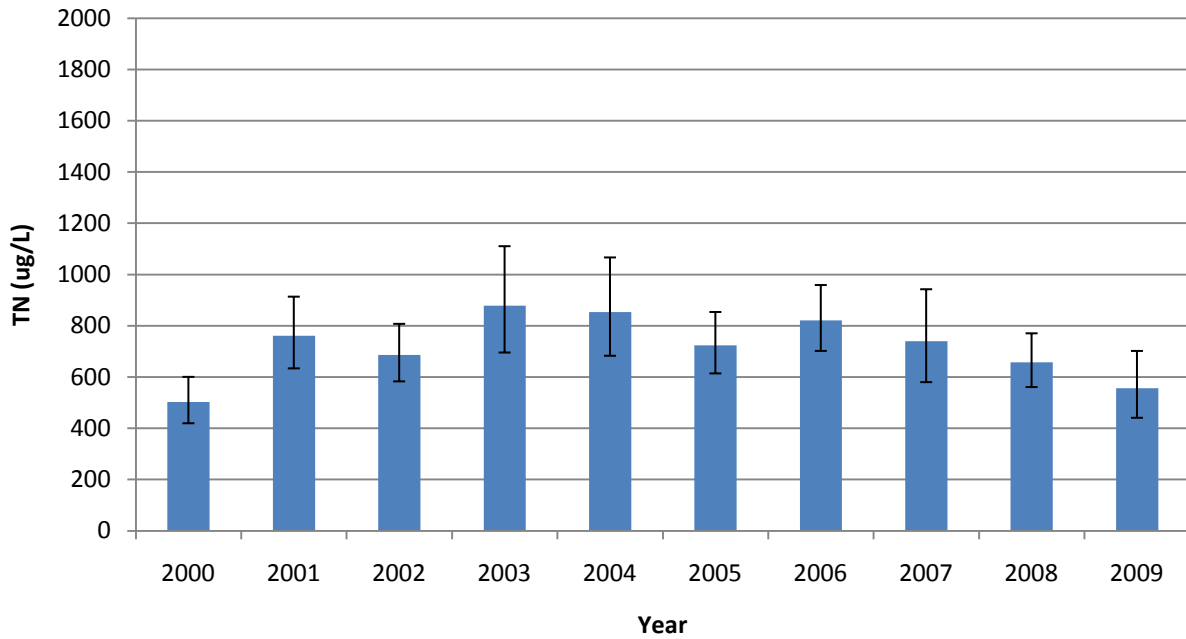


## Appendix C. Geometric Means and 90% Confidence Intervals for Total Nitrogen

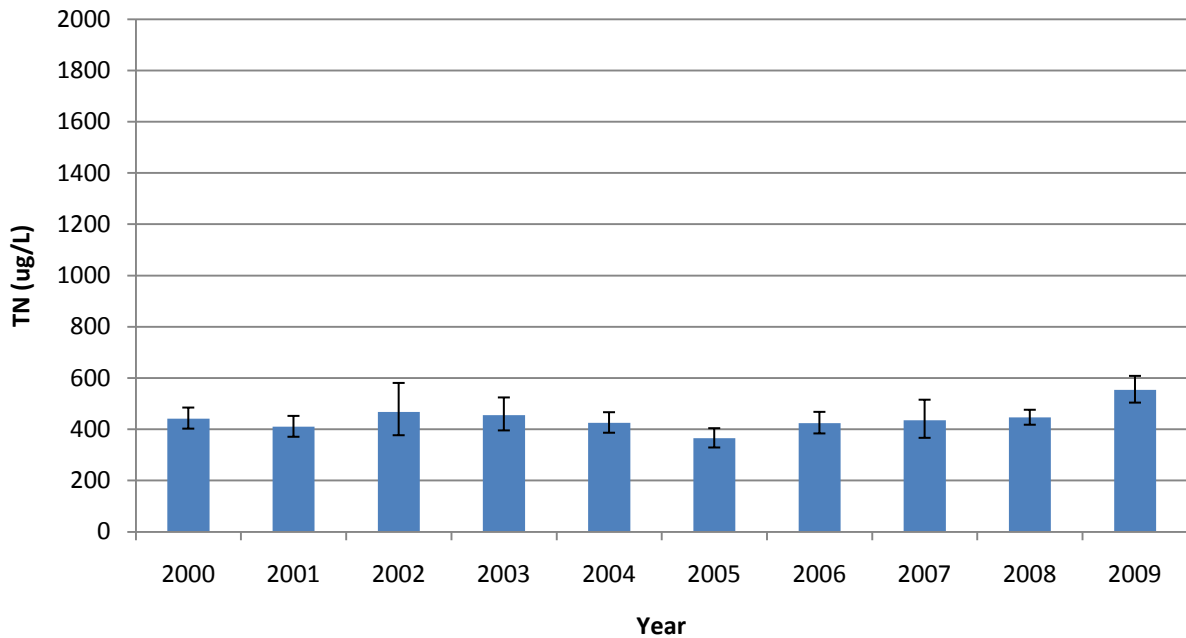
Note that samples were not collected for all years at all stations. Lack of data does not indicate a mean value of zero.



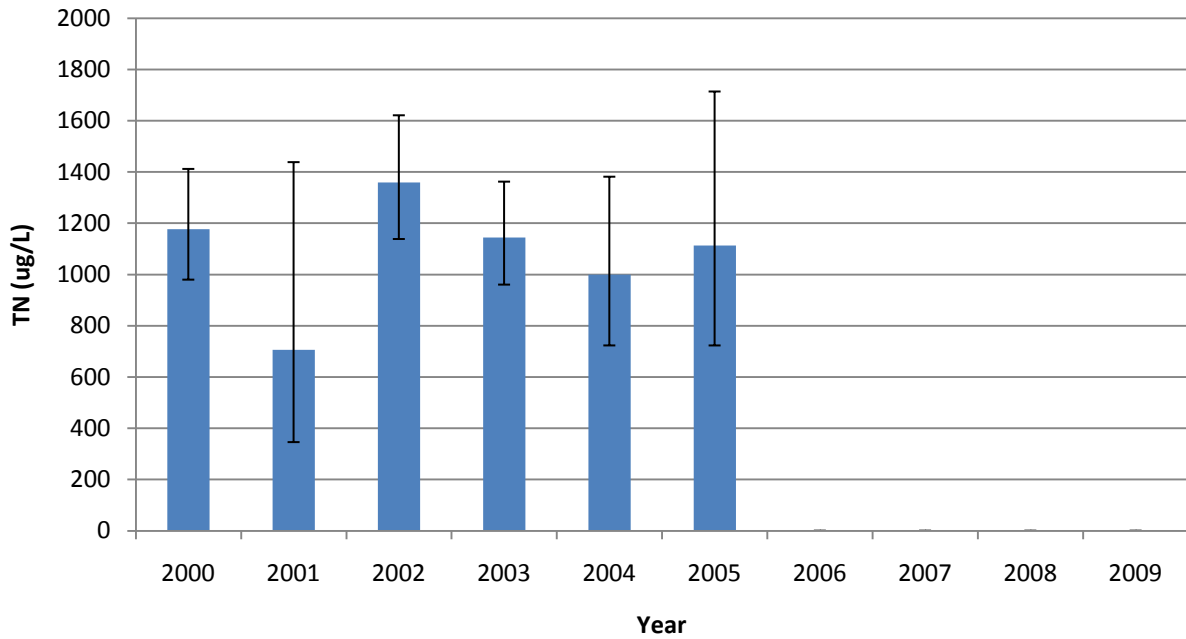
### PBA-3 Inner Ryders Cove



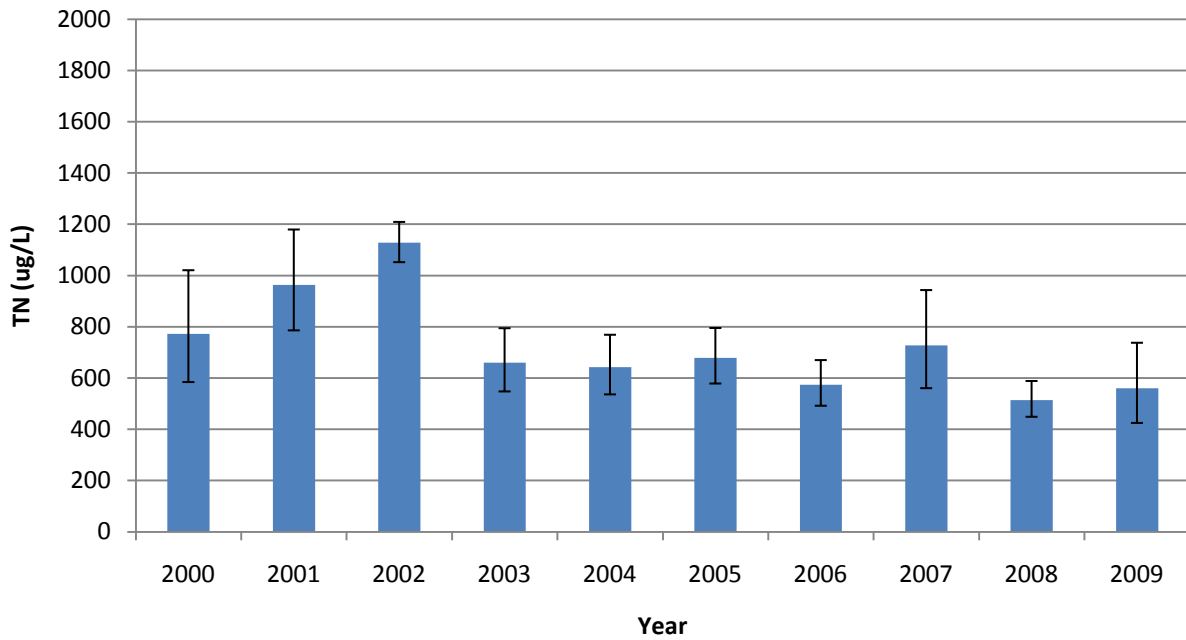
### CM-13 Outer Ryders Cove

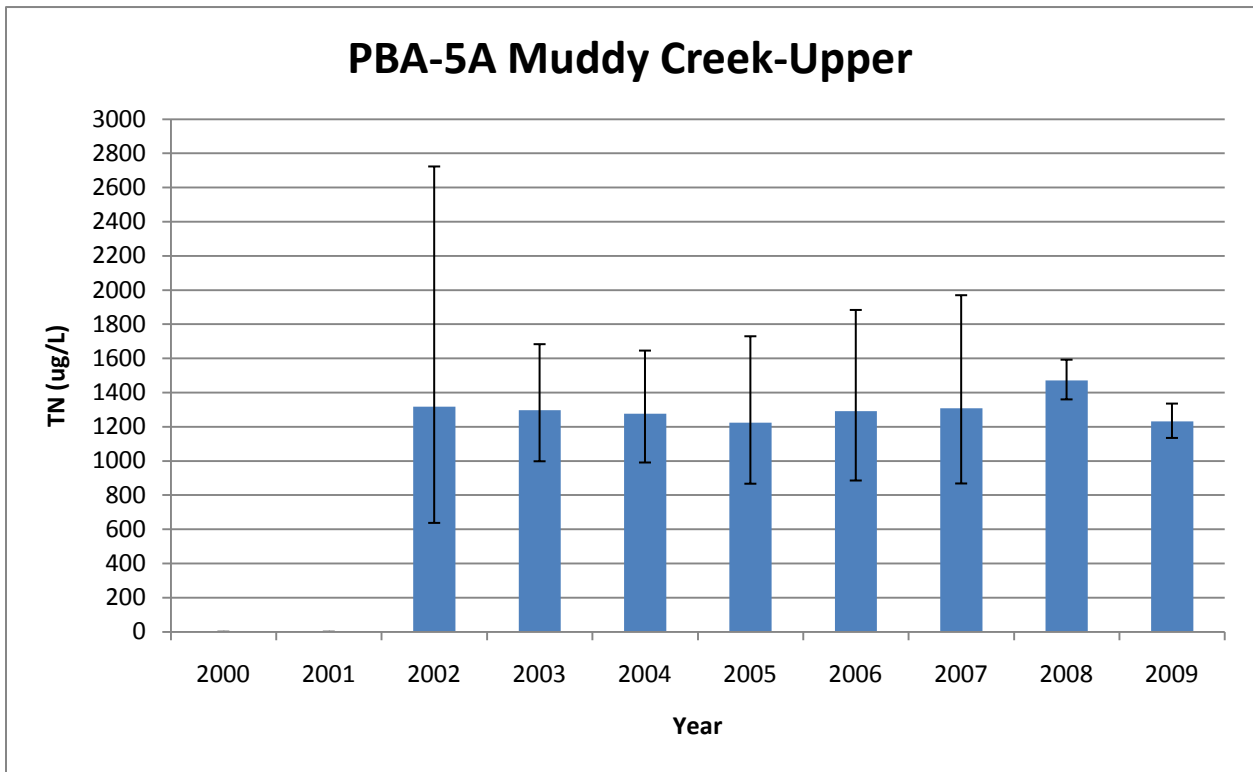
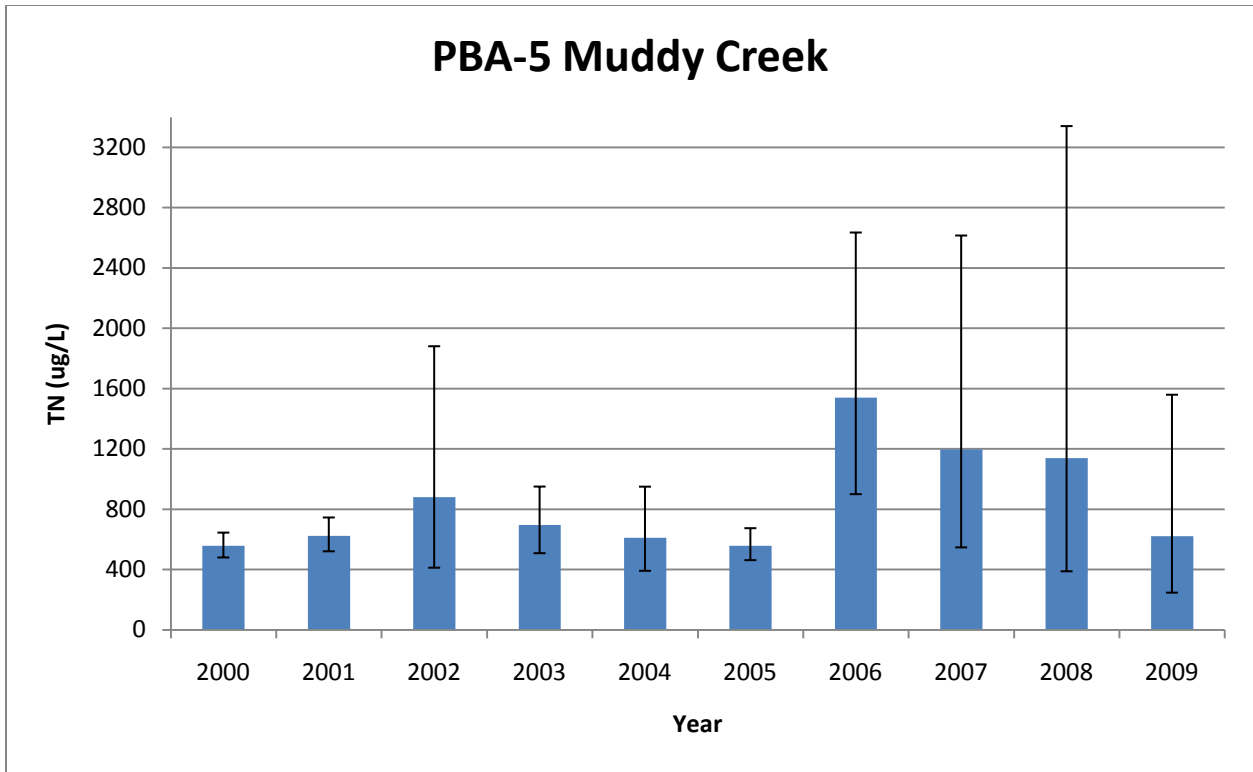


### CM-14 Frost Fish Creek

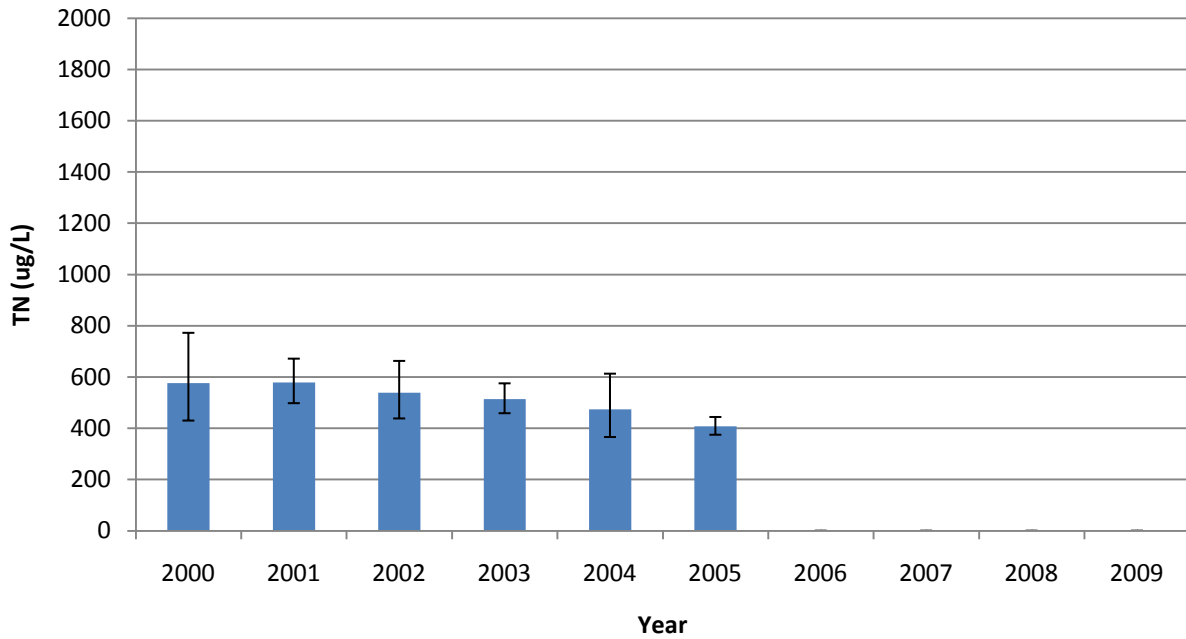


### PBA-4 Crow's Pond

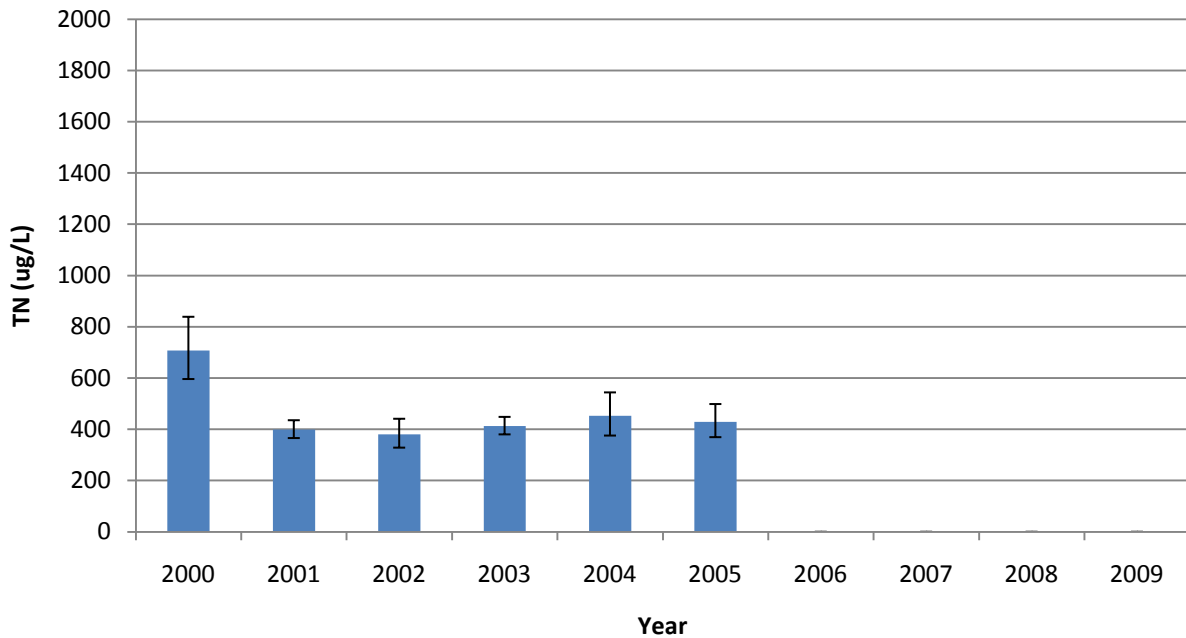




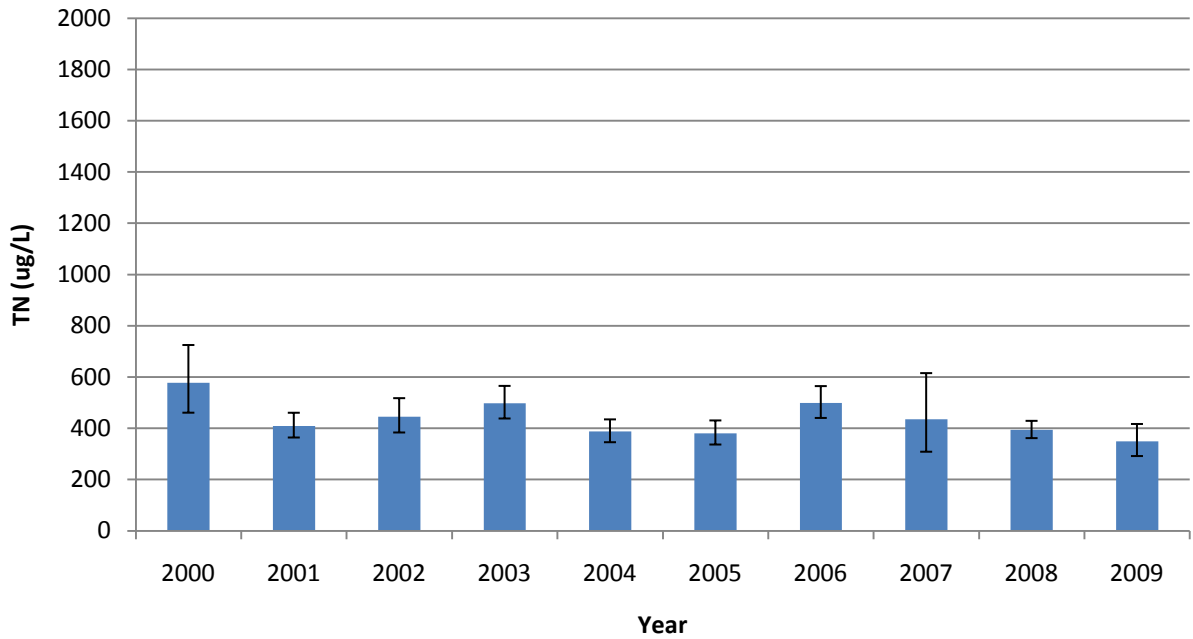
### PBA-6 Big Bay-SW



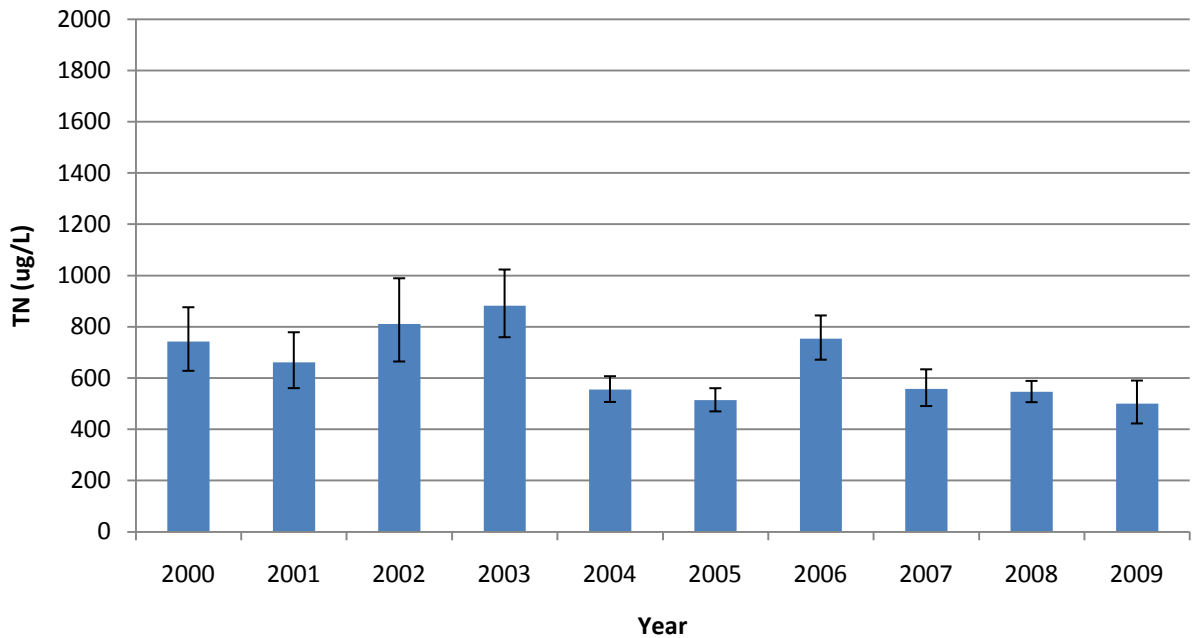
### PBA-7 Big Bay-Mid



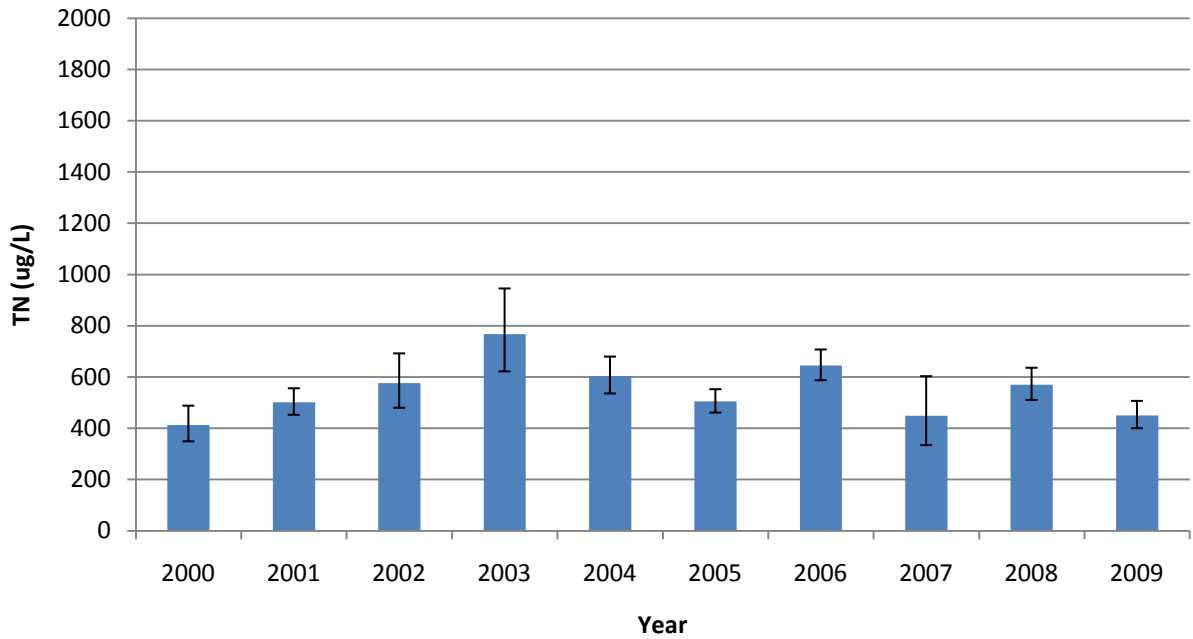
### PBA-8 Big Bay-NE



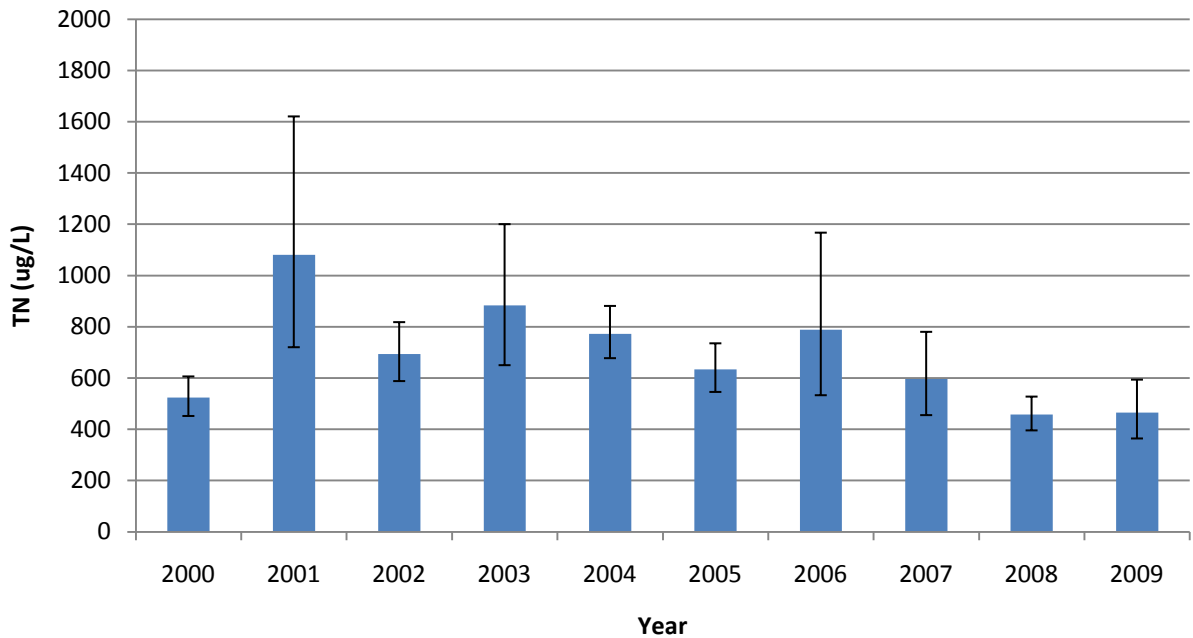
### PBA-9 Round Cove



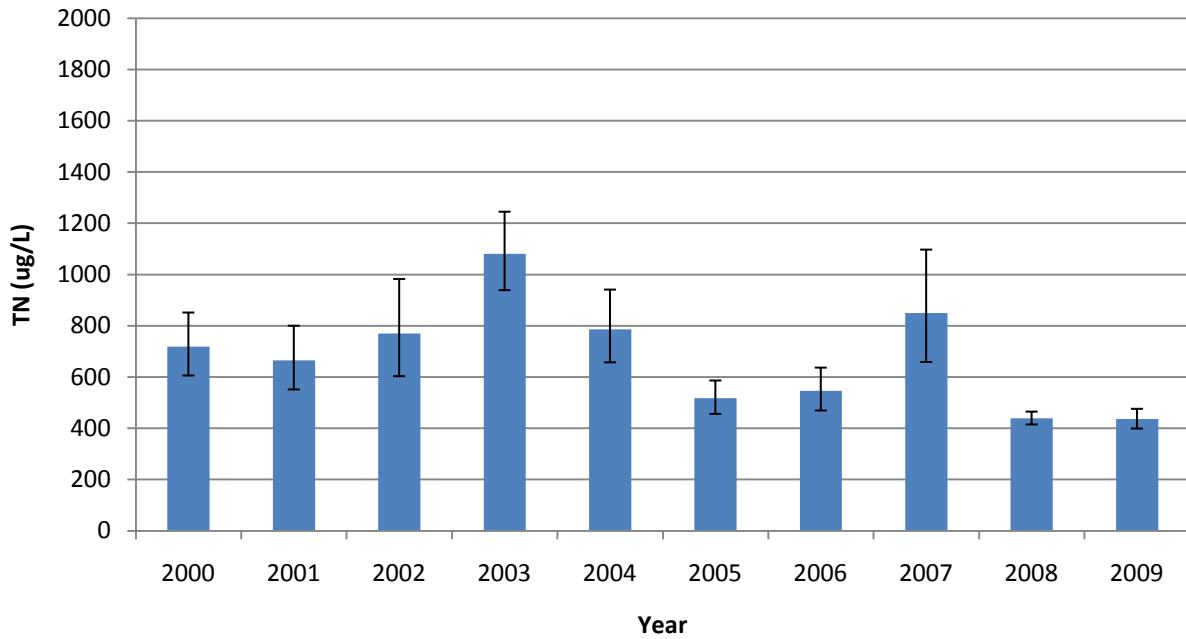
### PBA-10 Quanset Pond



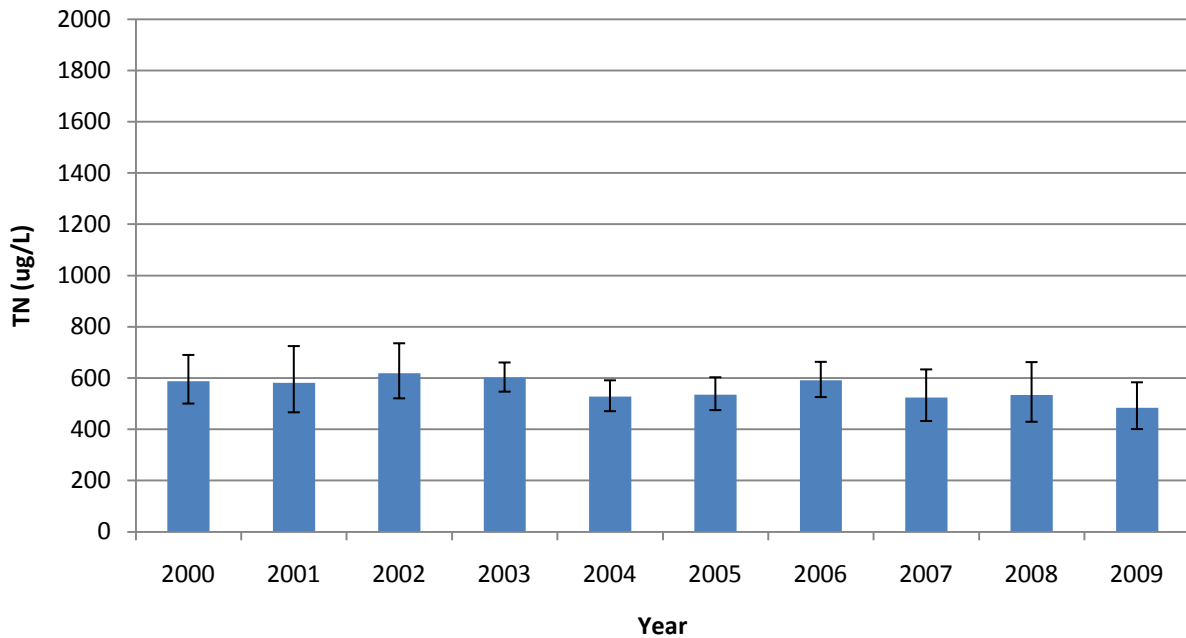
### PBA-11 Paw Wah Pond



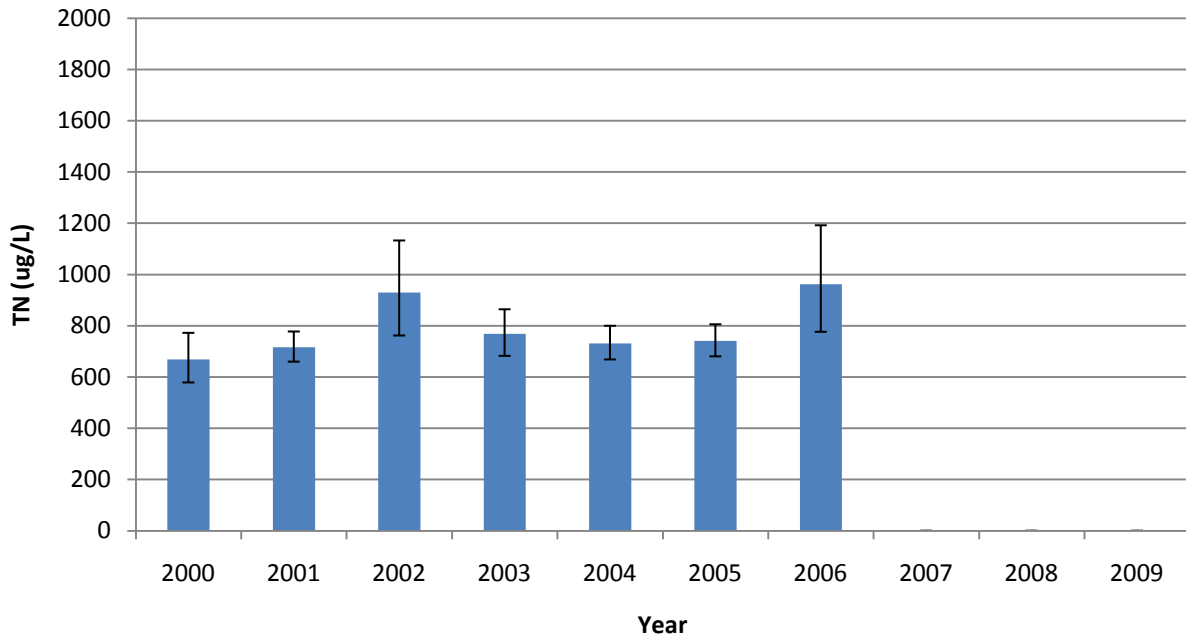
### PBA-12 Namequoit South



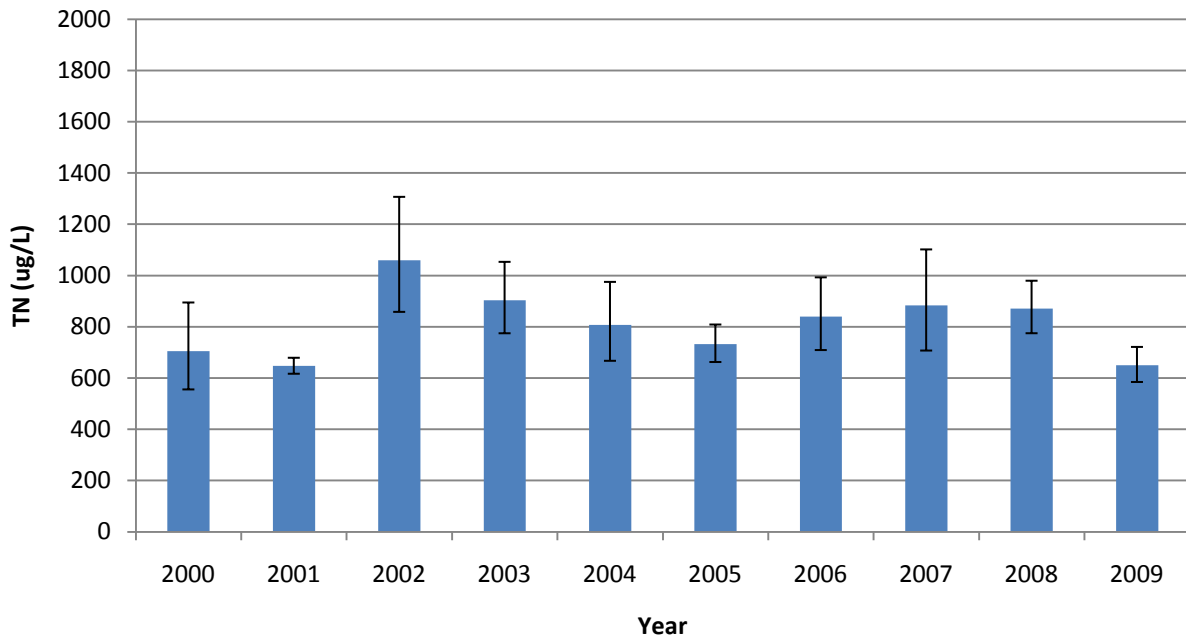
### PBA-13 Namequoit North



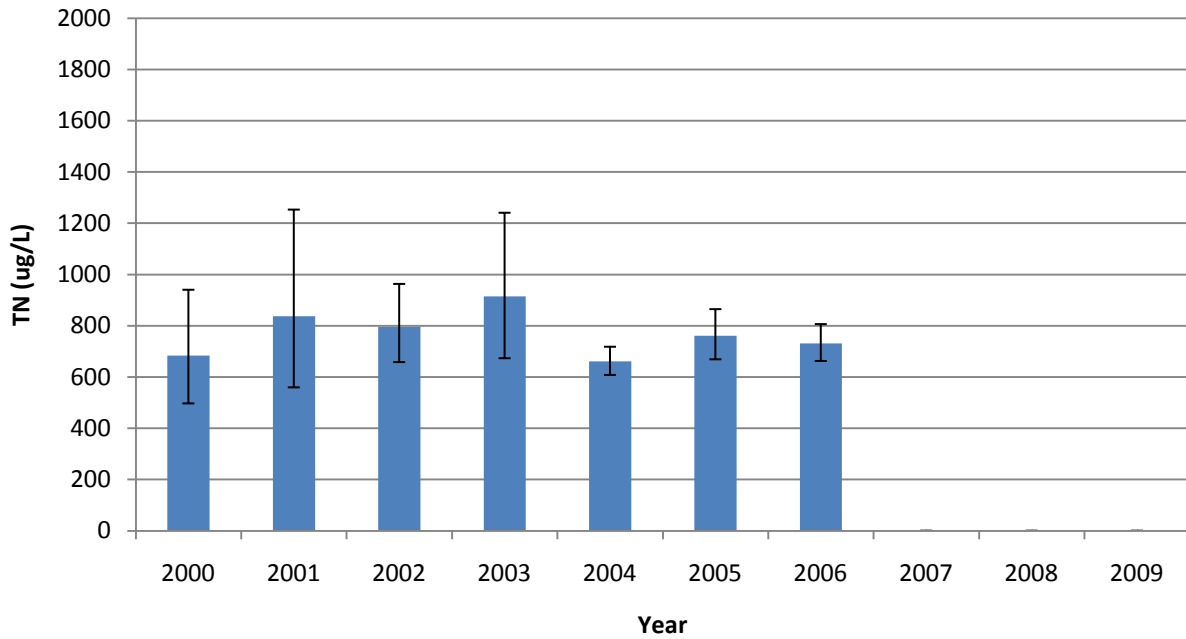
### PBA-14 Arey's Pond



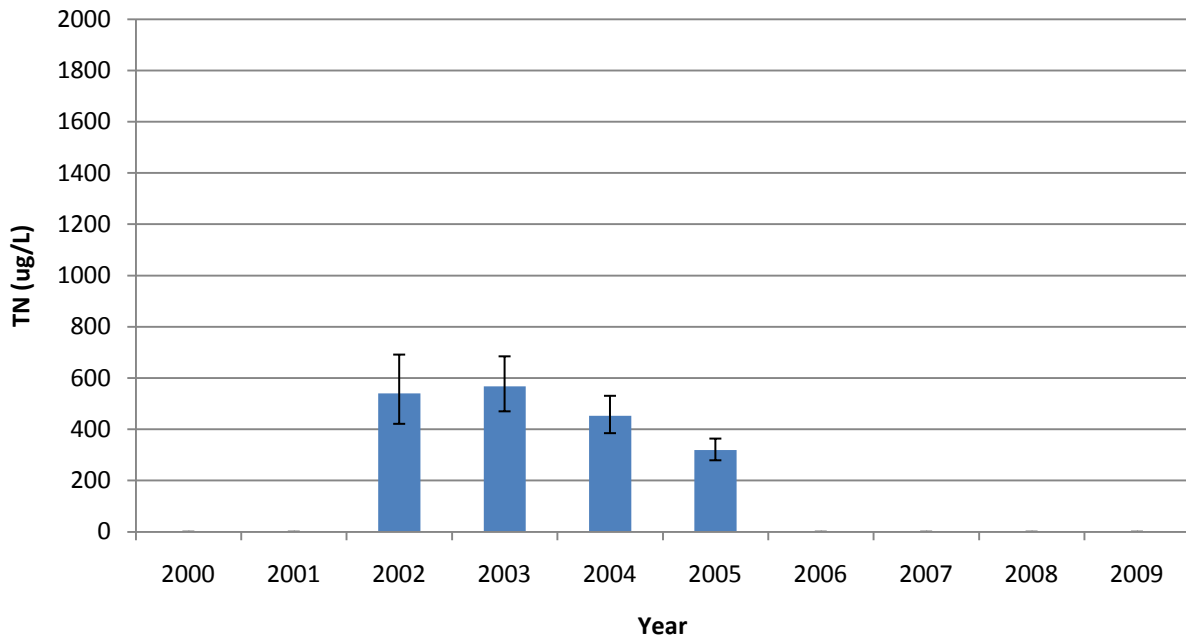
### PBA-15 Kescayogansett Pond



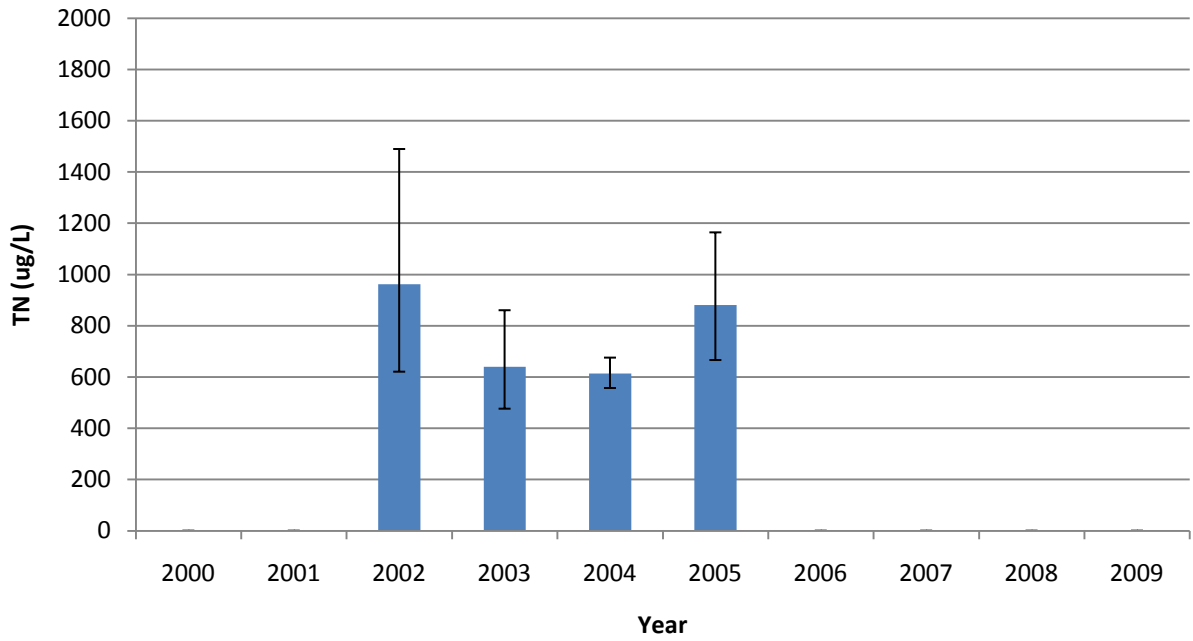
### PBA-16 Meetinghouse Pond



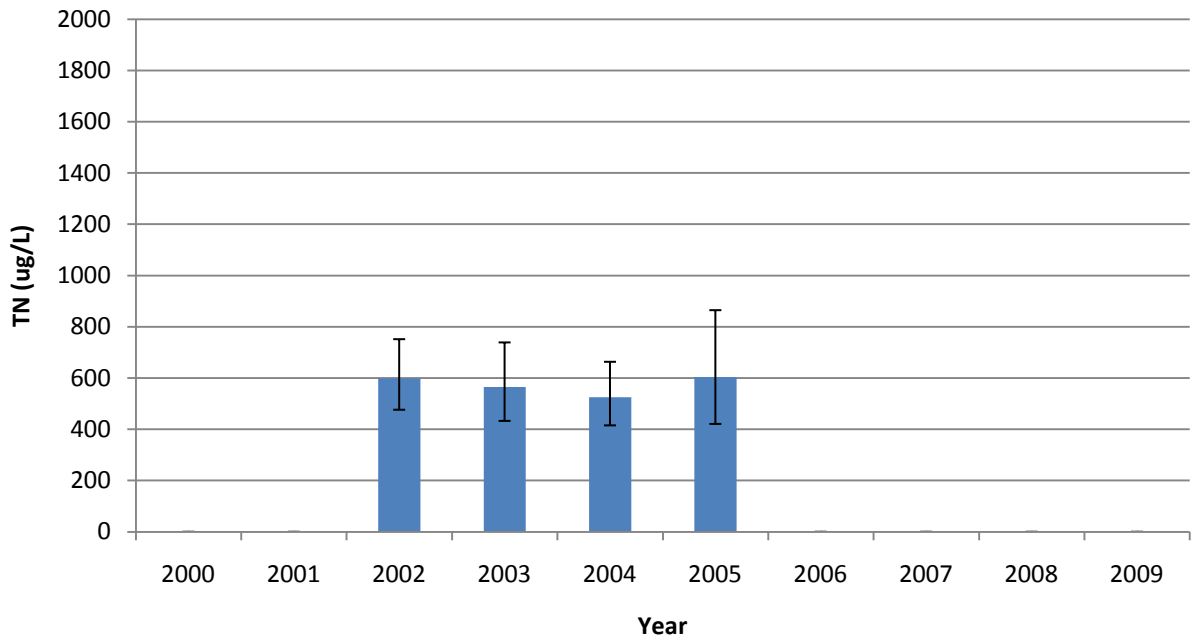
### PBA-18 Allen's/Ministers Point



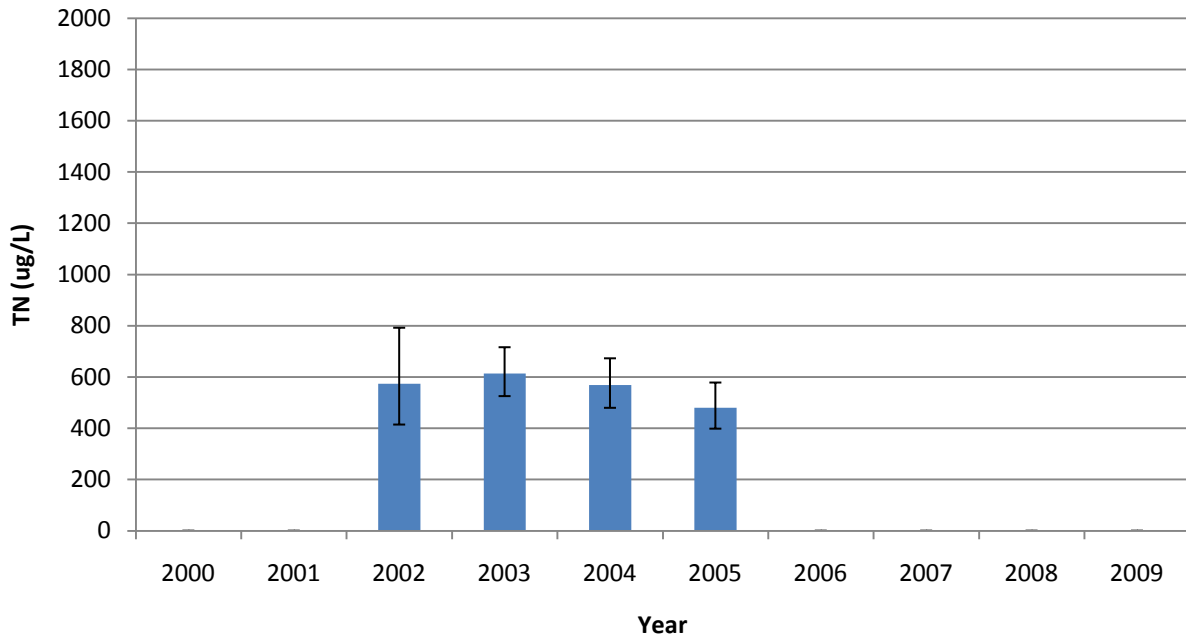
### PBA-19 Nickersons Neck



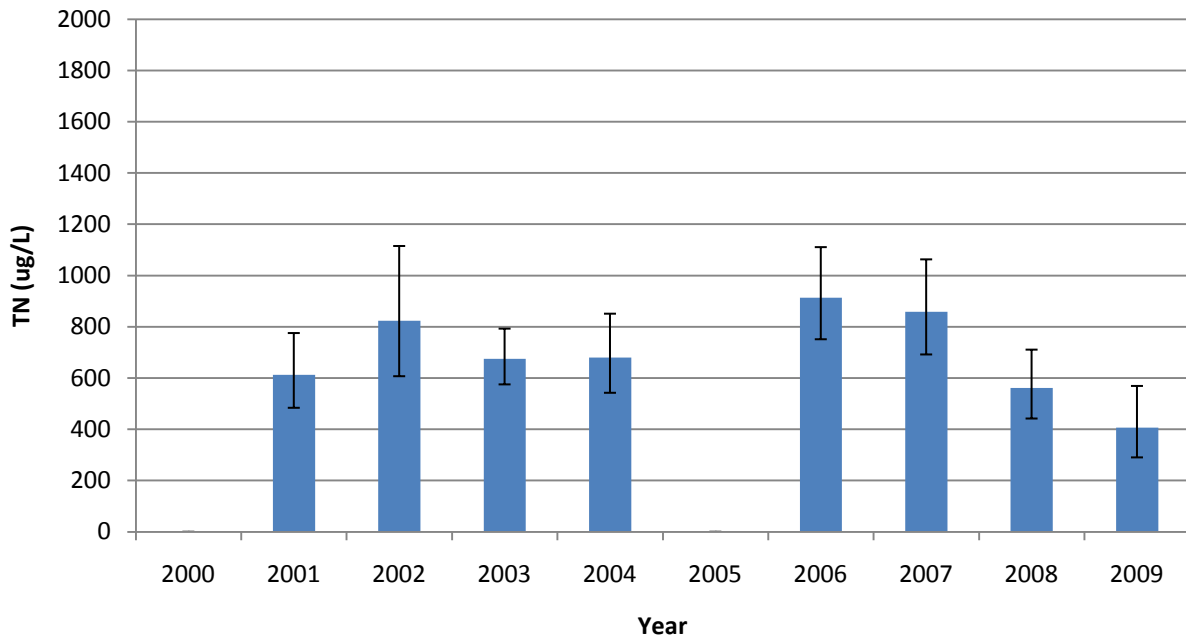
### PBA-20 Strong Island



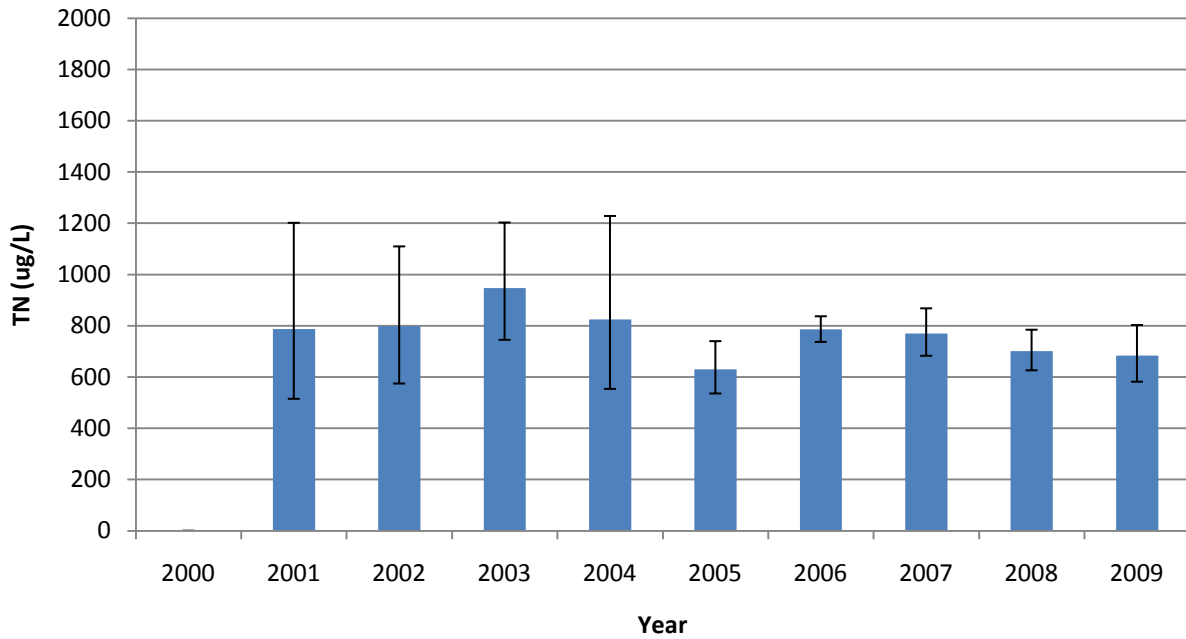
### PBA-21 Little Pleasant Bay



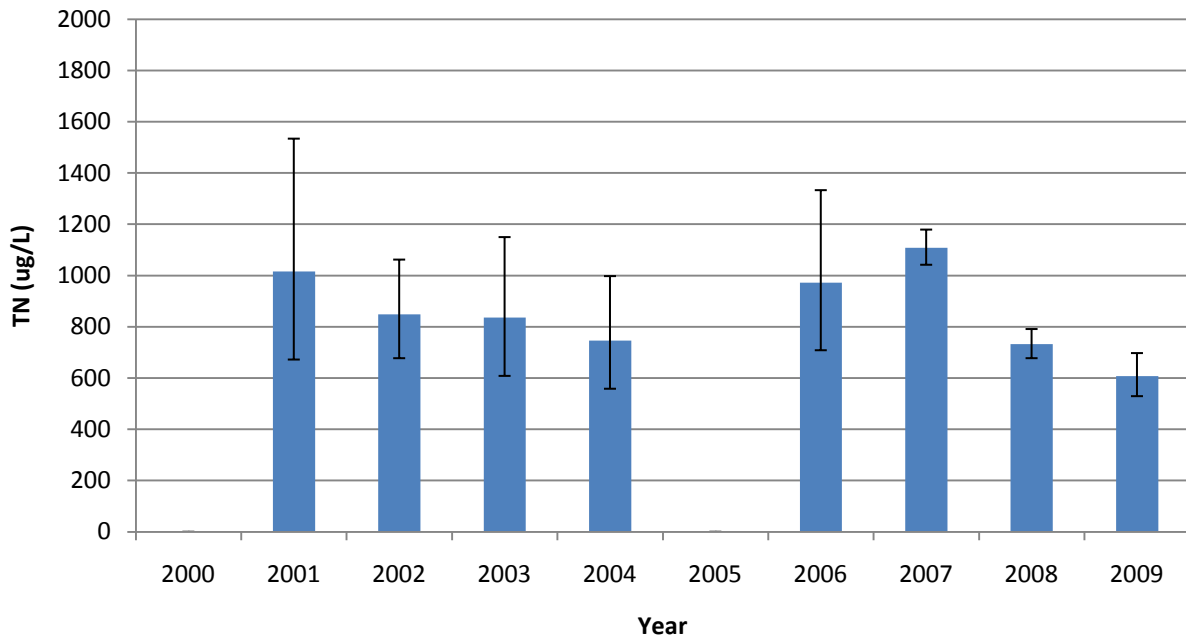
### WMO-3 Pochet Mouth



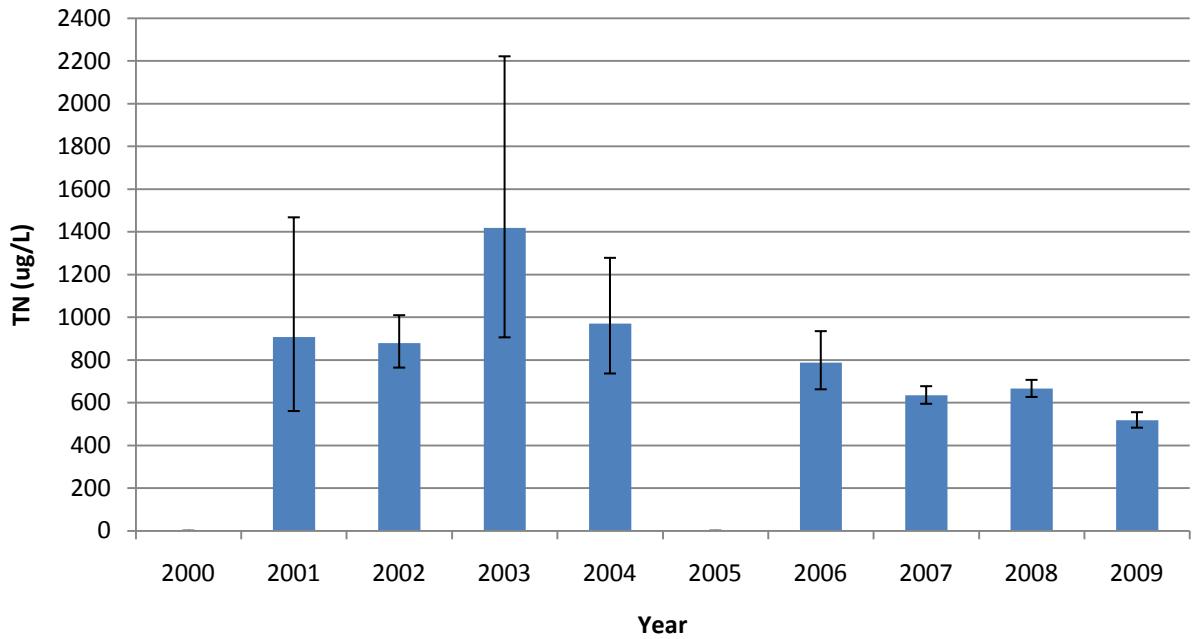
### WMO-5 Pochet Upper



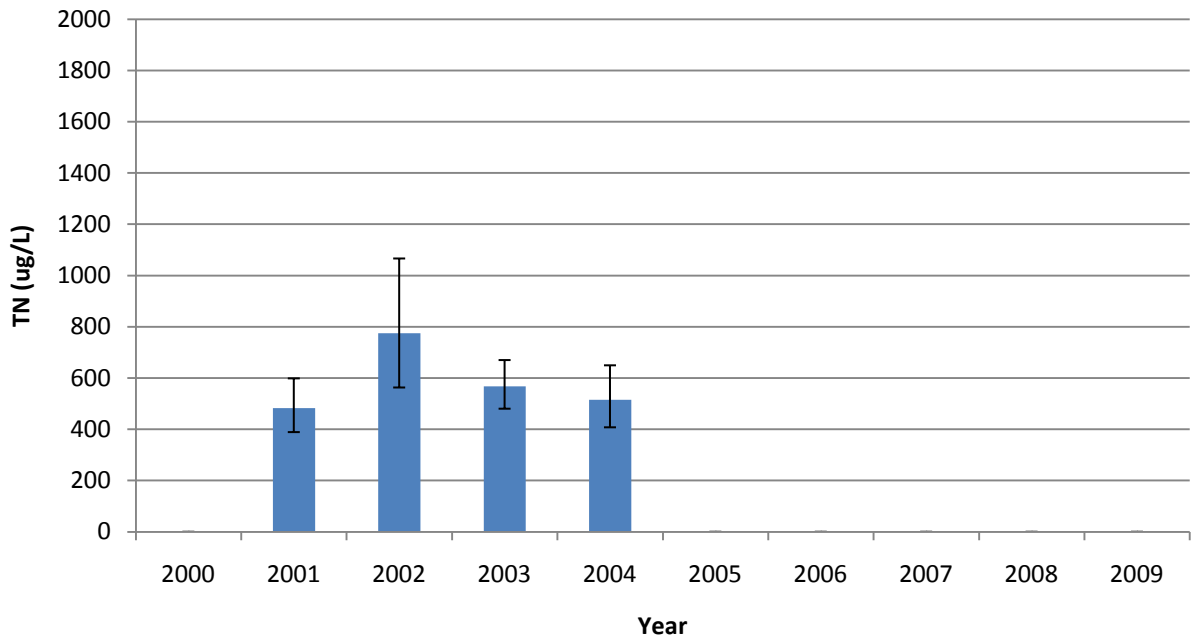
### WMO-6 Namequoit River-Mid



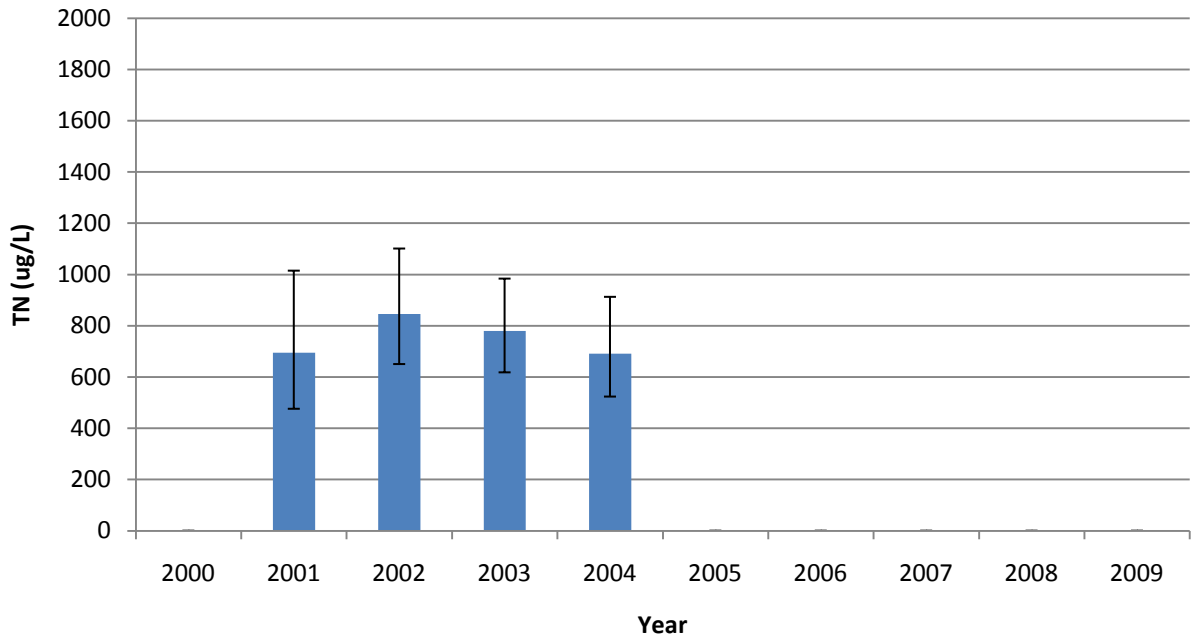
### WMO-10 River at Rattles Dock



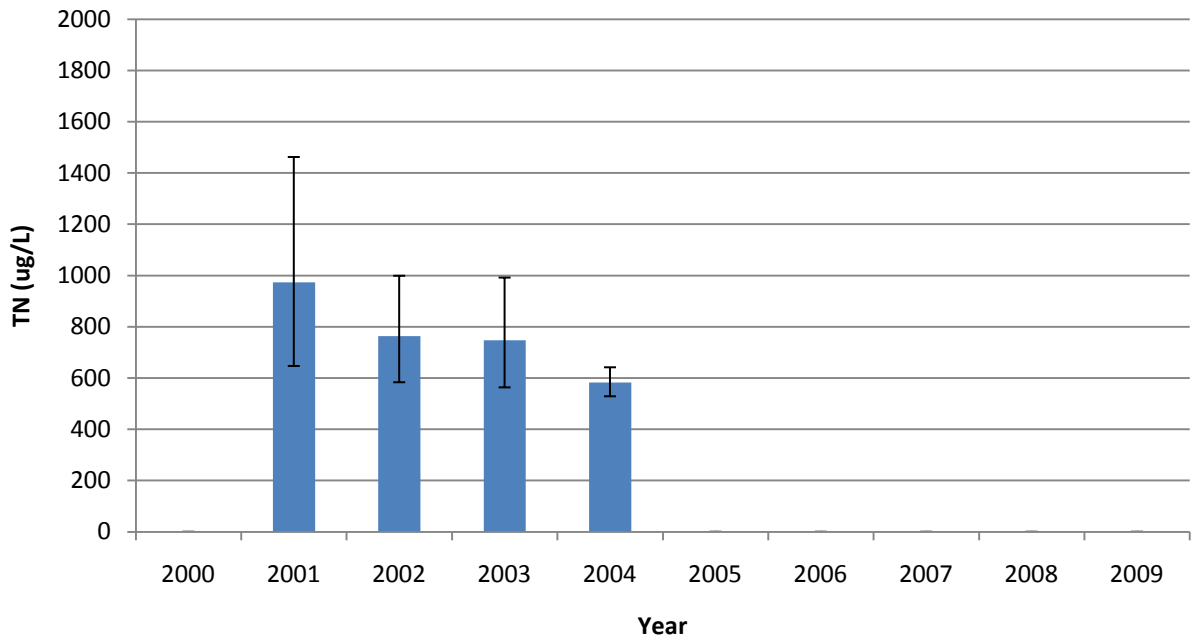
### WMO-2 Pleasant Bay off Quanset



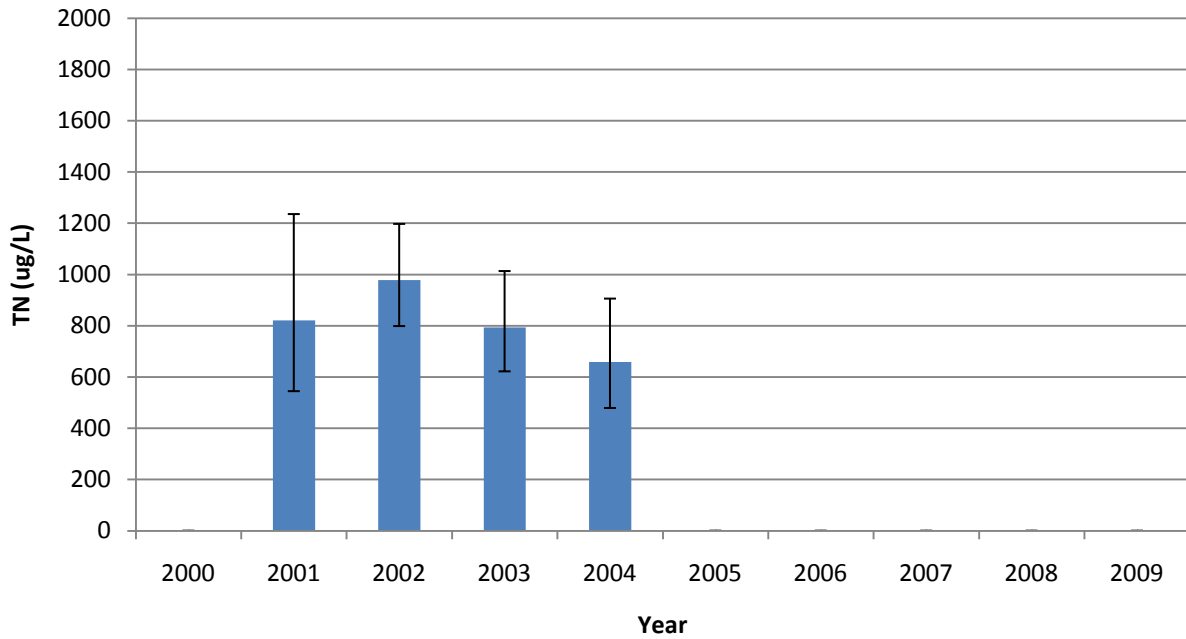
### WMO-4 Pochet-Mid



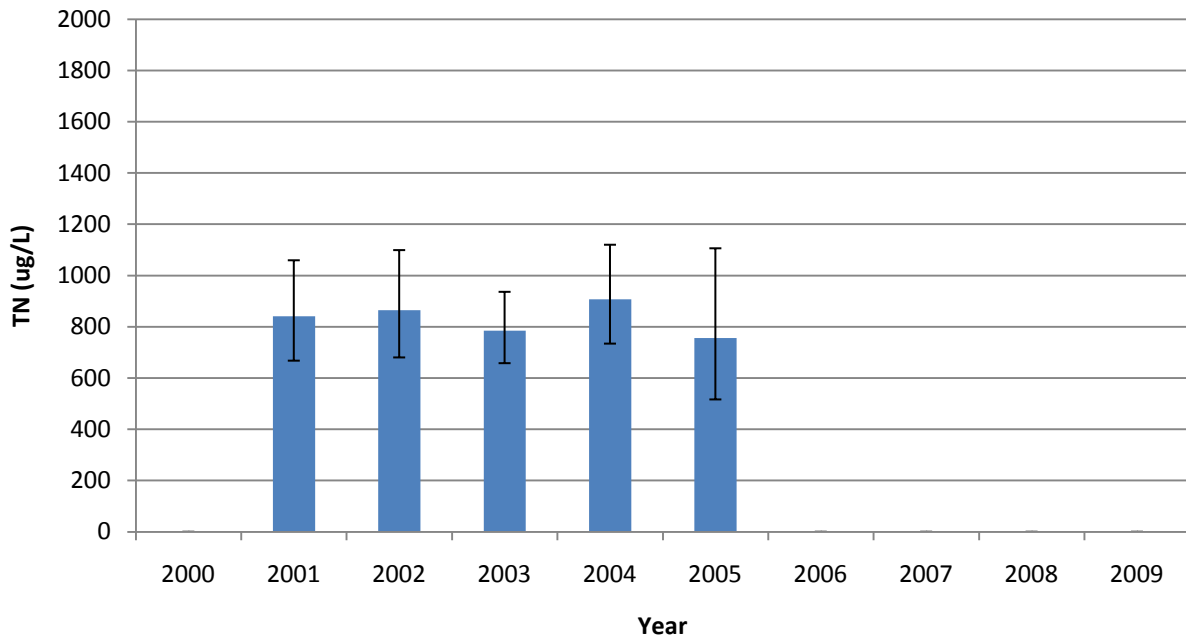
### WMO-7 Namequoit River-Mouth



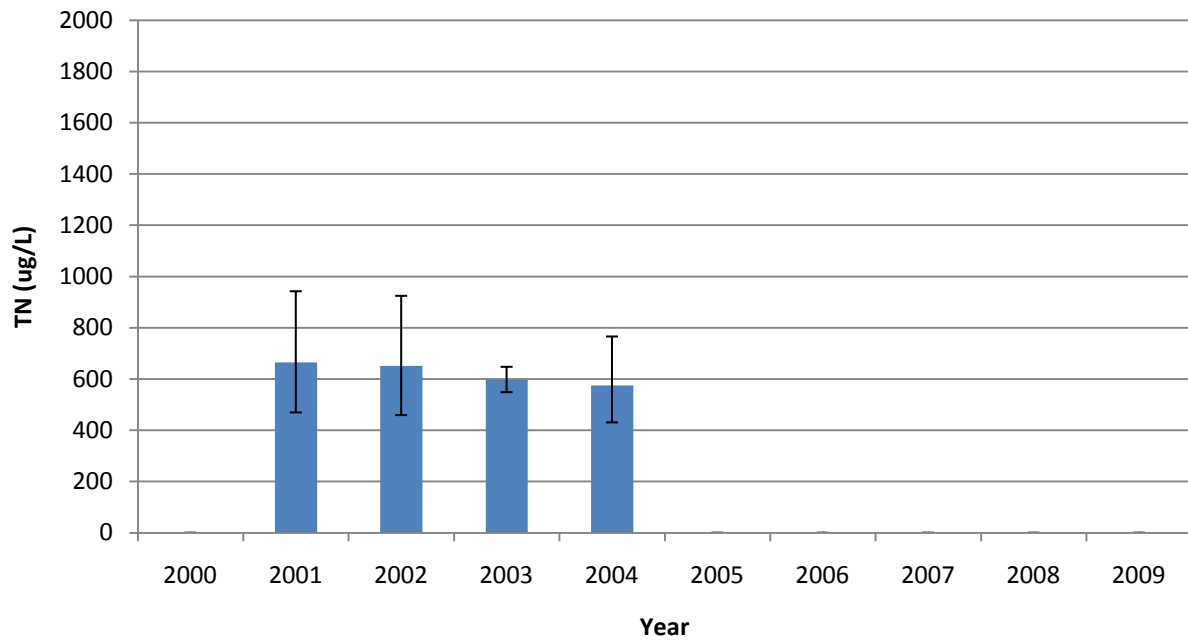
### WMO-8 Lower River



### WMO-9 Mid River

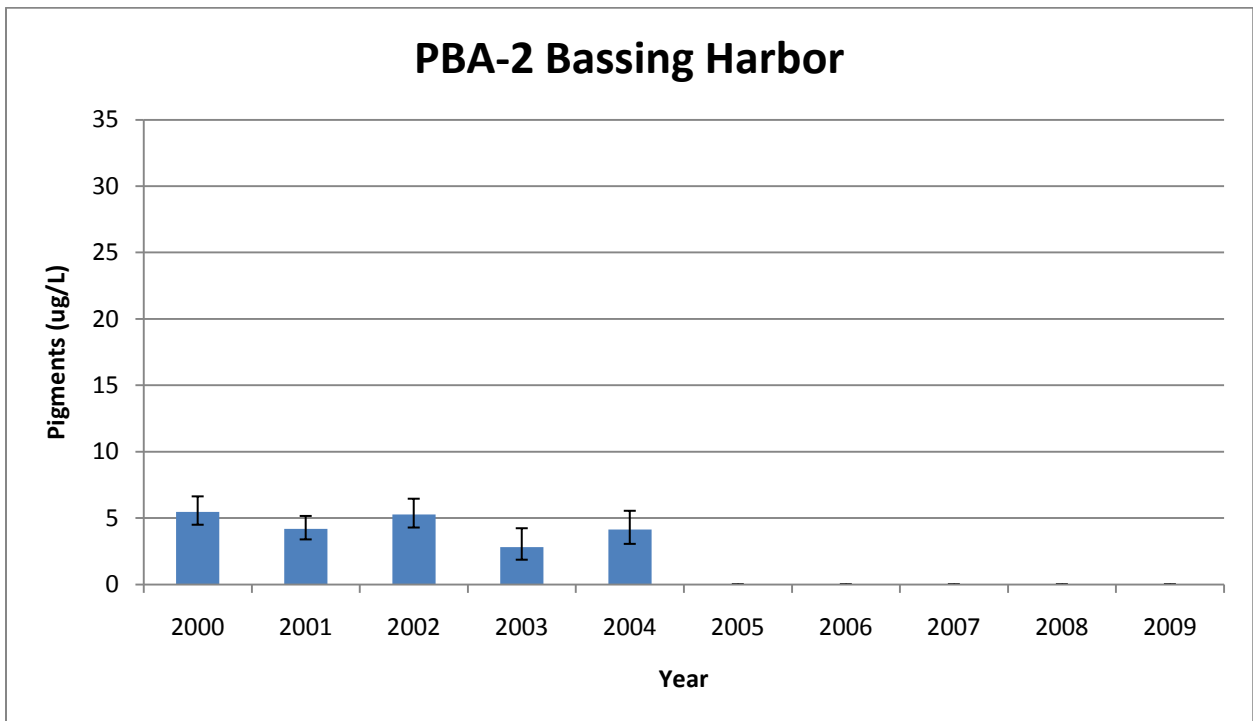
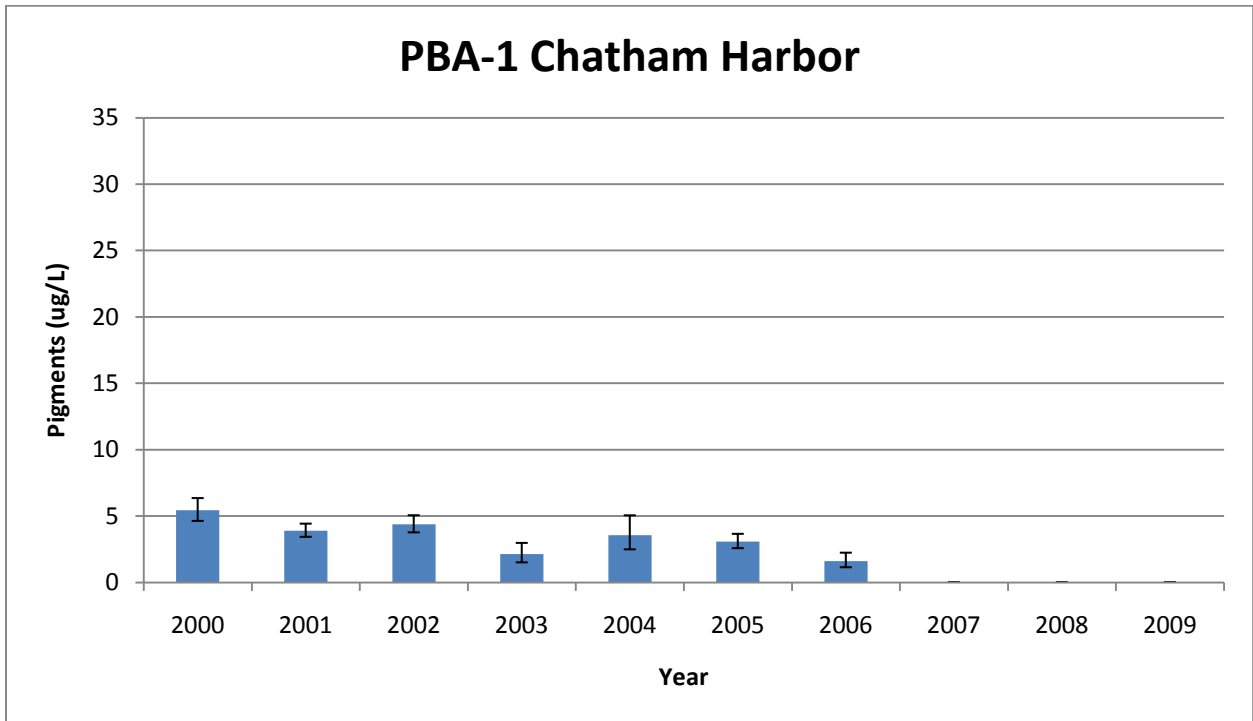


## WMO-12 Little Quanset Pond

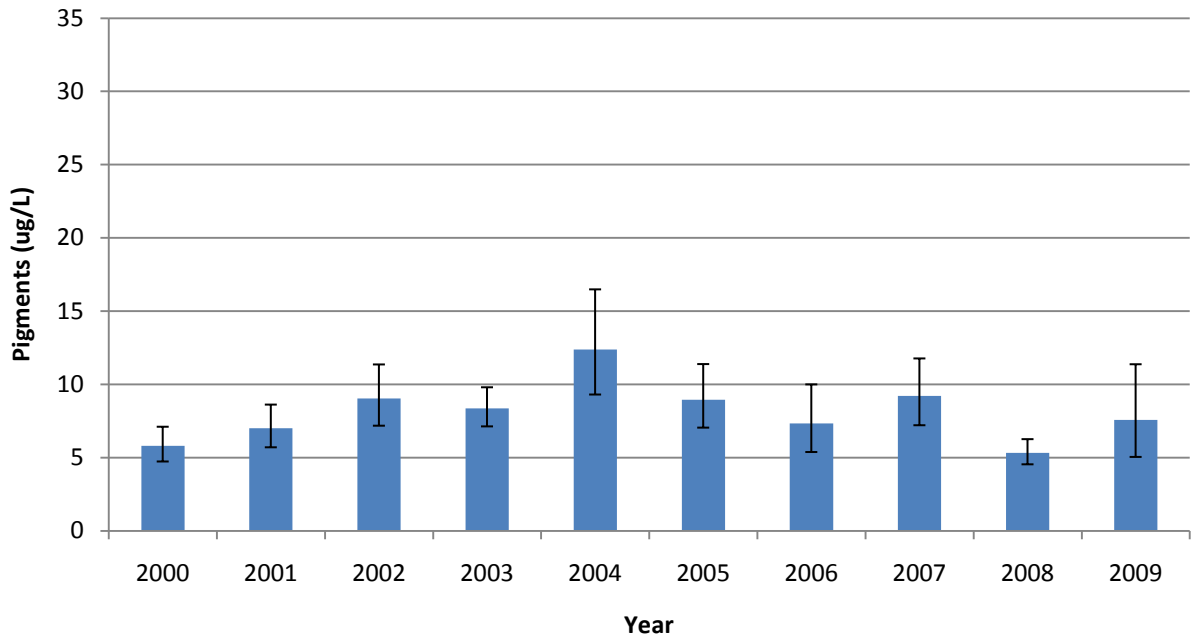


## Appendix D. Geometric Means and 90% Confidence Intervals for Total Pigments

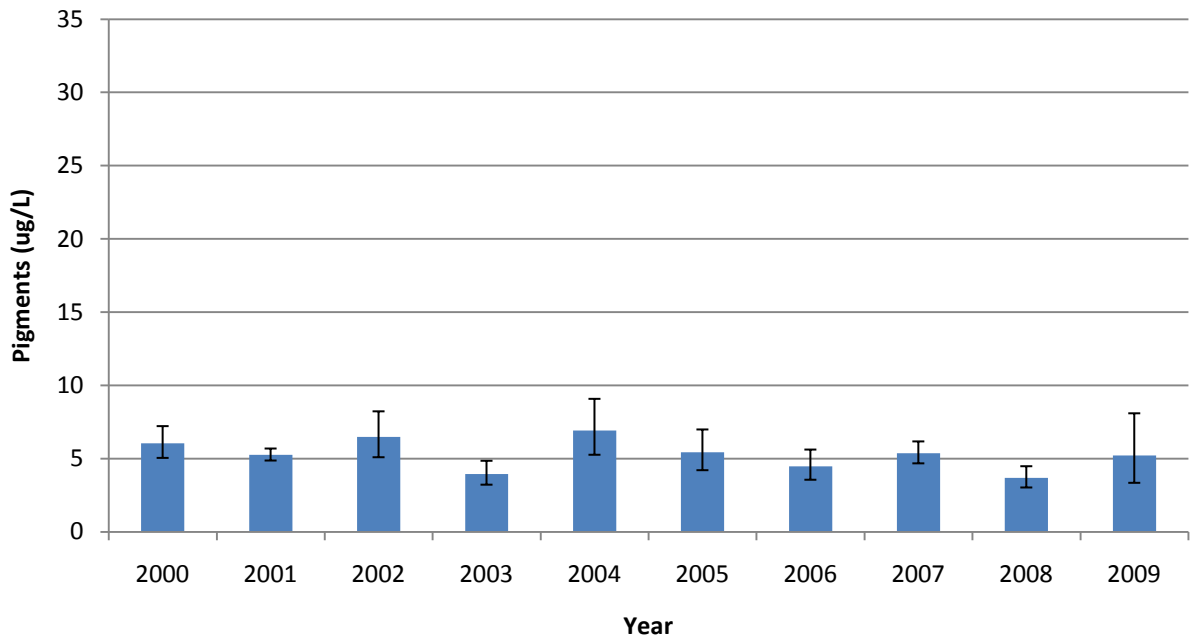
Note that samples were not collected for all years at all stations. Lack of data does not indicate a mean value of zero.



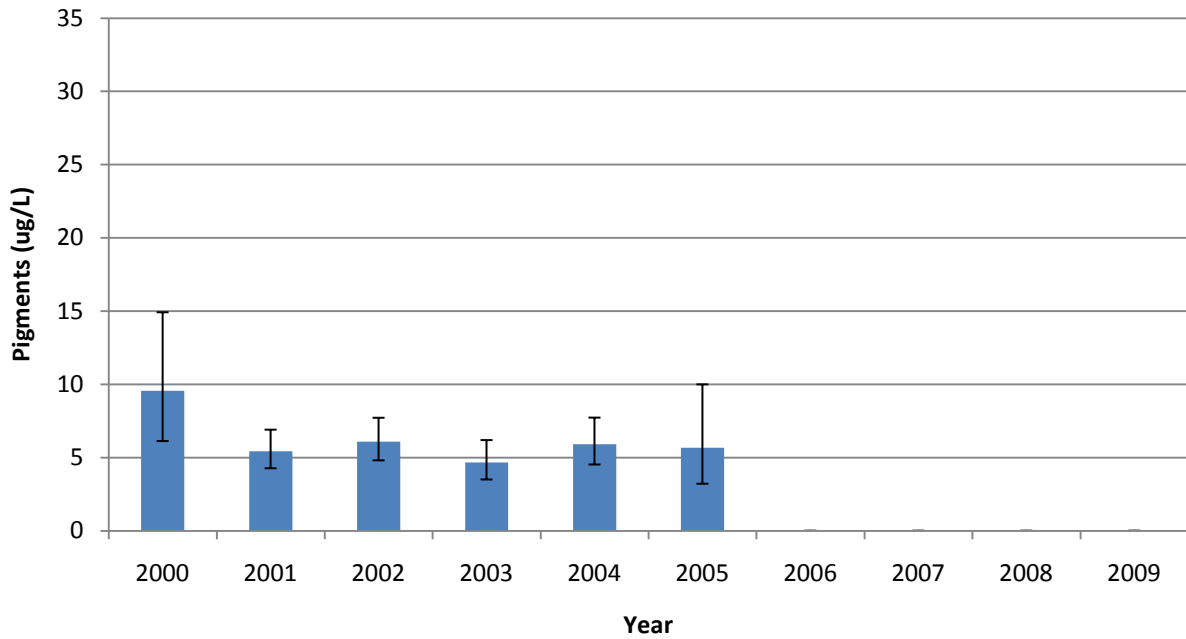
### PBA-3 Inner Ryders Cove



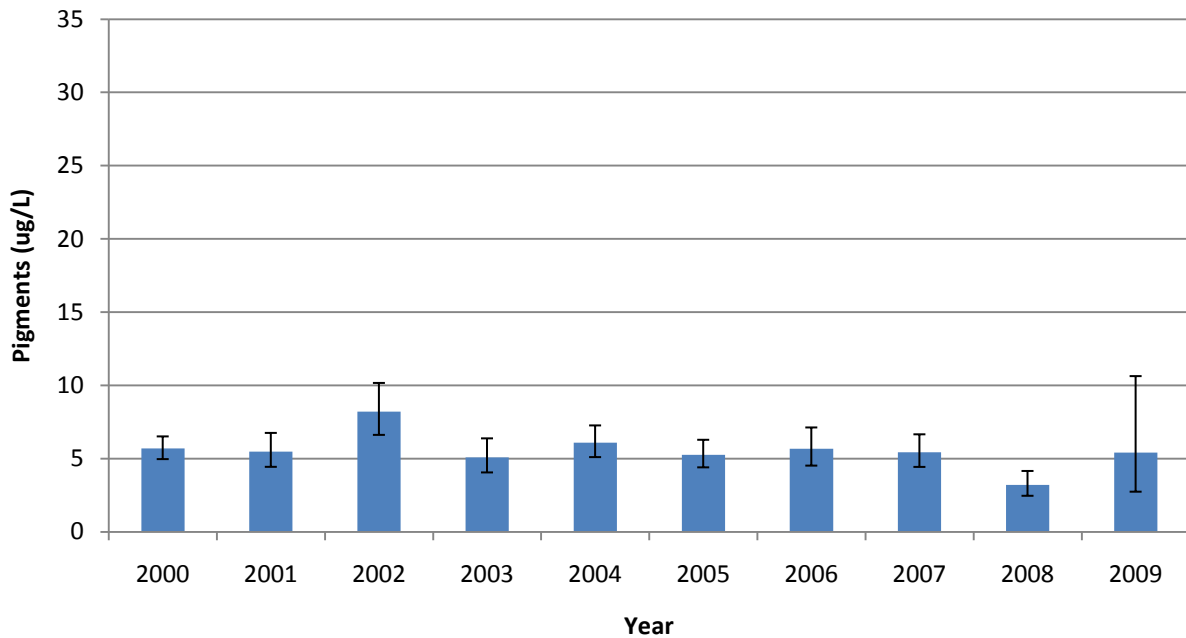
### CM-13 Outer Ryders Cove

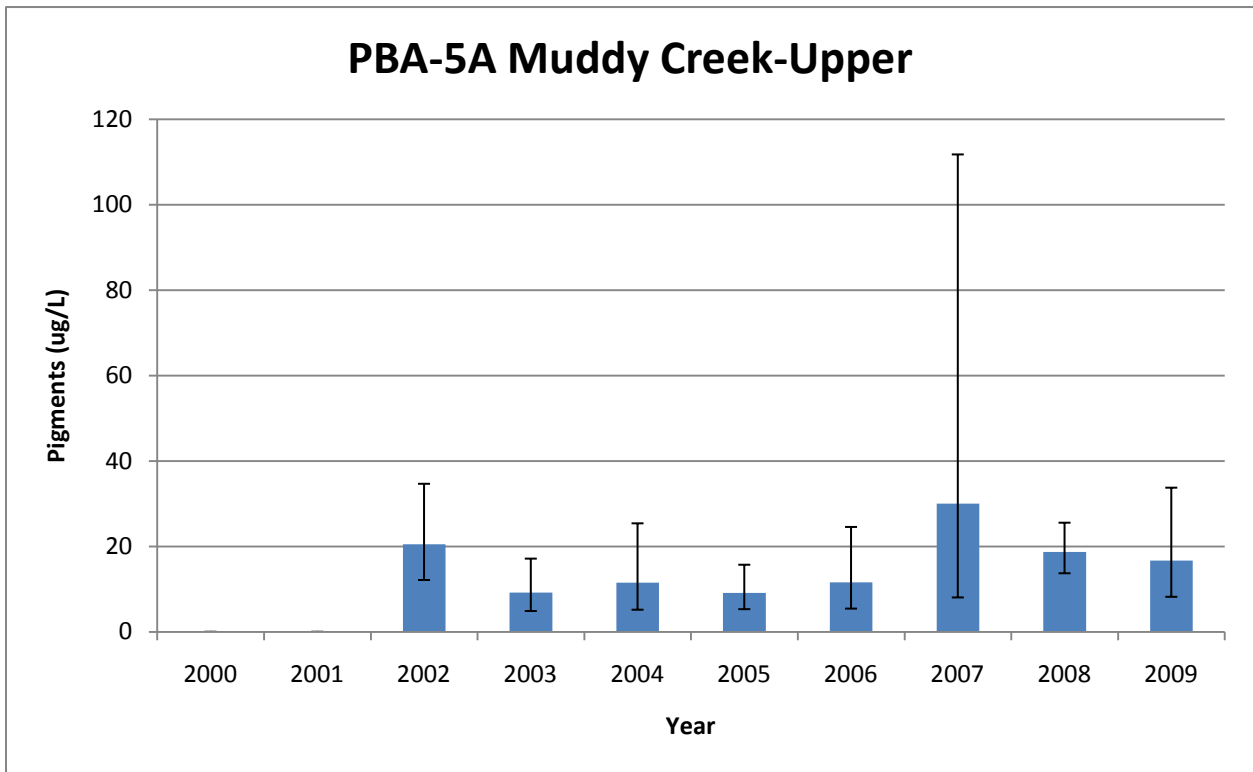
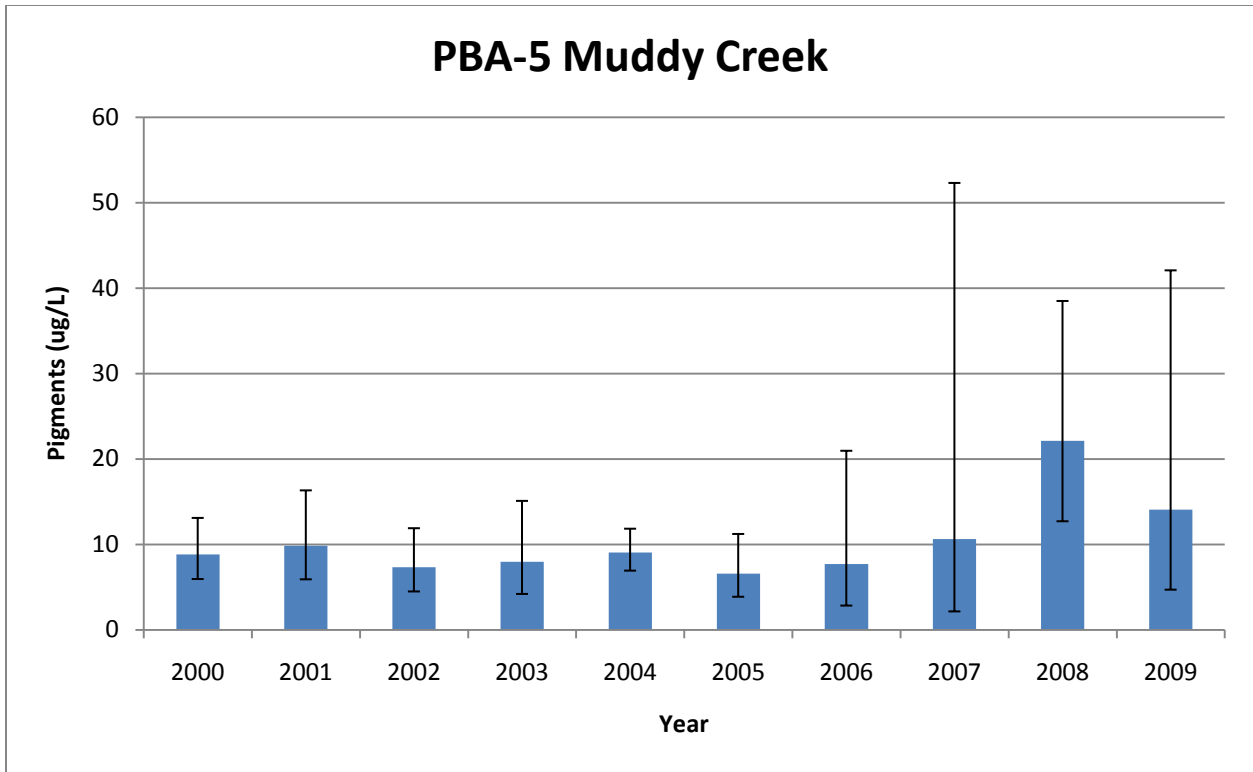


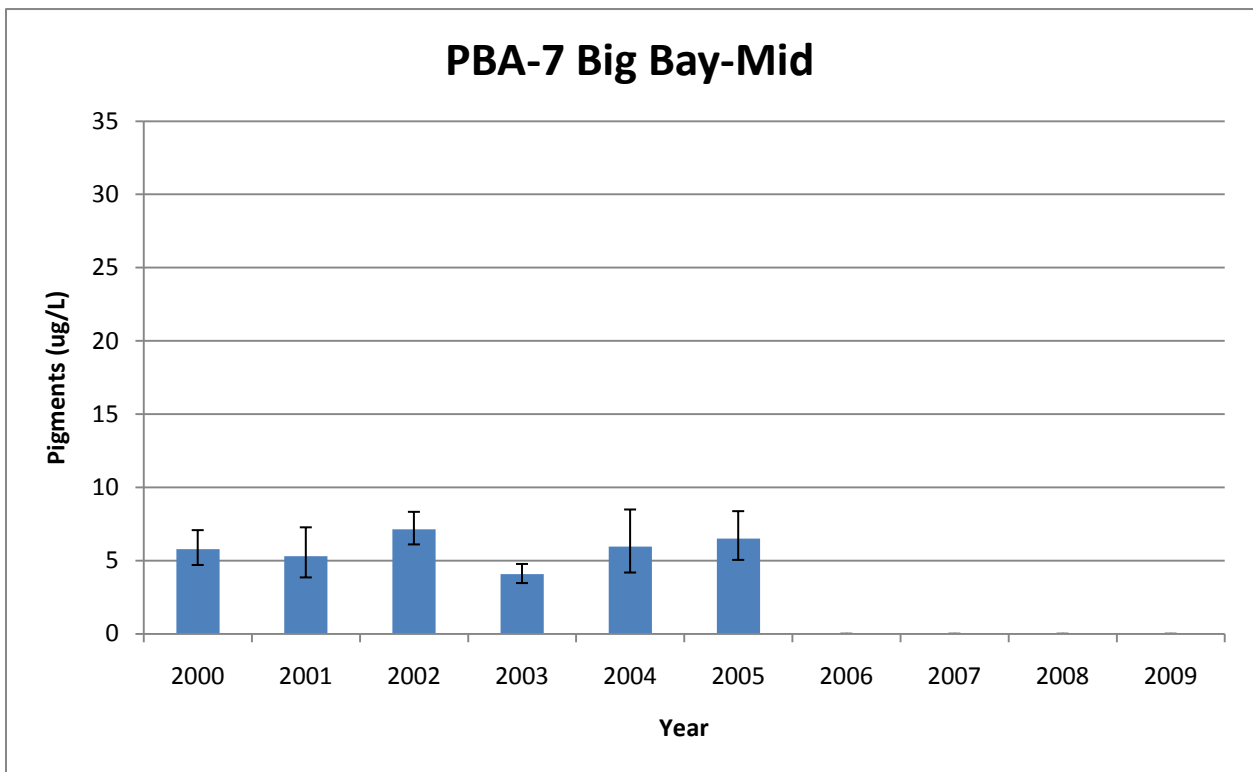
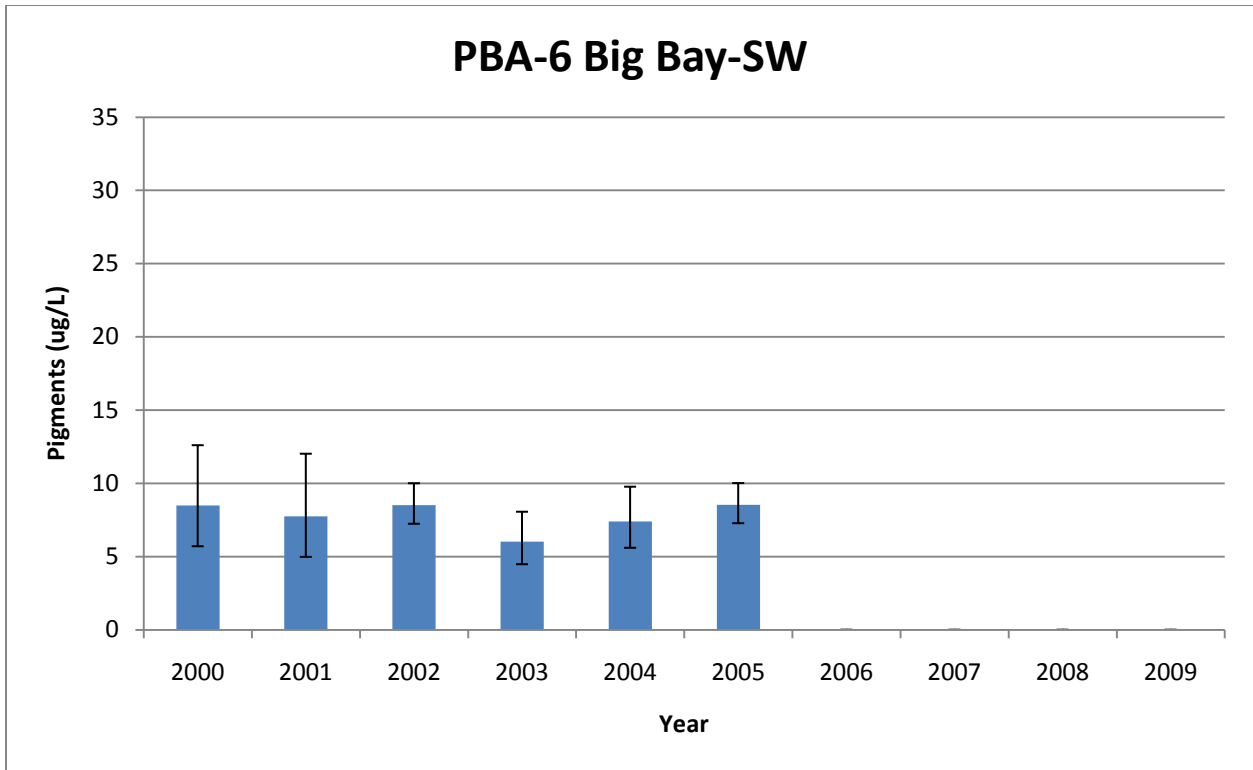
### CM-14 Frost Fish Creek

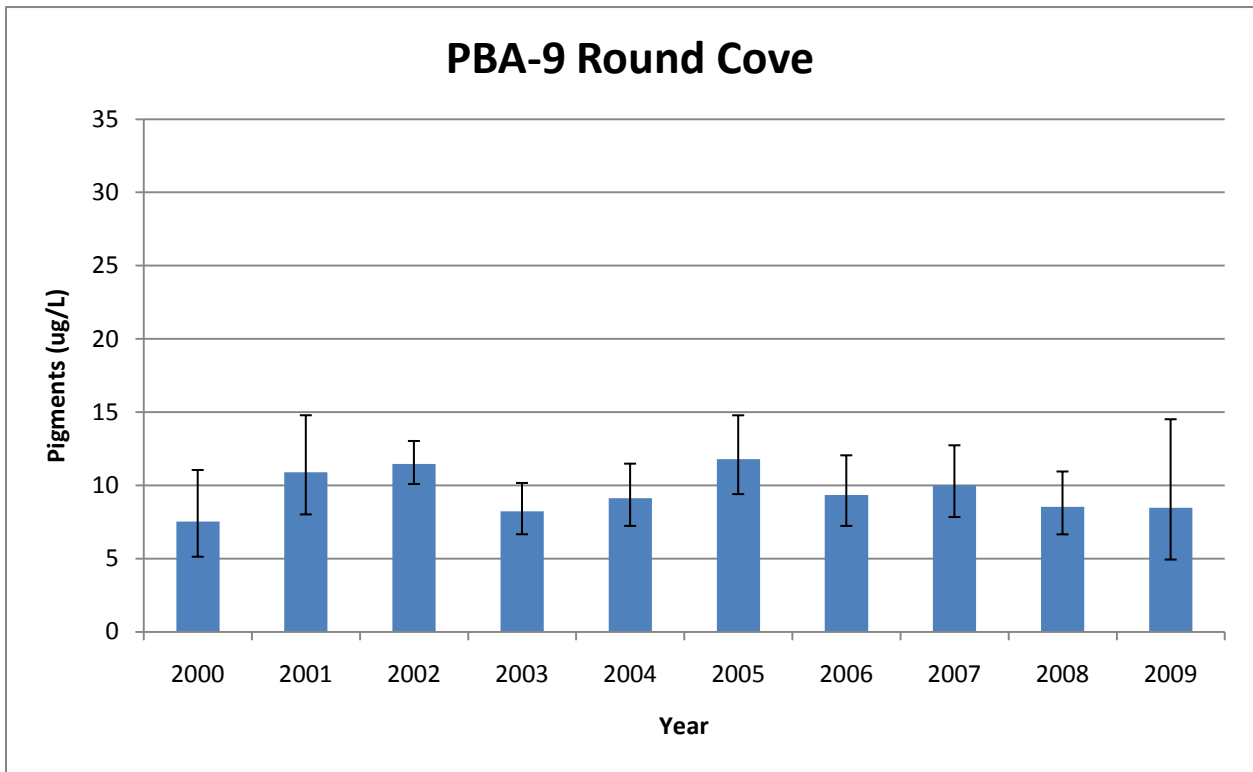
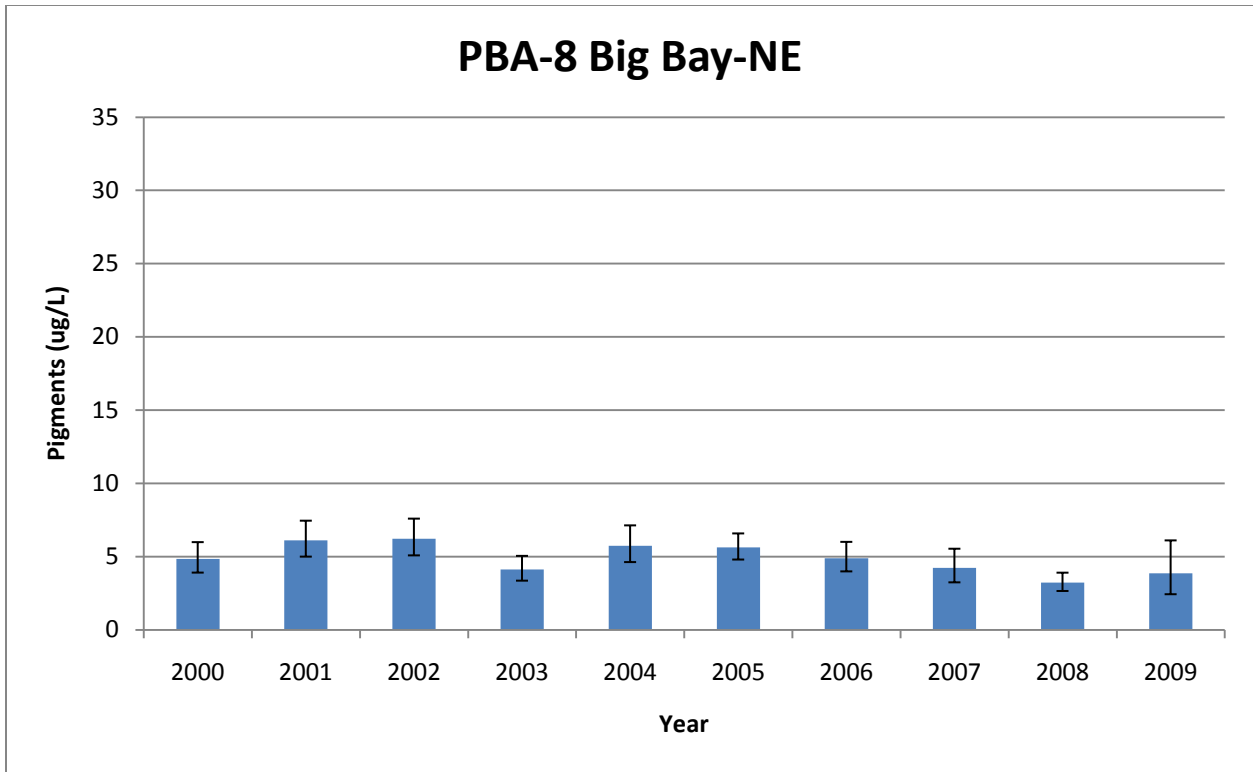


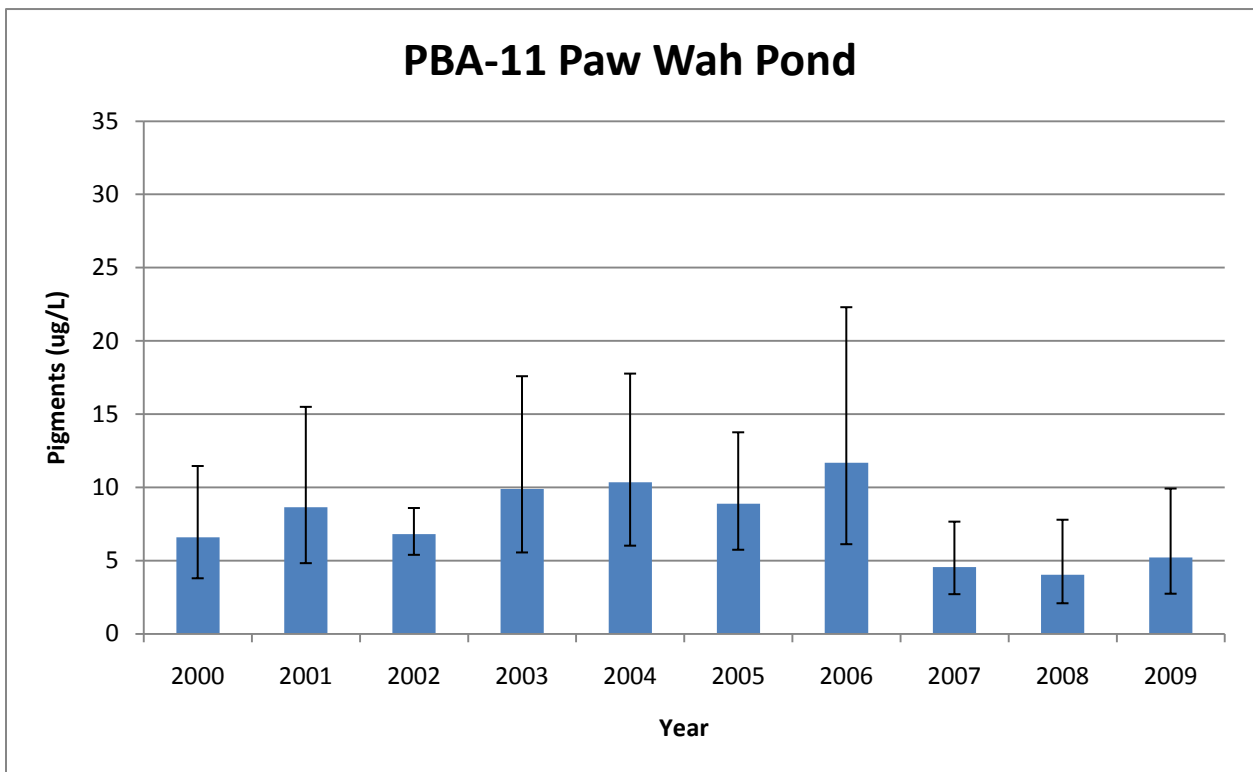
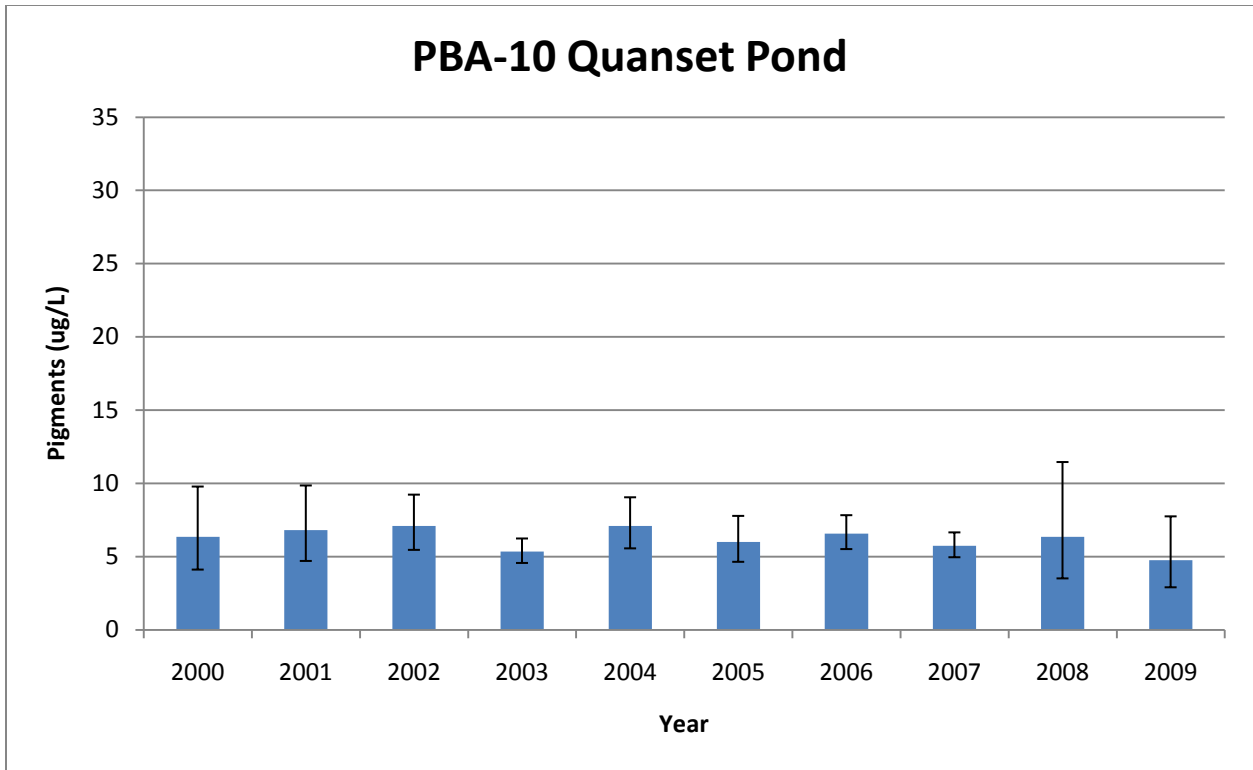
### PBA-4 Crow's Pond



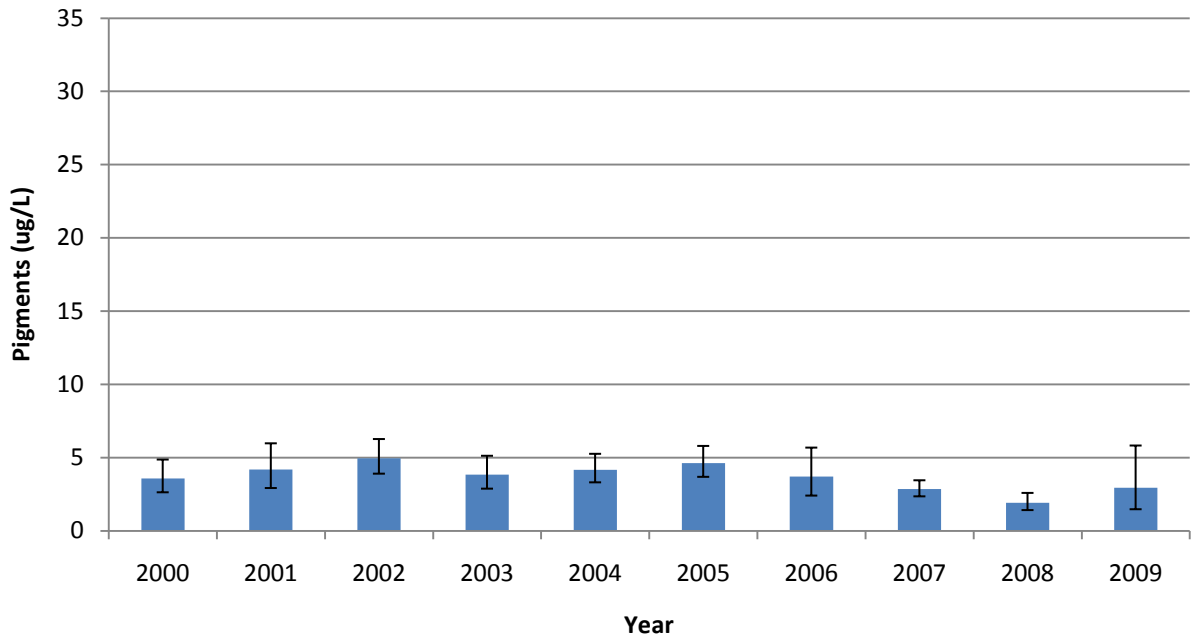




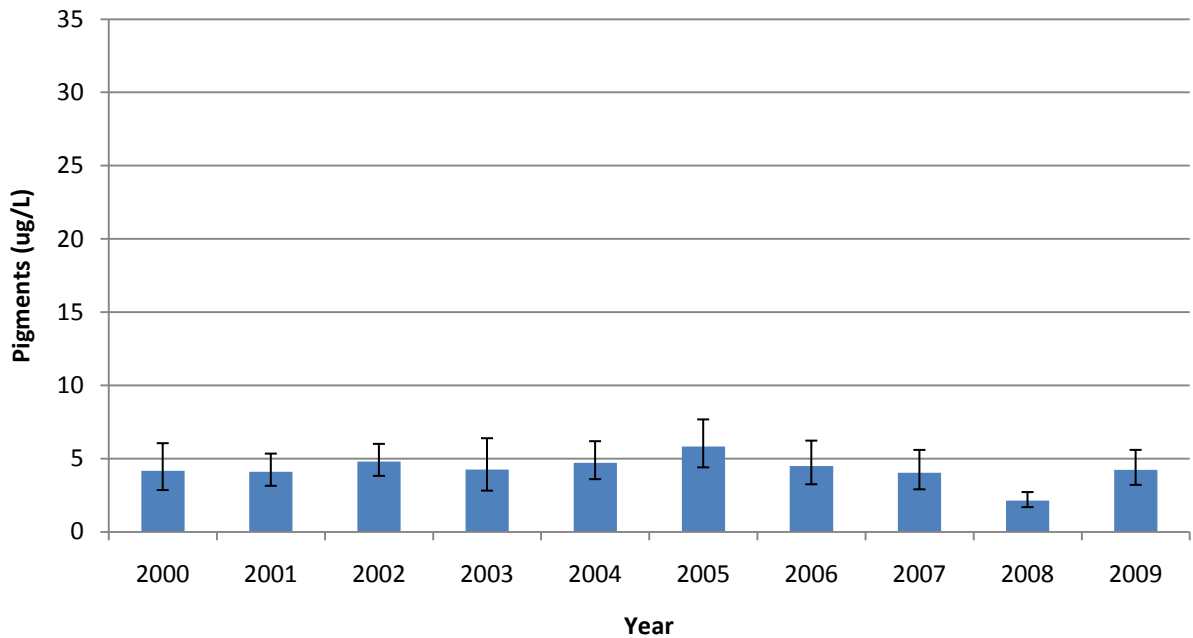


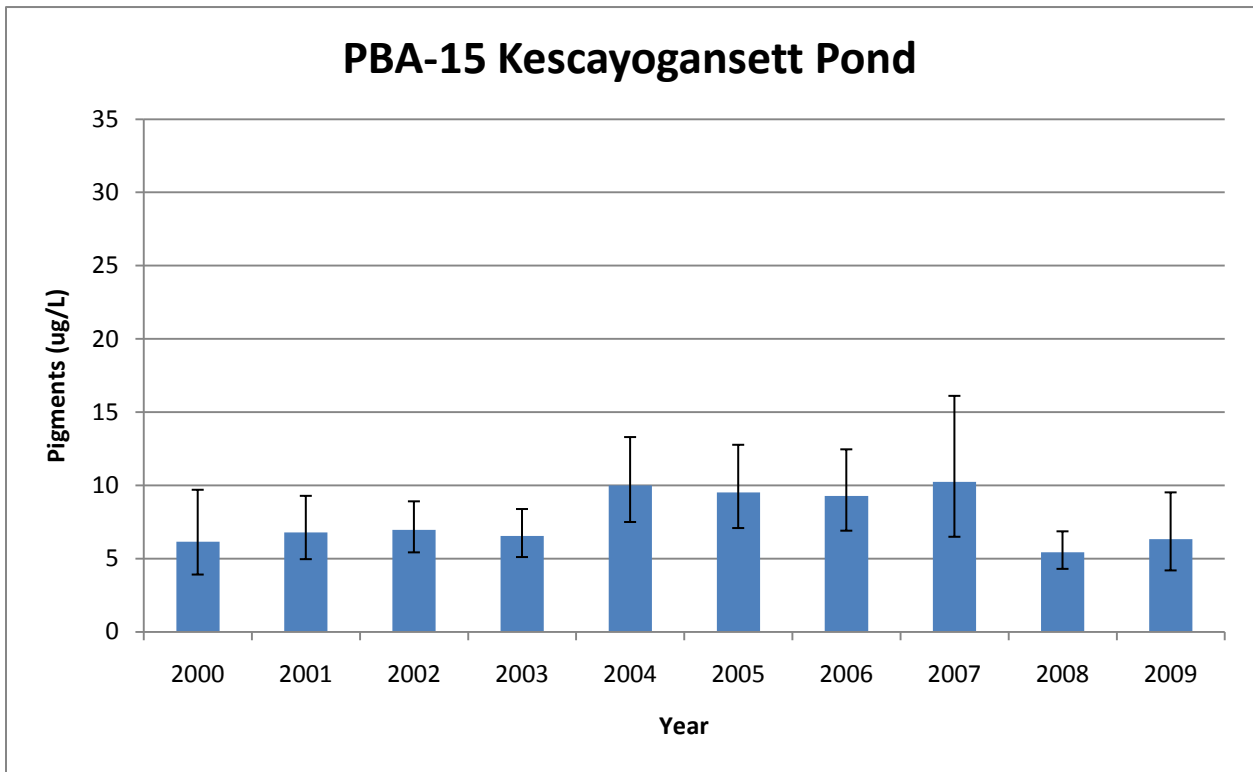
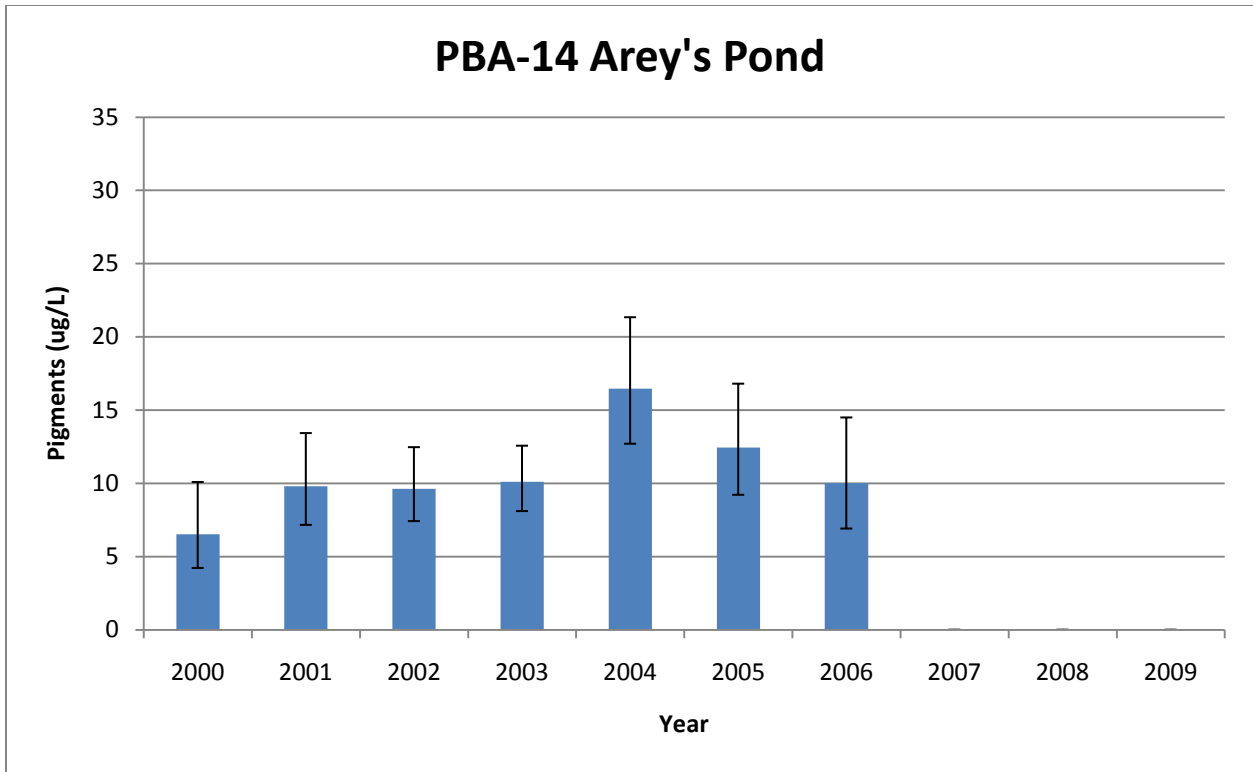


### PBA-12 Namequoit South

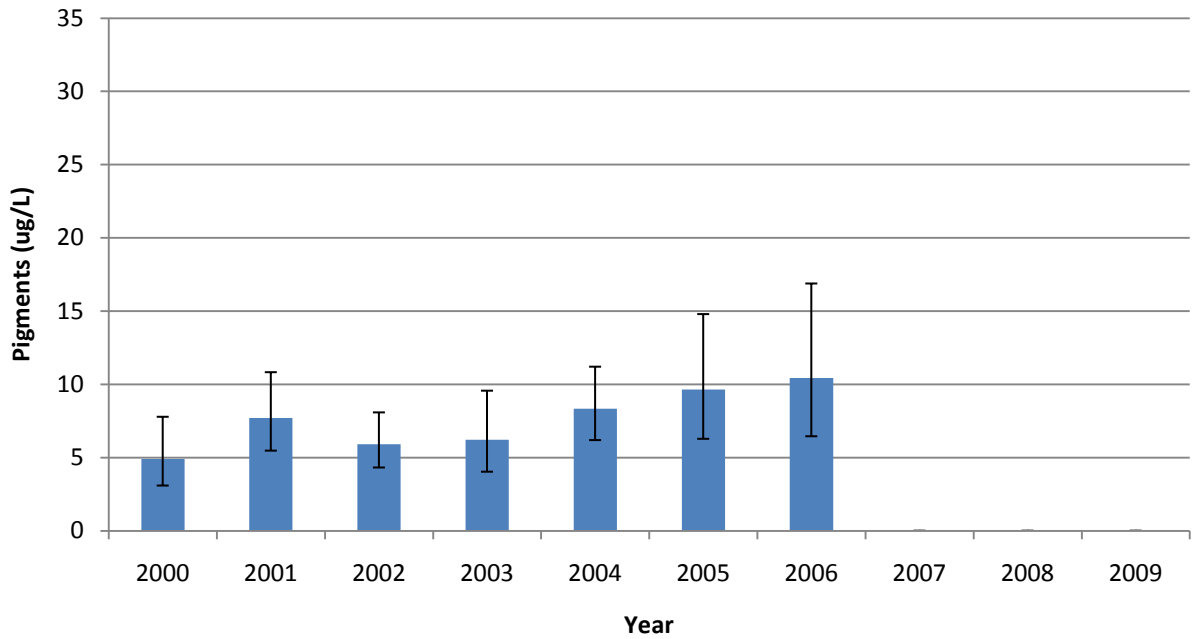


### PBA-13 Namequoit North

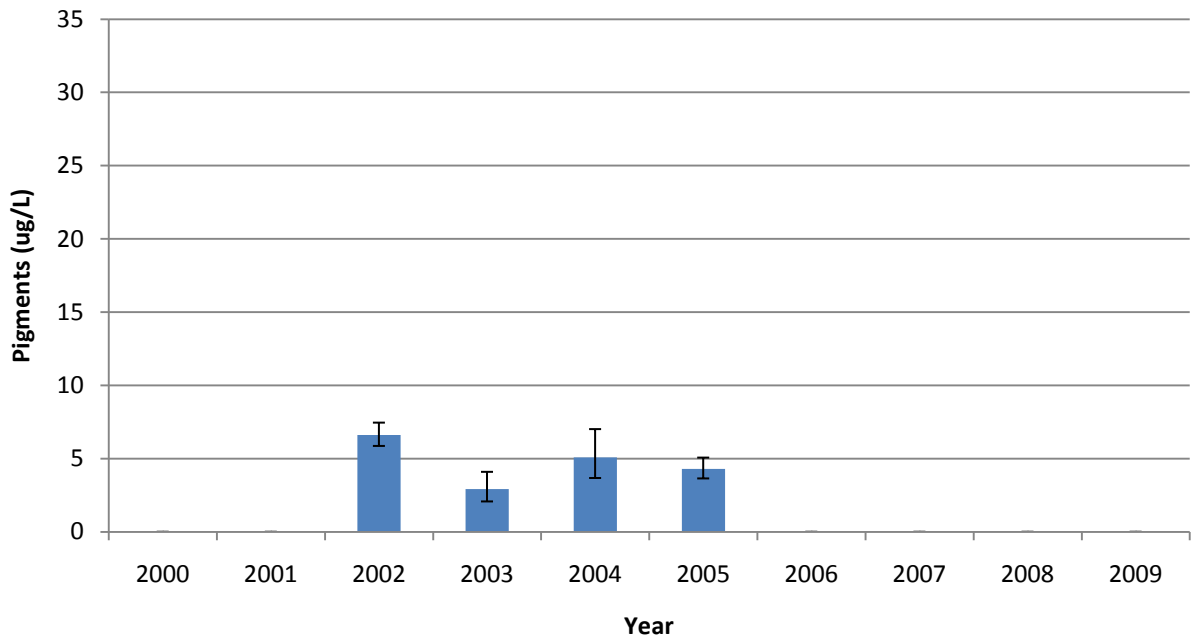


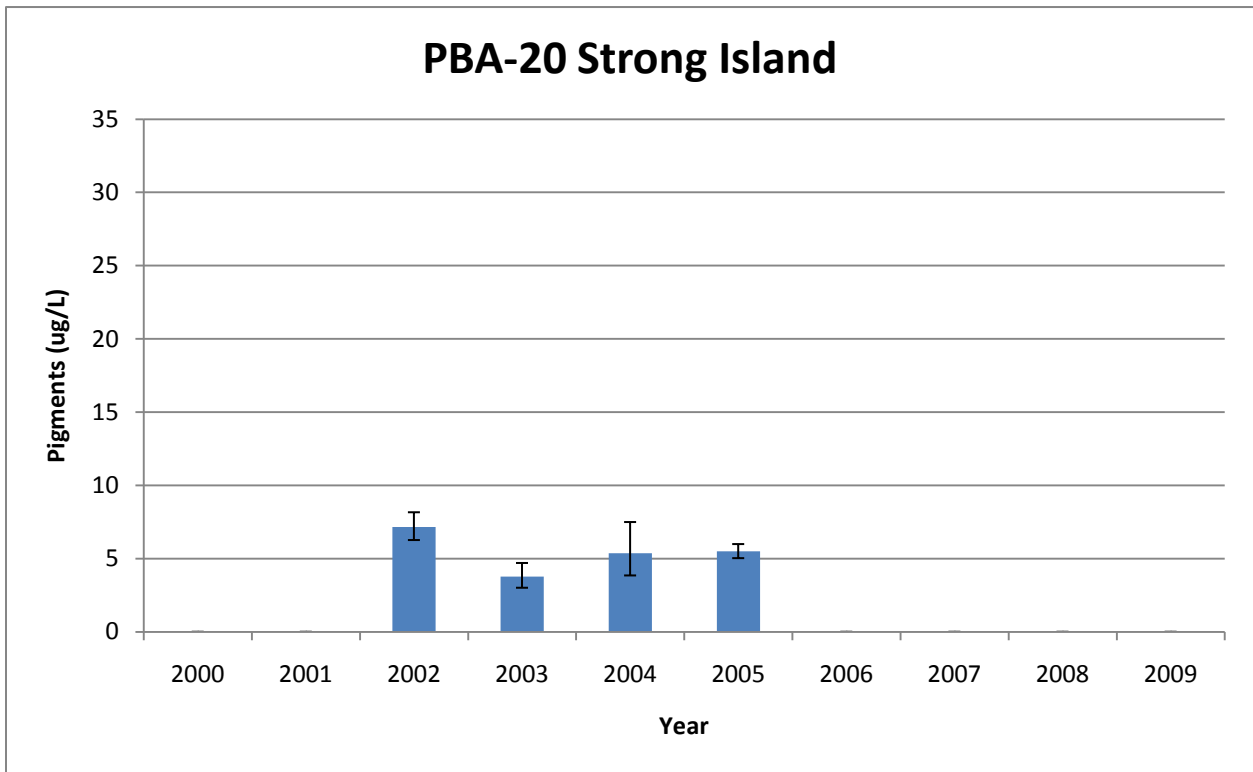
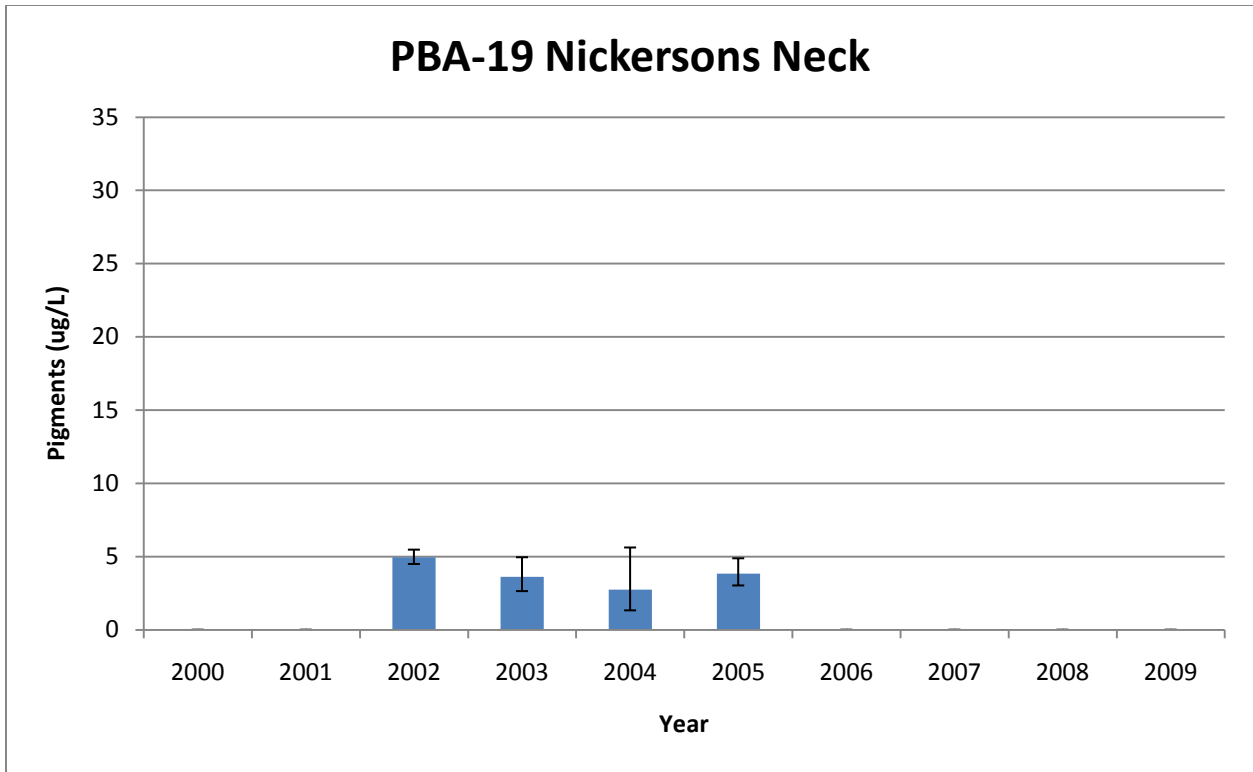


### PBA-16 Meetinghouse Pond

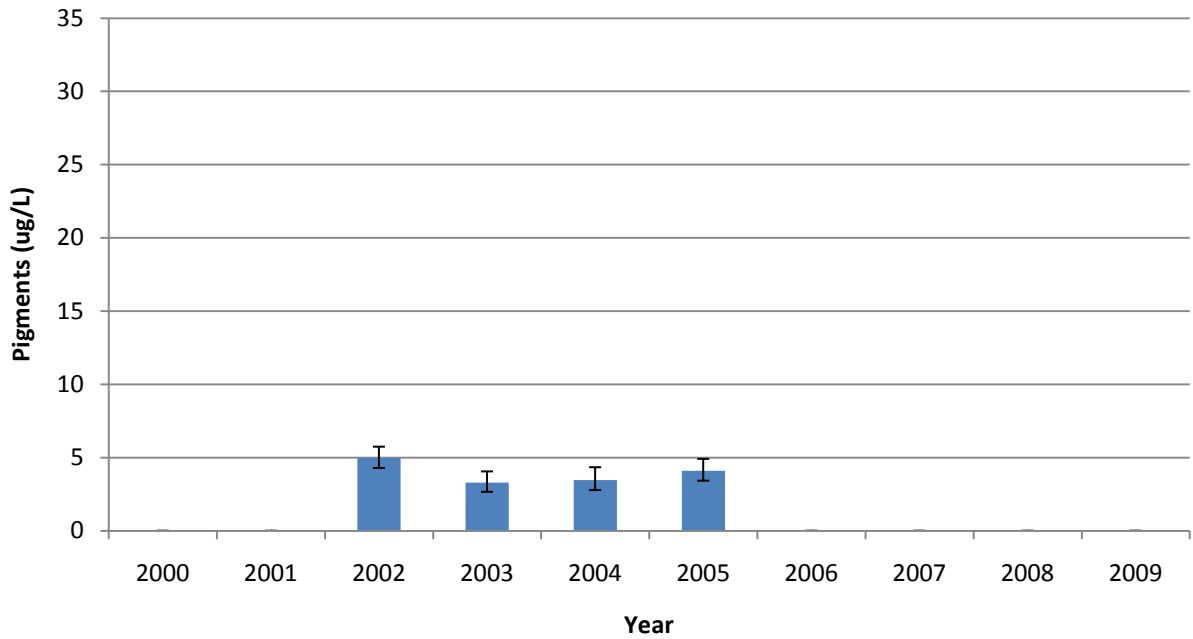


### PBA-18 Allen's/Ministers Point

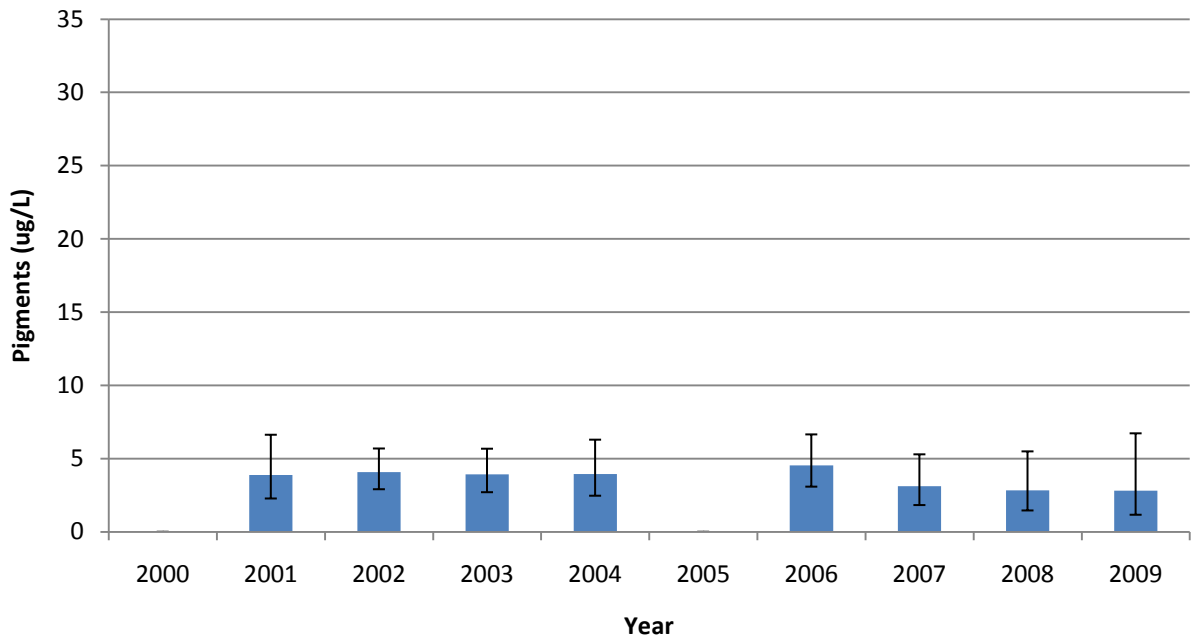


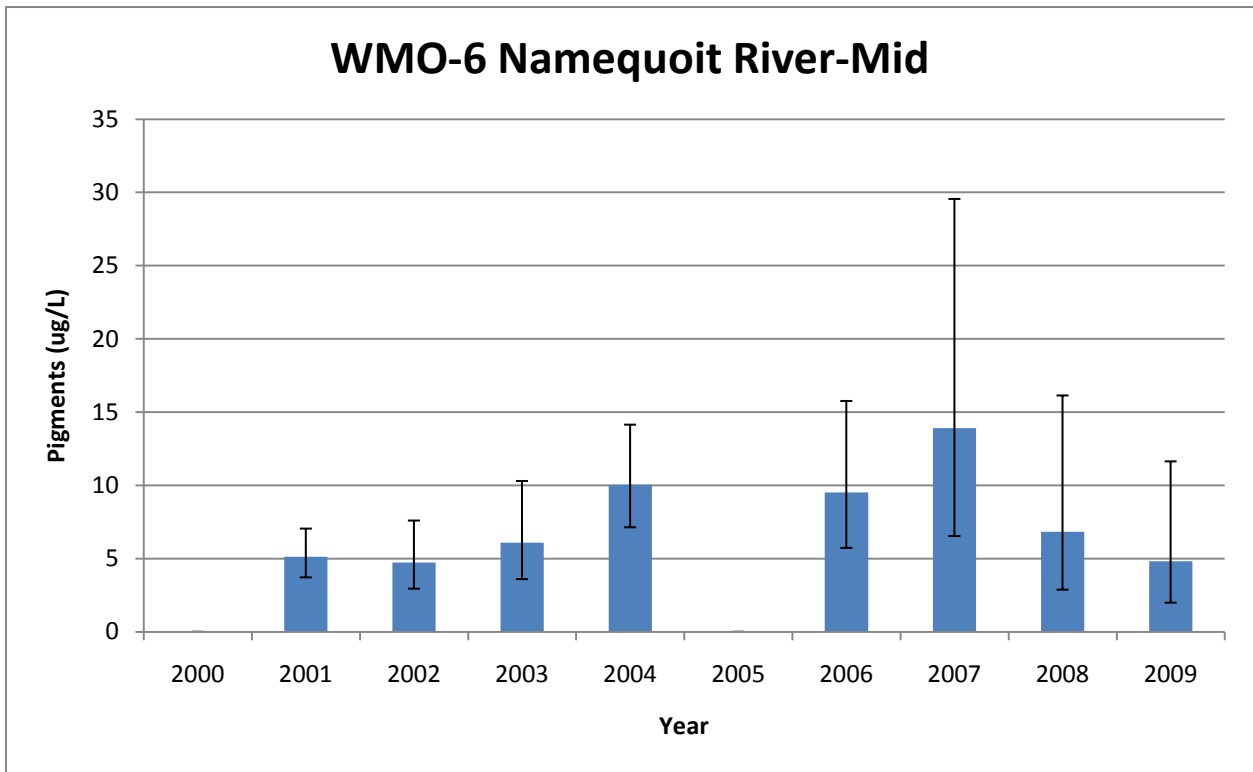
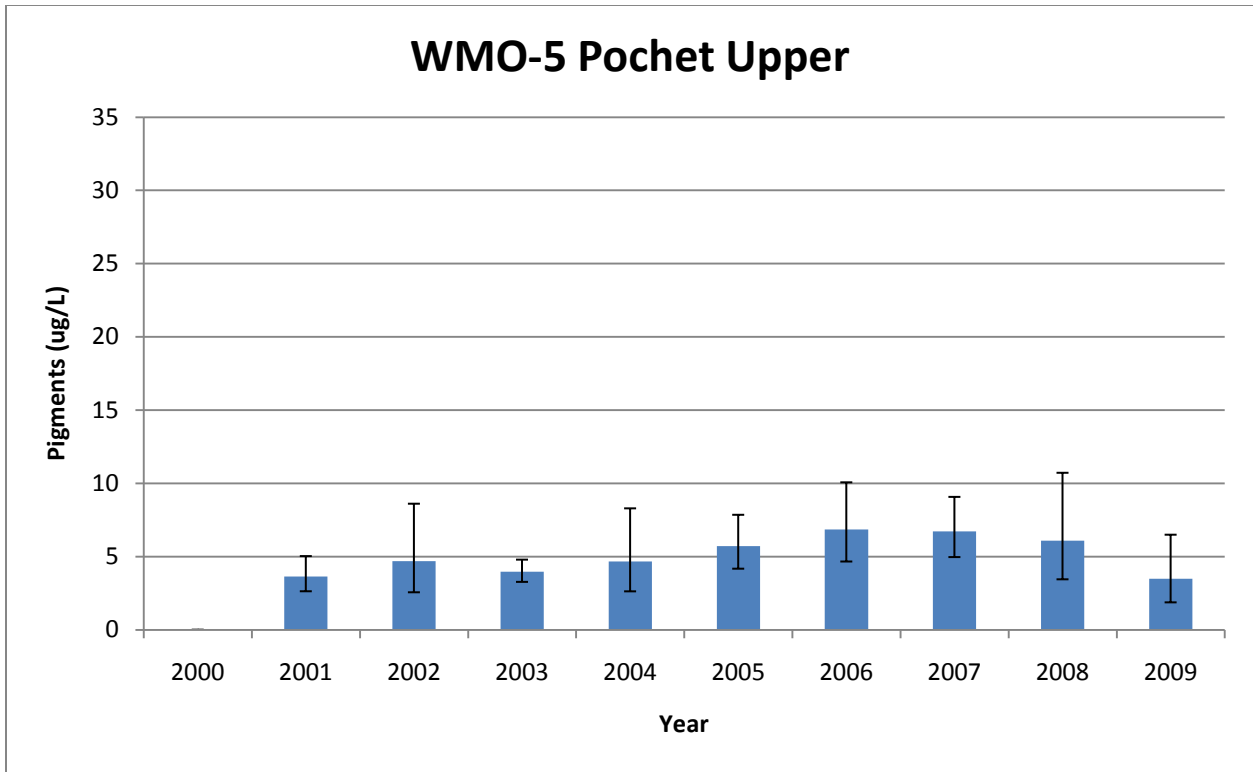


### PBA-21 Little Pleasant Bay

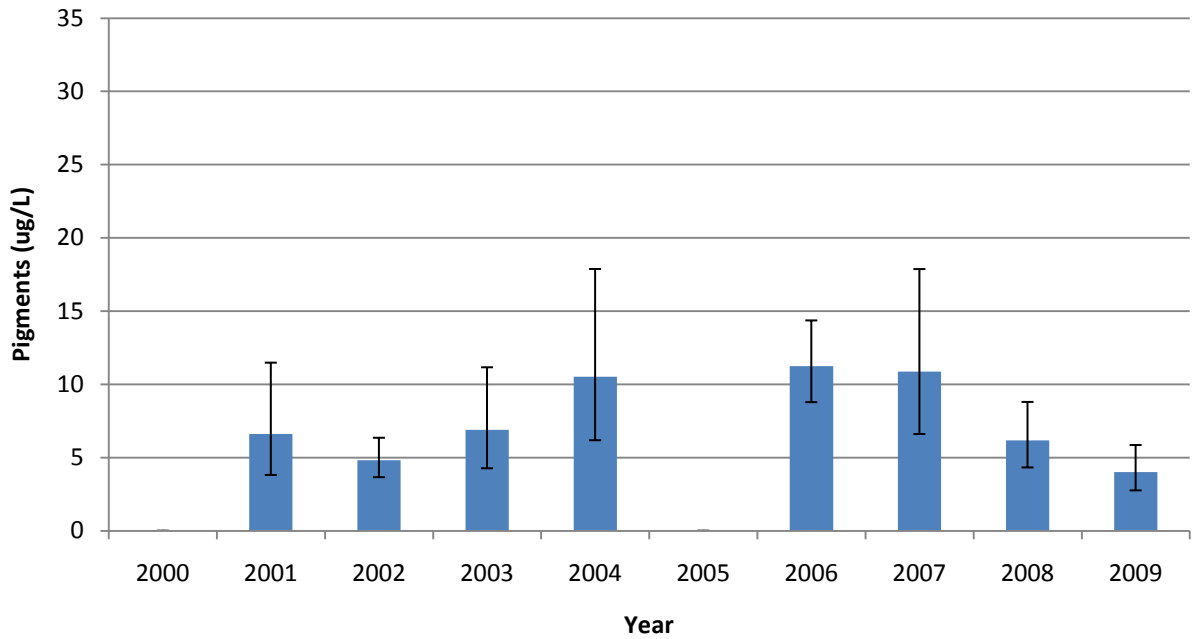


### WMO-3 Pochet Mouth

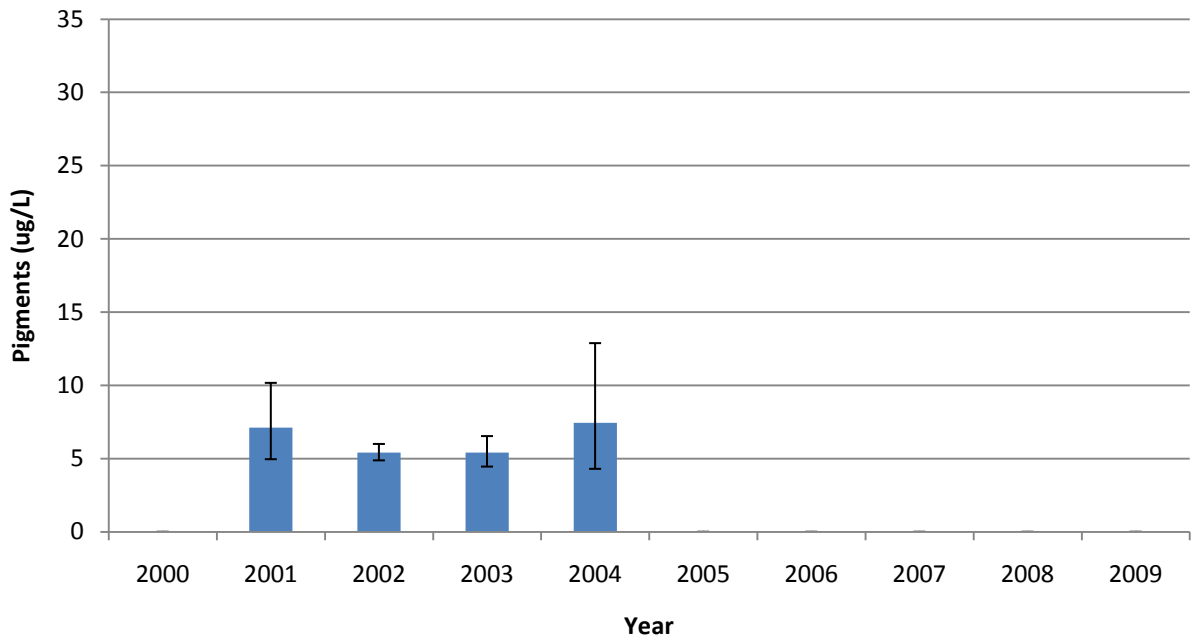


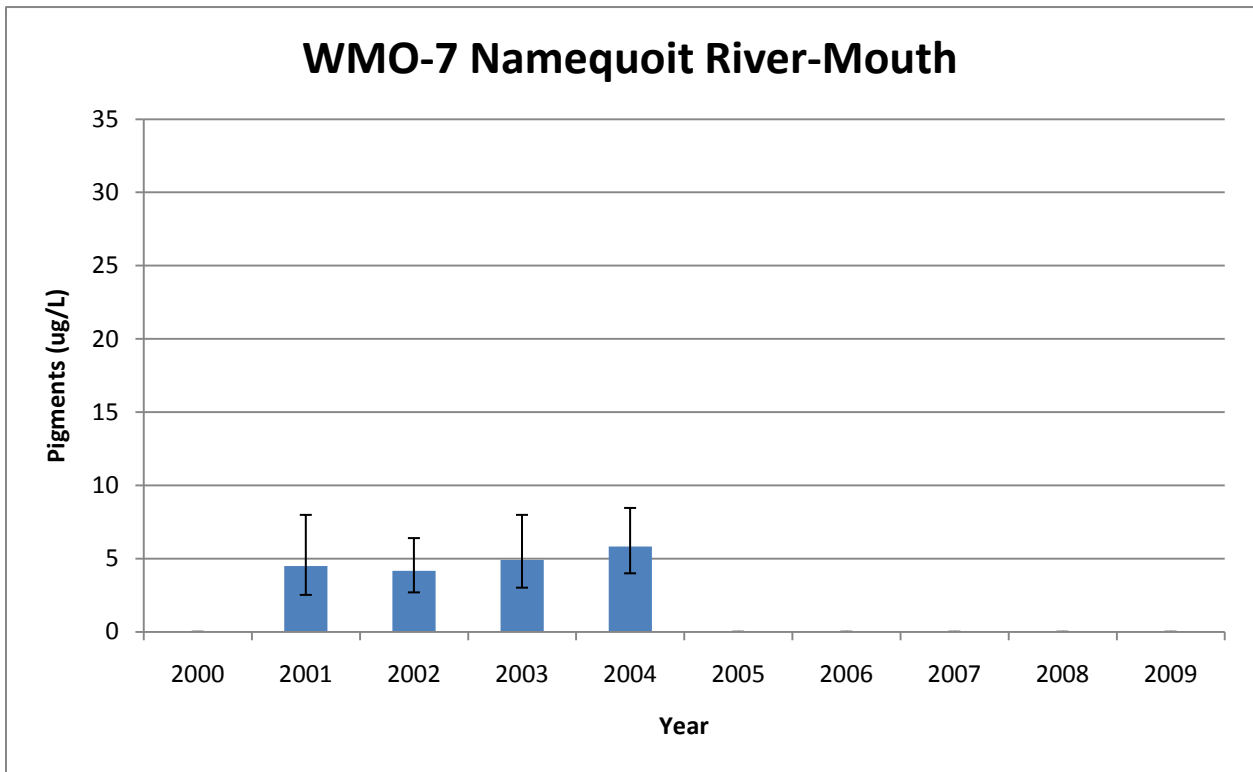
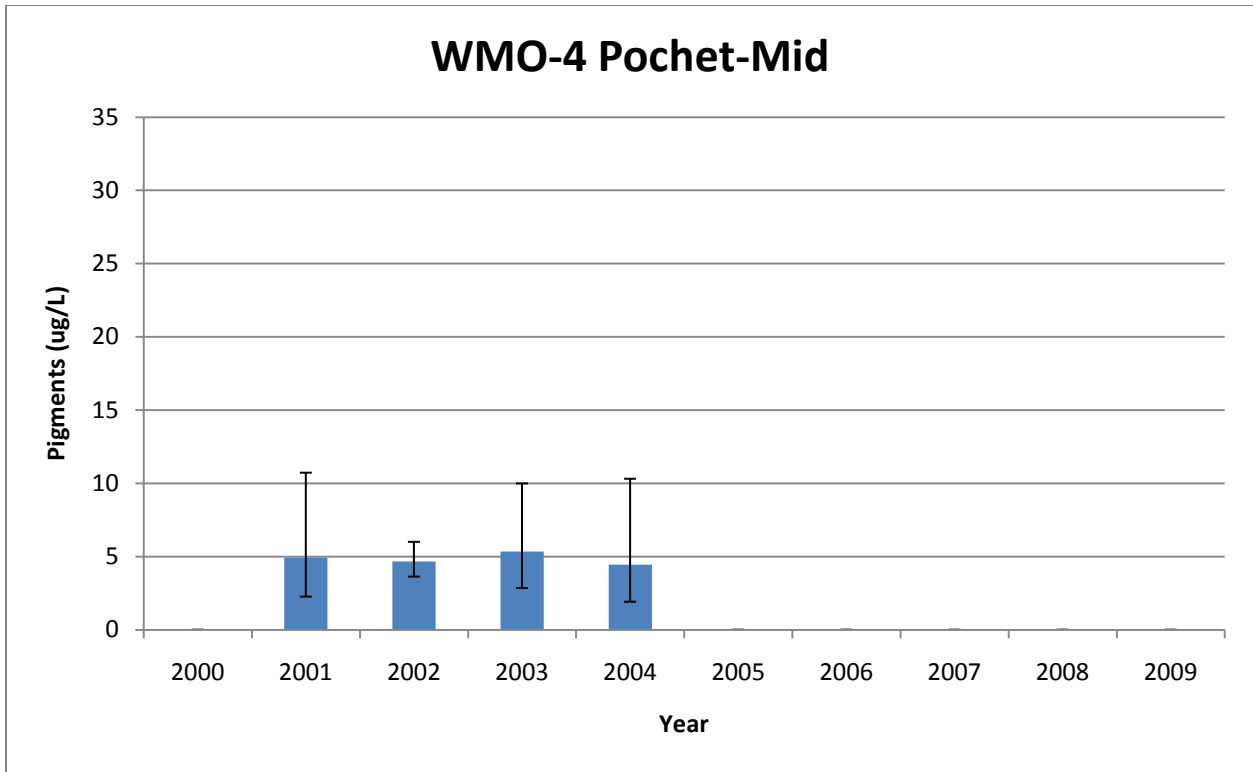


### WMO-10 River at Rattles Dock

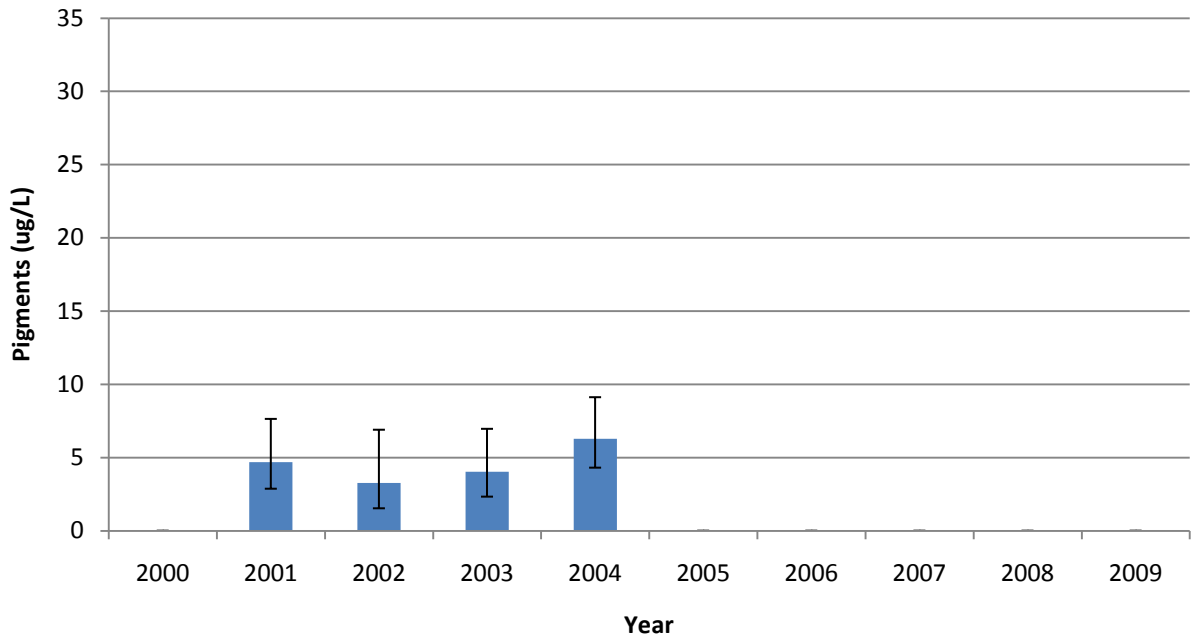


### WMO-2 Pleasant Bay off Quanset

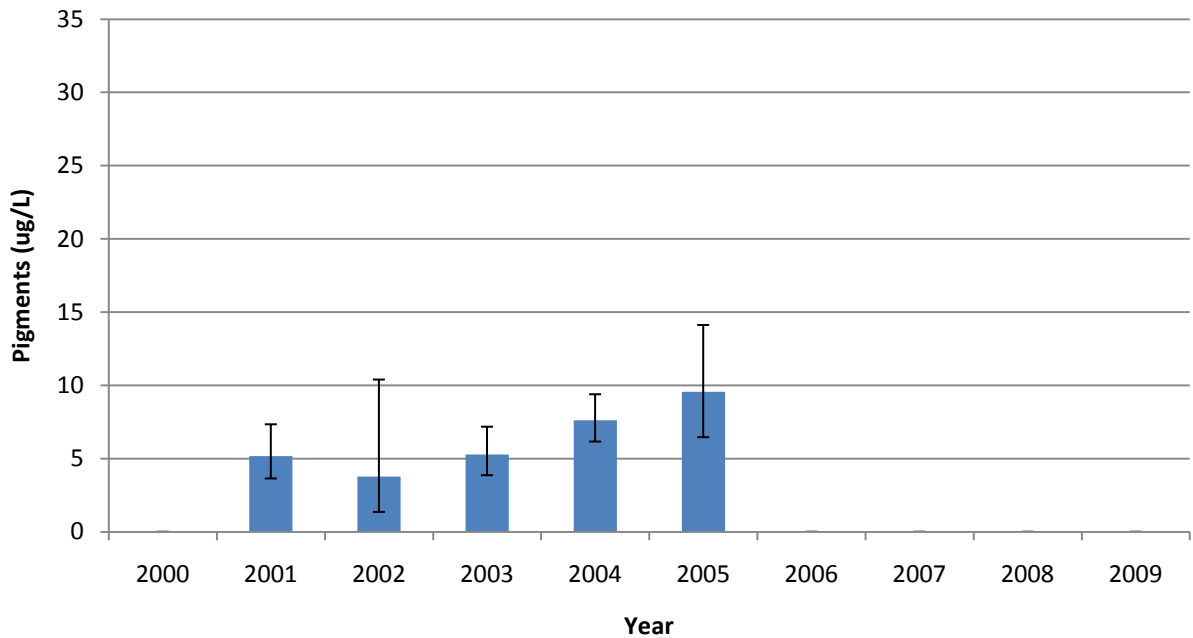




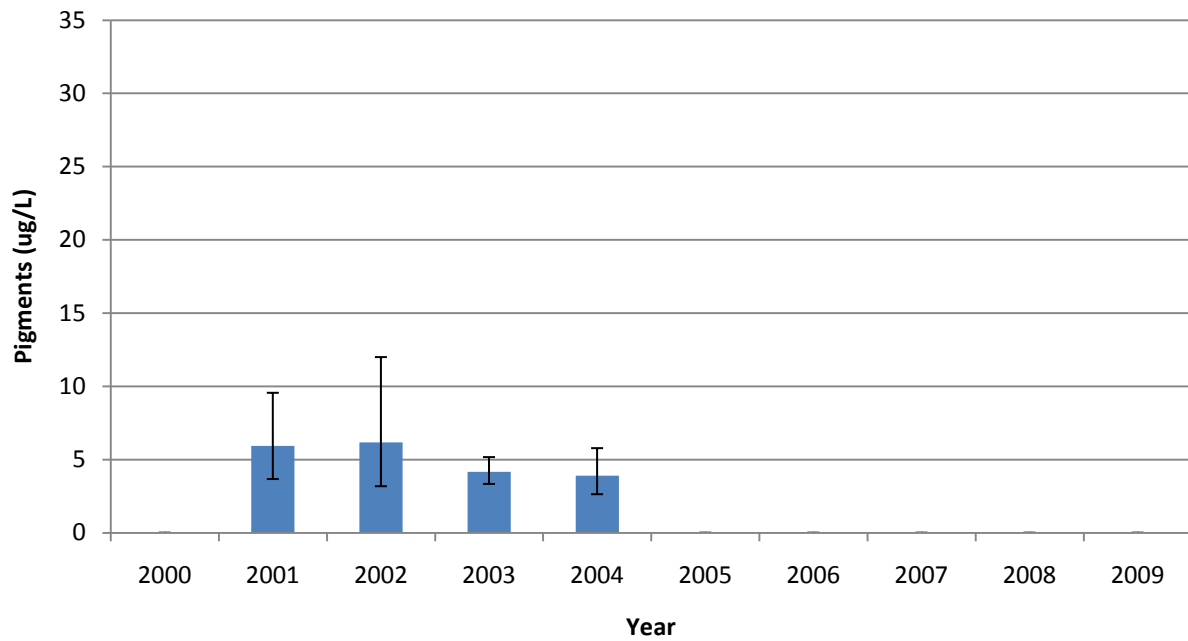
### WMO-8 Lower River



### WMO-9 Mid River



## WMO-12 Little Quanset Pond



## **Appendix E. Tables of Summary Statistics**

The following tables present summary statistics for each station in Pleasant Bay. Logarithmic transformations were applied to the total nitrogen, bioactive nitrogen, total pigments, phosphate, and dissolved inorganic nitrogen data before calculating the means and 90% confidence intervals (CI). The resulting estimates were then “back-transformed” into their original units. Therefore, these estimates are better referred to as geometric means and CIs. Dissolved oxygen did not require this transformation prior to calculation of the mean and CIs because it is normally distributed.

		Total Nitrogen (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	528	503	454	405	340	273	419			
	90% CI	633	695	563	514	439	318	535			
		440	363	366	319	264	234	328			
PBA-2	Mean	512	445	500	518	450					
	90% CI	646	519	793	669	657					
		406	381	315	401	309					
PBA-3	Mean	502	761	686	879	854	724	820	739	658	556
	90% CI	601	914	808	1111	1067	854	959	943	771	702
		420	634	583	696	683	614	702	580	561	441
CM-13	Mean	442	410	468	456	425	365	424	435	446	554
	90% CI	485	452	581	524	467	405	468	516	476	609
		403	371	377	396	387	329	384	367	418	504
CM-14	Mean	1176	706	1359	1144	1000	1113				
	90% CI	1412	1438	1621	1362	1382	1714				
		980	346	1139	961	723	723				
PBA-4	Mean	772	963	1128	660	642	678	574	727	514	560
	90% CI	1021	1180	1209	795	769	795	670	943	589	738
		585	786	1052	548	536	579	492	561	449	425
PBA-5	Mean	556	623	880	695	610	558	1540	1196	1139	620
	90% CI	645	745	1881	950	950	674	2635	2615	3341	1559
		480	521	412	508	391	462	900	547	388	247
PBA-5A	Mean			1318	1297	1277	1225	1292	1308	1472	1231
	90% CI			2724	1684	1646	1730	1884	1970	1593	1336
				638	998	991	867	886	868	1361	1135
PBA-6	Mean	576	578	539	514	474	408				
	90% CI	773	672	663	575	613	444				
		430	498	438	459	366	375				
PBA-7	Mean	707	399	381	413	452	429				
	90% CI	839	436	441	449	544	499				
		596	366	329	380	376	370				
PBA-8	Mean	578	410	446	498	388	381	499	436	394	349
	90% CI	725	461	518	565	435	431	565	615	429	417
		461	364	384	438	346	337	440	309	362	292
PBA-9	Mean	742	661	811	882	555	513	753	558	546	500
	90% CI	876	779	989	1024	607	561	844	634	589	590
		628	561	665	759	507	470	672	491	506	423
PBA-10	Mean	413	502	577	767	604	505	645	449	570	450
	90% CI	488	556	692	946	680	553	707	603	636	507
		349	453	480	622	536	461	588	334	511	400
PBA-11	Mean	524	1081	694	884	773	634	789	596	457	465
	90% CI	606	1621	818	1201	881	736	1167	780	528	594
		452	720	588	650	678	546	533	456	396	364
PBA-12	Mean	718	664	770	1081	787	517	547	850	439	436
	90% CI	852	800	982	1245	941	587	637	1097	465	476
		606	552	603	939	657	456	470	659	415	399
PBA-13	Mean	588	581	619	601	528	535	591	524	533	484
	90% CI	690	725	736	661	591	603	663	634	662	584
		501	466	521	547	471	475	526	433	430	401
PBA-14	Mean	669	716	929	768	731	741	962			
	90% CI	772	778	1133	864	800	806	1192			
		579	660	762	683	669	681	777			

		Total Nitrogen (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
<b>PBA-15</b>	Mean	705	647	1059	903	807	732	839	883	871	650
	90% CI	895	679	1307	1053	975	809	993	1102	980	722
		556	617	858	775	667	663	709	707	775	585
<b>PBA-16</b>	Mean	684	838	796	914	661	761	731			
	90% CI	941	1253	963	1241	718	865	807			
		497	560	658	673	608	669	663			
<b>PBA-18</b>	Mean			540	568	452	319				
	90% CI			692	685	531	364				
				422	470	385	279				
<b>PBA-19</b>	Mean			962	640	614	881				
	90% CI			1490	861	676	1164				
				621	477	557	666				
<b>PBA-20</b>	Mean			599	566	525	604				
	90% CI			752	739	664	865				
				476	433	416	421				
<b>PBA-21</b>	Mean			573	614	568	480				
	90% CI			792	716	673	579				
				415	526	480	399				
<b>WMO-3</b>	Mean		613	823	675	680		914	858	561	407
	90% CI		776	1115	793	851		1111	1063	711	569
				484	607	575	543		751	692	442
<b>WMO-5</b>	Mean		787	799	947	825	630	786	770	701	684
	90% CI		1202	1110	1203	1228	740	837	868	785	803
				515	575	745	554	536	737	683	626
<b>WMO-6</b>	Mean		1016	848	837	747		972	1109	732	608
	90% CI		1534	1062	1150	998		1333	1179	791	698
				672	678	609	558		709	1042	678
<b>WMO-10</b>	Mean		907	878	1419	970		787	635	666	518
	90% CI		1468	1010	2222	1278		935	677	707	555
				561	764	906	737		663	595	627
<b>WMO-2</b>	Mean		483	775	568	515					
	90% CI		599	1067	670	650					
				389	563	481	408				
<b>WMO-4</b>	Mean		695	847	780	692					
	90% CI		1015	1101	984	913					
				476	651	618	524				
<b>WMO-7</b>	Mean		973	764	748	583					
	90% CI		1463	999	992	642					
				647	584	564	529				
<b>WMO-8</b>	Mean		821	978	794	659					
	90% CI		1236	1198	1014	906					
				545	799	622	479				
<b>WMO-9</b>	Mean		841	865	785	907	756				
	90% CI		1060	1099	937	1120	1106				
				668	681	658	734	517			
<b>WMO-12</b>	Mean		665	652	596	575					
	90% CI		943	925	648	766					
				470	459	549	431				

		Total Pigments (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	5.4	3.9	4.4	2.1	3.6	3.1	1.6			
	90% CI	6.4	4.4	5.1	3.0	5.1	3.7	2.2			
PBA-2	Mean	5.5	4.2	5.3	2.8	4.1					
	90% CI	6.6	5.2	6.5	4.2	5.6					
PBA-3	Mean	5.8	7.0	9.0	8.4	12.4	9.0	7.3	9.2	5.3	7.6
	90% CI	7.1	8.6	11.4	9.8	16.5	11.4	10.0	11.8	6.3	11.4
CM-13	Mean	6.0	5.3	6.5	4.0	6.9	5.4	4.5	5.4	3.7	5.2
	90% CI	7.2	5.7	8.2	4.9	9.1	7.0	5.6	6.2	4.5	8.1
CM-14	Mean	9.6	5.4	6.1	4.7	5.9	5.7				
	90% CI	14.9	6.9	7.7	6.2	7.7	10.0				
PBA-4	Mean	5.7	5.5	8.2	5.1	6.1	5.3	5.7	5.4	3.2	5.4
	90% CI	6.5	6.8	10.2	6.4	7.3	6.3	7.1	6.7	4.2	10.6
PBA-5	Mean	8.8	9.8	7.3	8.0	9.1	6.6	7.7	10.6	22.1	14.1
	90% CI	13.1	16.3	11.9	15.1	11.8	11.2	21.0	52.3	38.5	42.1
PBA-5A	Mean			20.5	9.2	11.5	9.1	11.6	30.0	18.7	16.6
	90% CI			34.7	17.1	25.4	15.7	24.6	111.8	25.6	33.8
PBA-6	Mean	8.5	7.7	8.5	6.0	7.4	8.5				
	90% CI	12.6	12.0	10.0	8.1	9.8	10.0				
PBA-7	Mean	5.8	5.3	7.1	4.1	6.0	6.5				
	90% CI	7.1	7.3	8.3	4.8	8.5	8.4				
PBA-8	Mean	4.8	6.1	6.2	4.1	5.7	5.6	4.9	4.2	3.2	3.9
	90% CI	6.0	7.5	7.6	5.0	7.1	6.6	6.0	5.5	3.9	6.1
PBA-9	Mean	7.5	10.9	11.5	8.2	9.1	11.8	9.3	10.0	8.5	8.5
	90% CI	11.1	14.8	13.0	10.2	11.5	14.8	12.1	12.7	11.0	14.5
PBA-10	Mean	6.3	6.8	7.1	5.3	7.1	6.0	6.6	5.7	6.3	4.7
	90% CI	9.8	9.9	9.2	6.2	9.0	7.8	7.8	6.7	11.5	7.7
PBA-11	Mean	6.6	8.7	6.8	9.9	10.3	8.9	11.7	4.6	4.0	5.2
	90% CI	11.5	15.5	8.6	17.6	17.8	13.8	22.3	7.7	7.8	9.9
PBA-12	Mean	3.6	4.2	4.9	3.8	4.2	4.6	3.7	2.9	1.9	2.9
	90% CI	4.9	6.0	6.3	5.1	5.3	5.8	5.7	3.5	2.6	5.8
PBA-13	Mean	4.2	4.1	4.8	4.2	4.7	5.8	4.5	4.0	2.1	4.2
	90% CI	6.1	5.3	6.0	6.4	6.2	7.7	6.2	5.6	2.7	5.6
PBA-14	Mean	6.5	9.8	9.6	10.1	16.5	12.4	10.0			
	90% CI	10.1	13.4	12.5	12.6	21.3	16.8	14.5			
		4.2	7.2	7.4	8.1	12.7	9.2	6.9			

		Total Pigments (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-15	Mean	6.2	6.8	7.0	6.5	10.0	9.5	9.3	10.2	5.4	6.3
	90% CI	9.7	9.3	8.9	8.4	13.3	12.8	12.5	16.1	6.9	9.5
		3.9	5.0	5.4	5.1	7.5	7.1	6.9	6.5	4.3	4.2
PBA-16	Mean	4.9	7.7	5.9	6.2	8.3	9.6	10.4			
	90% CI	7.8	10.8	8.1	9.6	11.2	14.8	16.9			
		3.1	5.5	4.3	4.0	6.2	6.3	6.5			
PBA-18	Mean			6.6	2.9	5.1	4.3				
	90% CI			7.5	4.1	7.0	5.1				
				5.9	2.1	3.7	3.6				
PBA-19	Mean			5.0	3.6	2.7	3.8				
	90% CI			5.5	5.0	5.6	4.9				
				4.5	2.6	1.3	3.0				
PBA-20	Mean			7.2	3.8	5.4	5.5				
	90% CI			8.2	4.7	7.5	6.0				
				6.3	3.0	3.9	5.0				
PBA-21	Mean			5.0	3.3	3.5	4.1				
	90% CI			5.7	4.1	4.3	4.9				
				4.3	2.7	2.8	3.4				
WMO-3	Mean		3.9	4.1	3.9	3.9		4.5	3.1	2.8	2.8
	90% CI		6.6	5.7	5.7	6.3		6.7	5.3	5.5	6.7
				2.3	2.9	2.7	2.5		3.1	1.8	1.5
WMO-5	Mean		3.6	4.7	4.0	4.7	5.7	6.9	6.7	6.1	3.5
	90% CI		5.0	8.6	4.8	8.3	7.9	10.1	9.1	10.7	6.5
				2.6	2.6	3.3	2.6	4.2	4.7	5.0	3.4
WMO-6	Mean		5.1	4.7	6.1	10.1		9.5	13.9	6.8	4.8
	90% CI		7.1	7.6	10.3	14.1		15.8	29.6	16.1	11.6
				3.7	2.9	3.6	7.1		5.7	6.5	2.9
WMO-10	Mean		6.6	4.8	6.9	10.5		11.2	10.9	6.2	4.0
	90% CI		11.5	6.4	11.2	17.9		14.4	17.9	8.8	5.9
				3.8	3.7	4.3	6.2		8.8	6.6	4.3
WMO-2	Mean		7.1	5.4	5.4	7.4					
	90% CI		10.2	6.0	6.5	12.9					
				5.0	4.9	4.5	4.3				
WMO-4	Mean		4.9	4.7	5.3	4.5					
	90% CI		10.7	6.0	10.0	10.3					
				2.3	3.6	2.9	1.9				
WMO-7	Mean		4.5	4.2	4.9	5.8					
	90% CI		8.0	6.4	8.0	8.5					
				2.5	2.7	3.0	4.0				
WMO-8	Mean		4.7	3.3	4.0	6.3					
	90% CI		7.6	6.9	7.0	9.1					
				2.9	1.5	2.3	4.3				
WMO-9	Mean		5.2	3.8	5.3	7.6	9.6				
	90% CI		7.3	10.4	7.2	9.4	14.1				
				3.6	1.4	3.9	6.2	6.5			
WMO-12	Mean		5.9	6.2	4.2	3.9					
	90% CI		9.6	12.0	5.2	5.8					
				3.7	3.2	3.3	2.6				

		Bioactive Nitrogen ( $\mu\text{g/L}$ )									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	133	92	124	98	91	84	72			
	90% CI	148	104	134	116	106	93	81			
		119	81	115	83	79	77	64			
PBA-2	Mean	151	106	134	106	101					
	90% CI	180	121	174	127	115					
		126	93	103	88	88					
PBA-3	Mean	190	174	251	290	331	256	227	272	225	241
	90% CI	219	212	282	386	410	311	308	407	277	374
		165	143	222	217	267	211	167	182	183	155
CM-13	Mean	166	137	189	163	164	122	125	141	155	141
	90% CI	185	149	205	192	179	150	155	162	177	158
		148	127	174	139	149	99	100	122	137	126
CM-14	Mean	367	244	273	294	270	227				
	90% CI	457	497	376	455	384	411				
		295	120	197	190	190	126				
PBA-4	Mean	217	190	226	219	191	159	171	161	129	176
	90% CI	263	275	261	264	231	187	241	192	142	263
		180	131	195	182	158	136	122	134	117	117
PBA-5	Mean	225	232	238	270	234	221	403	325	276	265
	90% CI	311	295	317	362	319	259	559	471	410	616
		163	183	178	202	172	189	291	225	185	114
PBA-5A	Mean			531	617	576	824	591	795	702	674
	90% CI			1156	823	754	1300	751	1179	883	872
				244	462	441	522	465	536	558	520
PBA-6	Mean	221	198	214	181	158	175				
	90% CI	313	263	241	221	176	194				
		156	150	190	148	142	159				
PBA-7	Mean	179	141	172	149	146	147				
	90% CI	214	173	207	177	171	197				
		149	115	142	126	125	109				
PBA-8	Mean	169	135	191	164	132	138	147	114	114	127
	90% CI	208	160	235	205	147	169	194	132	142	187
		137	114	155	131	119	113	112	98	91	87
PBA-9	Mean	254	236	286	247	216	214	252	204	231	180
	90% CI	325	302	338	276	229	239	285	226	272	233
		198	185	243	221	203	191	223	183	197	140
PBA-10	Mean	171	162	186	208	179	161	174	150	210	150
	90% CI	229	198	205	238	202	190	203	182	252	173
		127	133	170	182	159	137	150	124	175	130
PBA-11	Mean	192	248	237	356	251	211	262	142	119	164
	90% CI	254	405	288	608	349	287	482	180	155	259
		146	152	196	208	181	155	143	112	91	104
PBA-12	Mean	254	126	198	183	168	135	128	170	115	134
	90% CI	364	143	242	226	181	154	163	212	130	167
		177	110	162	148	157	119	101	136	102	107
PBA-13	Mean	170	135	193	206	168	147	155	170	134	135
	90% CI	212	156	218	244	184	162	186	207	167	158
		137	117	170	174	152	134	129	139	108	116
PBA-14	Mean	305	255	328	290	334	313	325			
	90% CI	390	305	399	337	363	350	430			
		239	213	270	250	307	281	246			

		Bioactive Nitrogen ( $\mu\text{g/L}$ )									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-15	Mean	272	190	348	320	335	302	294	274	312	201
	90% CI	372	205	460	404	411	337	370	329	345	221
		199	177	263	253	274	271	233	228	282	183
PBA-16	Mean	300	350	340	460	288	345	291			
	90% CI	387	646	465	716	315	428	374			
		233	189	248	296	263	279	226			
PBA-18	Mean			158	108	122	101				
	90% CI			180	128	138	114				
				138	91	109	90				
PBA-19	Mean			200	109	141	188				
	90% CI			321	133	176	288				
				125	90	113	123				
PBA-20	Mean			194	128	120	118				
	90% CI			232	142	145	134				
				163	116	98	104				
PBA-21	Mean			165	149	116	109				
	90% CI			192	173	133	125				
				142	128	101	95				
WMO-3	Mean		163	193	185	158		146	157	116	103
	90% CI		204	224	213	199		187	184	156	159
				130	166	162	125		114	134	86
WMO-5	Mean		240	262	345	248	235	235	231	214	245
	90% CI		401	433	495	371	340	331	326	253	395
				144	158	240	166	163	167	164	182
WMO-6	Mean		342	242	277	305		293	307	212	209
	90% CI		491	322	358	389		412	411	271	267
				238	182	214	240		208	229	166
WMO-10	Mean		213	241	308	322		289	281	263	200
	90% CI		260	295	431	414		340	309	293	225
				175	198	221	251		246	255	236
WMO-2	Mean		150	200	177	147					
	90% CI		182	227	211	168					
				123	177	148	128				
WMO-4	Mean		212	270	257	198					
	90% CI		303	327	315	264					
				148	223	210	148				
WMO-7	Mean		285	216	218	206					
	90% CI		431	333	230	242					
				188	140	207	175				
WMO-8	Mean		203	210	242	212					
	90% CI		270	278	317	256					
				153	159	185	175				
WMO-9	Mean		200	237	237	287	240				
	90% CI		310	337	268	336	321				
				129	167	209	244	180			
WMO-12	Mean		206	185	206	196					
	90% CI		276	277	248	243					
				153	123	171	159				

		Dissolved Inorganic Nitrogen ( $\mu\text{g/L}$ )									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	19	12	20	20	12	20	29			
	90% CI	27	21	25	39	22	31	47			
PBA-2	Mean	37	15	26	35	23					
	90% CI	61	30	36	46	43					
PBA-3	Mean	39	35	40	67	111	51	92	101	102	92
	90% CI	60	49	61	120	175	100	166	191	158	287
CM-13	Mean	32	19	25	32	36	23	39	53	68	58
	90% CI	45	25	33	69	48	34	57	60	89	67
CM-14	Mean	124	91	112	151	131	123				
	90% CI	230	325	206	331	203	263				
PBA-4	Mean	70	40	58	80	80	57	73	67	43	52
	90% CI	115	83	82	138	112	75	131	103	60	89
PBA-5	Mean	30	12	51	25	64	64	252	81	30	73
	90% CI	56	24	147	148	105	165	498	527	135	667
PBA-5A	Mean			156	328	313	544	370	149	351	462
	90% CI			525	718	512	1139	503	740	556	735
PBA-6	Mean	23	27	22	39	18	22				
	90% CI	45	54	38	64	30	31				
PBA-7	Mean	41	15	22	34	20	20				
	90% CI	74	32	29	56	33	37				
PBA-8	Mean	41	11	20	34	20	18	45	29	17	27
	90% CI	48	17	25	55	32	25	69	43	30	33
PBA-9	Mean	46	27	29	51	63	24	88	54	28	51
	90% CI	61	39	46	77	83	36	135	84	66	60
PBA-10	Mean	21	23	30	52	41	37	50	53	34	34
	90% CI	37	37	38	68	61	53	77	85	55	58
PBA-11	Mean	42	46	50	35	43	33	75	68	28	33
	90% CI	71	76	84	85	58	48	171	107	46	52
PBA-12	Mean	107	35	74	97	74	45	53	87	43	40
	90% CI	226	51	111	133	97	53	76	118	50	51
PBA-13	Mean	72	43	76	73	76	43	77	95	73	63
	90% CI	111	67	103	111	102	72	99	137	97	82
PBA-14	Mean	126	88	98	76	99	88	150			
	90% CI	160	116	158	130	127	136	220			
		99	66	60	45	77	57	103			

		Dissolved Inorganic Nitrogen ( $\mu\text{g/L}$ )									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-15	Mean	104	69	124	125	141	126	91	121	185	94
	90% CI	137	93	189	213	177	162	173	161	231	126
PBA-16	Mean	79	51	81	73	113	98	47	92	148	70
	90% CI	222	385	295	515	179	199	285			
PBA-18	Mean	103	41	55	97	48	47	40			
	90% CI			18	26	13	20				
PBA-19	Mean			22	37	18	26				
	90% CI			15	19	9	15				
PBA-20	Mean			37	13	47	101				
	90% CI			90	43	78	198				
PBA-21	Mean			15	4	28	52				
	90% CI			31	31	17	24				
WMO-3	Mean			59	47	29	31				
	90% CI			16	20	9	19				
WMO-5	Mean			44	53	39	31				
	90% CI			66	70	50	39				
WMO-6	Mean			30	40	30	24				
	90% CI			44	71	68	62		77	95	55
WMO-10	Mean		44	71	68	62		77	95	55	44
	90% CI		63	124	96	92		126	125	81	80
WMO-2	Mean		31	40	48	42		48	71	37	24
	90% CI		79	136	173	132	112	122	128	105	135
WMO-4	Mean		137	319	260	168	220	214	222	140	199
	90% CI		46	58	115	103	57	70	74	79	92
WMO-7	Mean		205	112	83	109		160	124	103	83
	90% CI		380	184	153	142		234	319	127	183
WMO-8	Mean		110	69	44	83		110	48	83	38
	90% CI		69	95	143	125		119	125	151	101
WMO-9	Mean		195	159	241	239		197	227	167	124
	90% CI		25	56	84	65		71	68	137	82
WMO-12	Mean		15	20	45	32					
	90% CI		28	40	78	56					
WMO-1	Mean		8	10	26	18					
	90% CI		63	132	106	101					
WMO-11	Mean		97	197	201	138					
	90% CI		41	88	56	73					
WMO-13	Mean		153	103	84	93					
	90% CI		337	191	132	118					
WMO-14	Mean		70	55	53	73					
	90% CI		64	111	127	98					
WMO-15	Mean		188	180	228	131					
	90% CI		22	68	71	74					
WMO-16	Mean		115	114	130	146	77				
	90% CI		136	233	207	199	152				
WMO-17	Mean		97	56	81	107	38				
	90% CI		46	43	72	89					
WMO-18	Mean		89	120	126	124					
	90% CI		23	16	41	64					

		Phosphate (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	17	15	13	15	14	9	17			
	90% CI	20	20	17	21	18	13	22			
PBA-2	Mean	24	27	24	24	26					
	90% CI	34	43	39	34	46					
PBA-3	Mean	32	38	25	29	24	30	44	32	34	27
	90% CI	43	47	34	40	38	47	72	42	41	37
CM-13	Mean	25	30	23	24	25	30	48	34	31	30
	90% CI	33	40	29	29	36	44	61	38	38	39
CM-14	Mean	40	67	38	41	42	46				
	90% CI	55	262	50	52	69	86				
PBA-4	Mean	25	33	21	25	27	30	38	34	25	22
	90% CI	32	45	28	33	37	39	55	39	29	26
PBA-5	Mean	30	17	30	16	27	27	62	38	27	28
	90% CI	39	39	55	71	54	49	98	77	226	37
PBA-5A	Mean			41	29	41	15	20	22	26	57
	90% CI			86	55	62	32	45	40	48	73
PBA-6	Mean	30	40	26	31	27	20				
	90% CI	40	64	31	42	31	33				
PBA-7	Mean	31	32	25	31	27	25				
	90% CI	40	46	28	38	32	38				
PBA-8	Mean	31	31	23	30	26	28	48	24	17	20
	90% CI	36	47	28	36	34	36	59	28	21	22
PBA-9	Mean	26	34	27	29	29	20	46	28	23	21
	90% CI	33	45	33	39	35	29	57	34	26	27
PBA-10	Mean	31	42	36	35	35	34	51	31	24	25
	90% CI	37	54	41	44	41	44	64	34	26	30
PBA-11	Mean	49	61	57	76	59	68	109	63	44	44
	90% CI	66	85	65	116	82	86	202	76	51	53
PBA-12	Mean	53	68	55	53	50	57	73	51	38	36
	90% CI	71	93	65	72	76	74	101	57	46	44
PBA-13	Mean	51	79	66	67	74	65	93	69	55	50
	90% CI	71	103	79	98	92	89	114	70	62	59
PBA-14	Mean	63	108	83	91	87	90	126			
	90% CI	83	143	106	126	116	118	166			
		48	82	65	66	65	68	96			

		Phosphate (µg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-15	Mean	61	89	100	89	98	93	132	107	98	77
	90% CI	81	120	127	127	135	119	162	122	110	97
		46	66	79	63	72	73	108	94	87	61
PBA-16	Mean	84	182	104	181	90	111	131			
	90% CI	163	417	148	333	112	165	180			
		43	79	73	98	73	74	95			
PBA-18	Mean			27	22	20	23				
	90% CI			38	29	28	29				
				19	17	14	18				
PBA-19	Mean			22	24	19	18				
	90% CI			26	35	30	29				
				19	17	13	12				
PBA-20	Mean			27	27	24	27				
	90% CI			32	35	33	36				
				23	21	18	20				
PBA-21	Mean			39	34	41	40				
	90% CI			43	50	48	53				
				35	24	35	30				
WMO-3	Mean		69	85	62	43		99	69	61	49
	90% CI		89	99	97	78		128	89	78	81
				54	73	39	24		76	53	48
WMO-5	Mean		118	112	138	119	126	167	168	167	162
	90% CI		176	144	256	178	184	246	223	200	211
				79	87	75	79	86	113	126	140
WMO-6	Mean		89	77	89	84		123	102	81	75
	90% CI		121	110	165	142		172	117	106	111
				65	53	48	50		89	89	62
WMO-10	Mean		64	78	91	87		132	103	93	66
	90% CI		137	102	167	130		155	113	106	87
				30	60	49	58		112	94	82
WMO-2	Mean		26	29	33	26					
	90% CI		34	35	41	35					
				21	25	27	19				
WMO-4	Mean		97	86	102	96					
	90% CI		130	120	193	157					
				73	62	54	58				
WMO-7	Mean		73	79	88	74					
	90% CI		139	125	147	129					
				38	49	52	42				
WMO-8	Mean		79	72	74	77					
	90% CI		127	110	141	132					
				50	48	39	45				
WMO-9	Mean		69	76	81	86	85				
	90% CI		148	116	153	136	145				
				33	50	43	55	50			
WMO-12	Mean		51	48	43	53					
	90% CI		64	58	56	70					
				41	39	32	40				

		Dissolved Oxygen (mg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	Mean	6.4	8.1	7.8	8.7	8.0	9.0	7.7			
	90% CI	6.7	8.4	8.2	9.2	8.5	9.3	7.9			
PBA-2	Mean	6.8	6.6	6.3	7.7	6.4					
	90% CI	7.2	7.1	6.7	11.1	7.8					
PBA-3	Mean	6.0	6.5	5.6	6.4	5.9	5.8	6.1	5.4	5.0	4.1
	90% CI	6.6	7.0	6.3	7.2	6.4	6.8	7.5	6.1	5.6	5.5
CM-13	Mean	6.5	6.8	6.4	6.4	6.3	6.0	6.3	5.7	4.2	4.7
	90% CI	7.1	7.3	6.8	7.1	6.6	6.4	6.8	6.1	4.6	5.0
CM-14	Mean	5.5	5.1	5.3	5.7	5.8	7.2				
	90% CI	6.5	6.1	5.7	6.0	7.7	12.3				
PBA-4	Mean	6.6	7.9	6.6	6.7	6.5	6.2	6.3	5.8	5.4	5.5
	90% CI	7.5	8.8	7.9	7.2	7.0	6.8	6.7	6.2	5.8	5.7
PBA-5	Mean	6.5	5.9	5.8	6.8	6.2	3.8	5.0	6.1	4.8	5.7
	90% CI	7.3	6.9	6.5	8.1	7.3	5.4	6.6	11.6	6.0	8.1
PBA-5A	Mean			4.8	8.0	6.2	7.4	4.9	7.7	6.2	5.6
	90% CI			6.8	13.3	7.7	9.1	7.2	10.8	9.2	7.6
PBA-6	Mean	6.3	5.4	5.5	5.6	6.1	5.9				
	90% CI	7.0	6.5	6.2	7.0	6.9	6.6				
PBA-7	Mean	6.8	6.5	7.4	6.3	6.5	5.7				
	90% CI	7.3	7.5	8.1	6.8	6.9	6.7				
PBA-8	Mean	5.4	6.6	7.0	7.6	6.8	6.7	7.2	6.1	6.7	5.6
	90% CI	6.7	7.2	7.5	8.2	7.2	7.4	7.9	6.7	8.0	6.0
PBA-9	Mean	6.2	7.0	6.2	7.0	7.0	5.9	5.5	6.7	4.7	5.2
	90% CI	7.4	7.5	6.7	7.6	7.4	6.4	6.4	7.3	5.1	5.4
PBA-10	Mean	5.9	5.4	5.4	5.9	6.0	5.3	5.2	5.5	4.1	3.7
	90% CI	6.6	5.8	5.6	6.3	6.3	5.8	5.6	5.8	4.5	4.7
PBA-11	Mean	5.2	4.6	4.1	5.2	4.7	4.6	4.6	5.2	4.1	3.7
	90% CI	6.1	5.7	5.1	7.4	6.1	5.6	5.7	5.9	4.3	4.6
PBA-12	Mean	5.9	5.1	5.0	5.6	5.9	5.0	5.4	5.6	4.7	4.9
	90% CI	6.7	5.5	5.5	6.0	6.2	5.5	6.0	6.3	5.1	5.3
PBA-13	Mean	5.4	5.0	4.5	5.5	5.1	5.0	5.5	6.0	4.6	4.8
	90% CI	6.1	5.3	4.8	6.2	5.4	5.8	5.8	6.5	4.9	5.1
PBA-14	Mean	4.5	4.8	4.2	5.2	4.8	4.7	3.6			
	90% CI	5.5	5.4	4.8	6.2	5.5	5.5	4.3			
		3.5	4.2	3.5	4.1	4.0	4.0	2.8			

		Dissolved Oxygen (mg/L)									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-15	Mean	5.5	4.7	4.7	5.0	4.5	4.7	4.8	5.5	4.9	3.6
	90% CI	6.1	5.2	5.1	5.7	5.0	5.3	5.5	6.6	5.7	4.3
		4.8	4.3	4.3	4.2	4.1	4.1	4.2	4.4	4.1	3.0
PBA-16	Mean	5.1	4.3	5.5	3.9	4.1	3.3	5.1			
	90% CI	6.5	6.1	6.4	5.6	4.9	4.7	6.3			
		3.8	2.5	4.5	2.2	3.3	1.9	3.9			
PBA-18	Mean			6.6	6.6	6.4	6.4				
	90% CI			6.8	6.8	6.6	6.9				
				6.4	6.3	6.3	5.9				
PBA-19	Mean			7.3	7.9	7.4	7.8				
	90% CI			7.7	8.6	7.8	8.9				
				6.9	7.3	7.0	6.7				
PBA-20	Mean			6.7	6.3	6.7	6.5				
	90% CI			7.0	6.6	7.0	6.9				
				6.5	6.0	6.5	6.1				
PBA-21	Mean			5.5	5.4	6.0	5.6				
	90% CI			6.0	6.5	6.2	6.0				
				5.0	4.3	5.8	5.3				
WMO-3	Mean		6.2	4.9	7.2	6.4		5.2	4.9	4.1	4.0
	90% CI		6.9	6.0	8.6	6.8		6.1	6.1	4.7	5.2
				5.6	3.9	5.8	6.1		4.3	3.7	3.6
WMO-5	Mean		4.8	4.8	5.8	5.4	4.1	4.1	3.0	2.2	2.4
	90% CI		5.2	5.5	6.5	6.3	5.3	5.5	4.4	2.7	3.5
				4.4	4.0	5.0	4.5	2.9	2.8	1.7	1.7
WMO-6	Mean		5.1	4.6	5.7	5.8		4.7	4.6	3.7	4.5
	90% CI		5.4	4.9	6.6	6.4		5.4	6.4	4.4	5.8
				4.7	4.3	4.7	5.2		3.9	2.7	3.0
WMO-10	Mean					7.3		4.3	4.3	3.5	4.1
	90% CI					7.4		4.7	5.0	3.8	4.5
						7.2		3.8	3.6	3.2	3.8
WMO-2	Mean		8.2	6.7	7.4	7.2					
	90% CI		8.7	7.9	8.6	8.3					
				7.7	5.4	6.2	6.0				
WMO-4	Mean		5.2	5.2	6.3	5.4					
	90% CI		5.6	5.8	6.8	6.6					
				4.9	4.6	5.7	4.3				
WMO-7	Mean		5.3	4.8	6.0	6.0					
	90% CI		5.6	5.2	6.6	6.4					
				5.0	4.5	5.4	5.6				
WMO-8	Mean		5.7	5.8	6.8	6.0					
	90% CI		5.9	6.6	8.0	6.4					
				5.4	5.1	5.6	5.7				
WMO-9	Mean		5.0	5.1	6.0	5.2	5.5				
	90% CI		5.4	5.9	7.2	5.5	7.2				
				4.7	4.2	4.7	4.9	3.8			
WMO-12	Mean		5.3	5.8	5.6	5.5					
	90% CI		5.5	6.5	6.3	6.7					
				5.2	5.2	4.8	4.3				

## Appendix F. Exceedances of Targets and Thresholds

The bioactive nitrogen modeled restoration values were established by the Massachusetts Estuaries Program (MEP) to support the development of the 2007 TMDL (Howes, Samimy, Schlezinger, Kelley, Ramsey, & Eichner, 2006). The dissolved oxygen target is the Massachusetts water quality standard for coastal waters. The total pigments target is the guidance value established by the National Oceanic and Atmospheric Administration (NOAA).

Station ID	MEP Modeled Restoration Value (mg/L) <sup>2</sup>	Percent of Samples Exceeding MEP Restoration Target for Bioactive Nitrogen									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	0.102	90%	27%	86%	27%	17%	14%	0%			
PBA-2	0.12	90%	13%	86%	20%	0%					
PBA-3	0.19	45%	25%	92%	85%	86%	93%	57%	50%	78%	71%
CM-13	0.138	84%	44%	100%	75%	93%	36%	25%	30%	60%	60%
CM-14	0.173	100%	67%	100%	100%	100%	50%				
PBA-4	0.149	80%	38%	100%	90%	69%	57%	50%	60%	20%	50%
PBA-5	0.208	56%	63%	80%	83%	67%	57%	100%	100%	100%	75%
PBA-5A	0.405			83%	100%	86%	100%	100%	100%	100%	100%
PBA-6	0.169	78%	60%	90%	75%	42%	50%				
PBA-7	0.153	67%	33%	71%	43%	36%	42%				
PBA-8	0.139	78%	50%	79%	71%	43%	29%	33%	13%	22%	30%
PBA-9	0.207	58%	58%	100%	79%	64%	62%	83%	40%	70%	10%
PBA-10		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PBA-11	0.209	33%	36%	57%	75%	50%	43%	58%	0%	13%	30%
PBA-12	0.16	75%	17%	86%	77%	64%	14%	25%	40%	0%	20%
PBA-13	0.172	64%	17%	71%	67%	40%	23%	50%	30%	20%	20%
PBA-14	0.253	58%	42%	85%	79%	100%	93%	83%			
PBA-15	0.208	92%	25%	100%	92%	100%	100%	100%	90%	100%	40%
PBA-16	0.262	75%	33%	69%	85%	69%	71%	50%			
PBA-18	0.112			89%	50%	70%	21%				
PBA-19	0.113			100%	60%	64%	90%				
PBA-20	0.118			100%	67%	64%	29%				
PBA-21	0.148			70%	58%	8%	14%				
WMO-3	0.164		50%	63%	67%	50%		33%	40%	0%	0%
WMO-5	0.211		67%	75%	83%	33%	83%	67%	40%	60%	60%
WMO-6	0.206		100%	67%	100%	100%		83%	100%	40%	40%
WMO-10	0.207		67%	73%	100%	100%		100%	100%	100%	40%
WMO-2	0.147		73%	100%	78%	50%					
WMO-4	0.179		67%	100%	100%	50%					
WMO-7	0.188		83%	67%	100%	80%					
WMO-8	0.182		83%	67%	100%	80%					
WMO-9	0.196		83%	83%	100%	100%	83%				
WMO-12	0.194		50%	33%	67%	83%					

<sup>2</sup> From Table VIII-6 in: Howes, Samimy, Schlezinger, Kelley, Ramsey, & Eichner, 2006.

Station ID	Percent of Samples Not Meeting Dissolved Oxygen Standard of 6 mg/L									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	20%	0%	0%	0%	0%	0%	0%			
PBA-2	20%	13%	29%	20%	20%					
PBA-3	57%	21%	64%	38%	58%	50%	38%	80%	100%	100%
CM-13	35%	6%	29%	33%	29%	42%	42%	70%	100%	100%
CM-14	64%	86%	86%	100%	75%	83%				
PBA-4	40%	13%	21%	17%	21%	33%	20%	70%	75%	100%
PBA-5	36%	38%	50%	33%	20%	83%	80%	67%	80%	50%
PBA-5A			83%	33%	33%	29%	80%	40%	60%	50%
PBA-6	30%	60%	60%	33%	33%	50%				
PBA-7	10%	33%	14%	36%	21%	50%				
PBA-8	50%	9%	7%	7%	13%	21%	17%	10%	50%	80%
PBA-9	25%	8%	42%	7%	14%	38%	75%	25%	100%	100%
PBA-10	58%	83%	100%	64%	64%	79%	92%	100%	100%	100%
PBA-11	58%	91%	93%	67%	83%	79%	75%	100%	100%	90%
PBA-12	58%	83%	86%	71%	50%	86%	75%	80%	100%	100%
PBA-13	67%	100%	100%	60%	90%	71%	83%	60%	100%	100%
PBA-14	75%	92%	100%	79%	86%	86%	100%			
PBA-15	80%	92%	100%	83%	100%	92%	90%	75%	88%	100%
PBA-16	42%	67%	67%	75%	92%	86%	71%			
PBA-18			0%	0%	0%	43%				
PBA-19			0%	0%	0%	0%				
PBA-20			0%	33%	0%	29%				
PBA-21			90%	75%	42%	71%				
WMO-3		50%	75%	38%	20%		83%	100%	100%	100%
WMO-5		100%	100%	50%	67%	100%	83%	100%	100%	100%
WMO-6		100%	100%	67%	53%		100%	75%	100%	100%
WMO-10					0%		100%	100%	100%	100%
WMO-2		0%	8%	17%	14%					
WMO-4		100%	100%	38%	67%					
WMO-7		100%	100%	61%	50%					
WMO-8		69%	67%	33%	61%					
WMO-9		100%	100%	67%	89%	75%				
WMO-12		100%	50%	88%	75%					

Station ID	Percent of Samples Exceeding NOAA Pigment Guidance of 5 µg/L									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PBA-1	55%	6%	29%	17%	17%	7%	0%			
PBA-2	70%	25%	57%	0%	33%					
PBA-3	70%	87%	93%	100%	100%	93%	75%	100%	60%	75%
CM-13	70%	63%	71%	17%	86%	67%	42%	60%	10%	70%
CM-14	90%	71%	71%	57%	71%	50%				
PBA-4	65%	69%	93%	42%	57%	50%	60%	60%	0%	70%
PBA-5	90%	88%	100%	83%	100%	71%	60%	50%	100%	100%
PBA-5A			100%	71%	86%	86%	83%	80%	100%	100%
PBA-6	80%	70%	100%	75%	92%	100%				
PBA-7	58%	36%	86%	31%	50%	75%				
PBA-8	60%	67%	71%	25%	64%	64%	42%	25%	0%	30%
PBA-9	83%	100%	100%	93%	93%	93%	100%	100%	90%	80%
PBA-10	58%	75%	79%	64%	79%	64%	75%	75%	50%	60%
PBA-11	58%	64%	71%	75%	67%	86%	83%	50%	25%	30%
PBA-12	25%	42%	50%	21%	36%	29%	25%	0%	0%	20%
PBA-13	50%	25%	57%	33%	40%	57%	33%	40%	0%	40%
PBA-14	67%	100%	100%	100%	100%	100%	100%			
PBA-15	75%	83%	75%	62%	100%	93%	100%	70%	60%	80%
PBA-16	58%	67%	71%	62%	86%	86%	100%			
PBA-18			100%	20%	60%	21%				
PBA-19			40%	20%	25%	30%				
PBA-20			100%	17%	64%	71%				
PBA-21			40%	0%	17%	21%				
WMO-3		33%	38%	25%	38%		33%	0%	20%	0%
WMO-5		0%	50%	17%	50%	83%	83%	80%	80%	40%
WMO-6		50%	67%	50%	100%		83%	100%	40%	40%
WMO-10		83%	55%	67%	100%		100%	88%	80%	30%
WMO-2		67%	80%	60%	67%					
WMO-4		33%	33%	17%	50%					
WMO-7		67%	33%	50%	67%					
WMO-8		67%	50%	50%	83%					
WMO-9		67%	50%	83%	100%	83%				
WMO-12		50%	67%	17%	33%					