Pleasant Bay Alliance Water Quality Monitoring Program: Statistical Analysis of 2000-2014 Water Quality Monitoring Data

July 2015

Prepared by:

The Cadmus Group, Inc.

Prepared for:

Pleasant Bay Alliance

Table of Contents

Executive Summary

Introduction

Pleasant Bay is an estuarine system located on Cape Cod in the Towns of Orleans, Chatham, Harwich, and Brewster, Massachusetts. The Pleasant Bay Alliance (Alliance) was formed in 1998 to oversee the implementation of a resource management plan for Pleasant Bay developed by the four towns. A key component of the resource management plan has been bay-wide water quality monitoring. Fifteen consecutive years of water quality data have been collected, at the time of this analysis, at sites throughout Pleasant Bay and its sub-embayments. In an effort to better understand these data to guide management planning, the Alliance retained The Cadmus Group, Inc. to update the statistical and trend analysis of monitoring data previously completed in 2010 (The Cadmus Group, 2010) to include results of 2010-2014 sampling.

Methods

Water quality monitoring data from 34 stations in Pleasant Bay over the period 2000 through 2014 were reviewed for analysis of bay-wide trends and station-specific trends. The duration of Pleasant Bay water quality monitoring to date (15 years) and sampling frequency (two times per month during July and August and once in early September) provides a dataset that is well-suited for analysis of long-term trends. Trend analysis was completed for the following parameters:

- Dissolved Inorganic Nitrogen (DIN)
- Total Nitrogen (TN)
- Total Phytopigments
- Salinity
- Bioactive Nitrogen (BioN)
- Phosphate (PO_4)
- Dissolved Oxygen (DO)

Analysis of water quality trends in Pleasant Bay is subject to added complexity because of a major disturbance event that occurred on April 16, 2007, when a large storm created a “break” in the outer barrier beach (Nauset Beach). The formation of this second inlet connecting Pleasant Bay to the Atlantic Ocean has increased the volume of water exchanged with the Atlantic Ocean and thus has the potential to influence water quality in the Bay. Statistical techniques that account for the potential effect of the 2007 break on water quality trends were, therefore, applied for this study.

Most of the water quality parameters included in the trend analysis are related to eutrophication. Eutrophication refers to the enrichment of an ecosystem with nutrients (nitrogen and phosphorus) and the corresponding ecosystem response of nutrient enrichment. Trends in dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, and phosphate concentrations provide information on whether nutrient enrichment in Pleasant Bay has been stable, increased or decreased over time, while trends in total algal phytopigments and dissolved oxygen provide information on ecosystem responses to changes in nutrient levels. Trends in salinity concentrations were also analyzed. Although salinity is not directly related to eutrophication, salinity is an important physical water quality parameter and salinity trends provide information on changes in the relative amount of freshwater versus ocean water in Pleasant Bay.

Trend analysis results provide insight into whether water quality in Pleasant Bay has been stable, improved, or declined with respect to eutrophication[1]. Trends of decreased nutrient concentrations, decreased total phytopigment concentrations, and increased dissolved oxygen concentrations are indicative of improved conditions because they describe a system with lower nutrient enrichment, less algal growth, and higher oxygen levels for aquatic biota (Figure ES- 1). Conversely, trends of increased nutrient concentrations, increased total phytopigment concentrations, and decreased dissolved oxygen concentrations are indicative of worsened conditions and continued eutrophication.

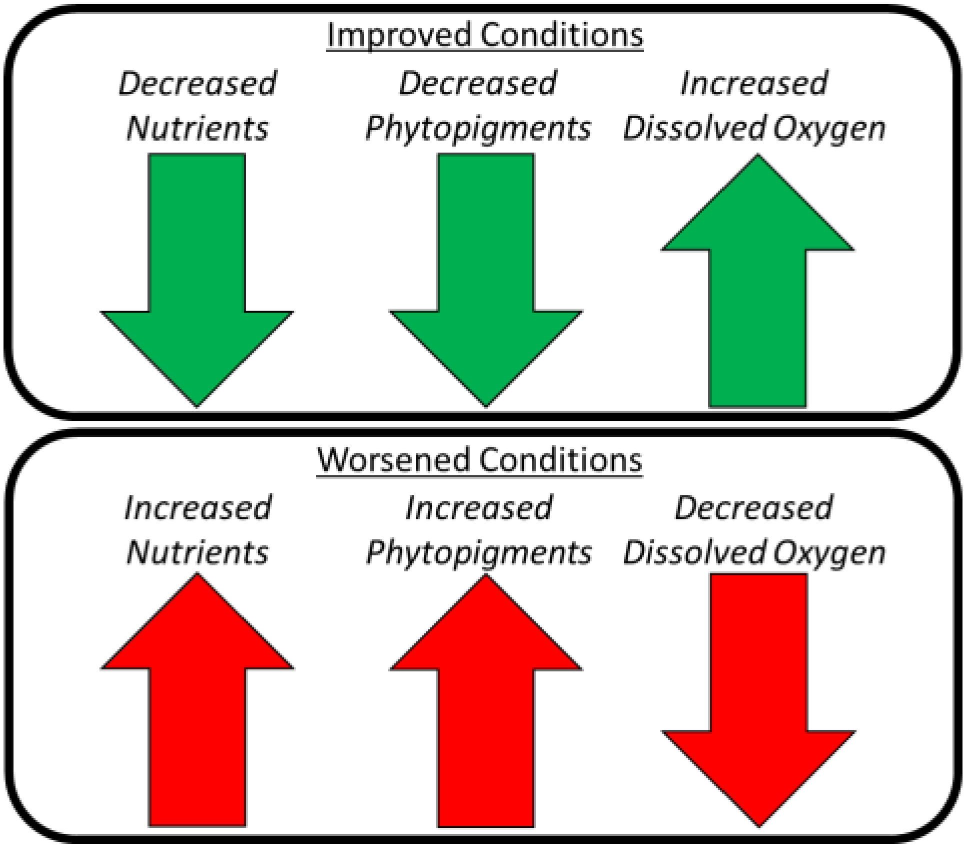


Figure ES- 1. Summary of trends in nutrients (dissolved organic nitrogen, bioactive nitrogen, etc.), total phytopigments, and dissolved oxygen concentrations associated with improved (top) and worsened (bottom) conditions in Pleasant Bay.

[1] While eutrophication-related parameters are important indicators of Pleasant Bay water quality, additional parameters are used to assess overall water quality (pathogens, metals, toxics, etc.). These additional parameters were not analyzed as part of this study.

Station-Specific Results

Twenty Pleasant Bay water quality monitoring stations had sufficient data for station-specific trend analysis (fourteen stations had large data gaps that preclude meaningful analysis of trends). Station-specific trend analysis involved fitting individual trendlines to sample data for each water quality parameter at each monitoring station and determining the statistical significance of trendlines. Statistical significance is based on the estimated likelihood that the trendline slope is due to random variation in sample data instead of a true change over time. A significance level of 5% was used for this study, which corresponds to a 5% likelihood of mischaracterizing a trendline as statistically significant even though no true trend exists. Results of "no statistically significant trend" do not necessarily mean that the water quality parameter did not change over the study period. Trends may not be detected as statistically significant because of insufficient sample data. Trend analysis results are summarized for each station-parameter pair in Table ES- 1.

Station-specific trend analysis results demonstrate that Pleasant Bay is a highly variable and complex system. Varied conditions throughout the Bay are reflected in differences in the direction and presence of trends among monitoring stations for each water quality parameter. None of the seven parameters analyzed have consistent trends across all twenty monitoring stations. Total nitrogen trends, for example, are increasing at four stations, decreasing at nine stations, and are not statistically different at seven stations over the period studied.

The complexity of water quality relationships in Pleasant Bay is reflected in the lack of consistent trends between parameters at a given station. None of the twenty stations included in trend analysis show improvements across all six eutrophication-related parameters and none show worsened conditions across all six parameters. Seven stations (Big Bay-SW, Paw Wah Pond, Namequoit-South, Meetinghouse Pond, Pochet Mouth, Namequoit River Mid, and River at Rattles Dock) have improving trends in bioactive nitrogen and/or total nitrogen, no significant trend or an improving trend in phosphate, and improving total phytopigment trends. Three of these seven also have trends of improved dissolved oxygen concentrations (Big Bay-SW, Namequoit-South, and River at Rattles Dock). Of the twenty stations included in trend analysis, these seven have results that are most in line with improvements in nutrient enrichment and ecosystem responses. However, the lack of dissolved inorganic nitrogen trends and consistent dissolved oxygen improvements preclude definitive statements on an overall decline in eutrophication at these stations. One station (Little Quanset Pond) has trends of increasing dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen concentrations and decreasing dissolved oxygen. While these trends are consistent with continued nutrient enrichment and declining ecosystem conditions, no significant trend was found for phosphate and total phytopigments at Little Quanset Pond.

Results for the remaining twelve stations (Outer Ryder's Cove, Inner Ryders Cove, Crow's Pond, Muddy Creek, Muddy Creek-Upper, Big Bay-NE, Round Cove, Quanset Pond, Namequoit-North, Arey's Pond, Kescayogansett Pond, and Pochet Upper) are more variable between parameters. Most show improved total phytopigment concentrations (i.e. decreased levels) but increasing concentrations of at least one nitrogen parameter. For example, Quanset Pond (PBA-10) has trends of increased dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen but decreased total phytopigment concentrations and no significant trend in dissolved oxygen. Such inconsistencies illustrate the potential influence of factors, in addition to nutrient levels, on algal growth and dissolved oxygen concentrations (e.g., pH, light, water clarity, or tidal flushing).

Table ES- 1. Results of station-specific trend analysis. The direction of statistically significant trends is indicated by the arrow direction (▲, ▲, ▲ = increase; ▼, ▼, ▼ = decrease). Arrow colors describe whether the trend is associated with improved or worsened conditions (green = improved; red = worsened). Station-parameter pairs with no significant trend are symbolized with a black square (■). Salinity trends are not associated with improved or worsened conditions because they are not directly related to eutrophication.

Station	DIN	BioN	TN	PO4	Pigment	DO	Salinity
Outer Ryder's Cove (CM-13)	▲	■	▲	▲	▼	▲	■
Inner Ryders Cove (PBA-3)	▲	■	■	■	▼	▲	▲
Crow's Pond (PBA-4)	■	▼	▼	▲	▼	▲	▲
Muddy Creek (PBA-5)	▲	■	■	■	■	■	▲
Muddy Creek-Upper (PBA-5A)	▼	■	■	■	▲	■	▲
Big Bay-SW (PBA-6)	■	■	▼	▼	▼	▲	▲
Big Bay-NE (PBA-8)	▲	■	▲	▼	▼	■	■
Round Cove (PBA-9)	▲	▼	▼	■	▼	▼	■
Quanset Pond (PBA-10)	▲	▲	▲	▼	▼	■	■
Paw Wah Pond (PBA-11)	■	▼	▼	■	▼	■	▲
Namequoit-South (PBA-12)	■	▼	▼	▼	▼	▲	▲
Namequoit-North (PBA-13)	▲	■	■	■	▼	■	■
Arey's Pond (PBA-14)	■	■	■	■	▼	▼	■
Kescayogansett Pond (PBA-15)	■	▼	▼	▲	▼	■	■
Meetinghouse Pond (PBA-16)	■	▼	■	■	▼	■	■
Pochet Mouth (WMO-3)	■	▼	▼	■	▼	■	■
Pochet Upper (WMO-5)	■	■	■	▲	▼	▲	■
Namequoit River Mid (WMO-6)	■	▼	▼	■	▼	■	■
River at Rattles Dock (WMO-10)	■	▼	▼	■	▼	▲	▲
Little Quanset Pond (WMO-12)	▲	▲	▲	■	■	▼	▲

DIN = Dissolved Inorganic Nitrogen, BioN = Bioactive Nitrogen; TN = Total Nitrogen
PO4 = Phosphate; Pigment = Total Phytopigments; DO = Dissolved Oxygen

Bay-Wide Results

Bay-wide trend analysis involved pooling sample data from all 34 Pleasant Bay monitoring stations and fitting a trendline for each water quality parameter. All seven water quality parameters tested demonstrated statistically significant trends. Trends for six of the seven parameters (the exception was salinity) were best characterized with a trendline that changed following the 2007 Nauset Beach break. Bay-wide trend results are summarized below and in Table ES- 2.

- *Dissolved Inorganic Nitrogen*: Concentrations of dissolved inorganic nitrogen show a significant increasing trend from 2000 to the 2007 Nauset Beach break. The increasing trend has continued after the break.
- *Bioactive Nitrogen*: Bioactive nitrogen concentrations show a significant decreasing trend from 2000 to the 2007 Nauset Beach break. Since the break, bioactive nitrogen concentrations are increasing (i.e., the pre-break trend has reversed).
- *Total Nitrogen*: Concentrations of total nitrogen show a significant decreasing trend from 2000 to the 2007 Nauset Beach break. Since the break, there is no significant trend in total nitrogen concentrations.
- *Phosphate*: Concentrations of phosphate show a significant increasing trend from 2000 to the 2007 Nauset Beach break. Since the break, there is no significant trend in phosphate concentrations.
- *Total Phytopigments*: Total phytopigment concentrations show no significant trend from 2000 to the 2007 Nauset Beach break. Since the break, total phytopigment concentrations have been decreasing.
- *Dissolved Oxygen*: No significant trend in dissolved oxygen concentrations is apparent from 2000 to the 2007 Nauset Beach break. Since the break, dissolved oxygen concentrations have been increasing.
- *Salinity*: The salinity trend was best characterized as a "step-change" type trend, with a statistically significant increase in salinity concentrations after the 2007 break relative to pre-break concentrations.

Table ES- 2. Results of bay-wide trend analysis. The direction of statistically significant trends is indicated by the arrow direction (▲, ▲, ▲ = increase; ▼, ▼, ▼ = decrease). Arrow colors are used to convey whether the trend is associated with improved or worsened conditions (green = improved; red = worsened). Station-parameter pairs with no significant trend are symbolized with a black square (■). The salinity trend was characterized as a step-change type trend, with a statistically significant increase in salinity concentrations after the 2007 break, and is not associated with improved or worsened conditions because it is not directly related to eutrophication.

Parameter	Pre-Break Trend	Post-Break Trend
Dissolved Inorganic Nitrogen	▲	▲
Bioactive Nitrogen	▼	▲
Total Nitrogen	▼	■
Phosphate	▲	■
Total Phytopigments	■	▼
Dissolved Oxygen	■	▲
Salinity	■	▲

Like the station-specific trend analysis results, bay-wide trend analysis results reflect the complexity of relationships between nutrient enrichment and ecosystem responses. Pre-break trends show a system with increased trends in two nutrient parameters (dissolved inorganic nitrogen and phosphate), decreased trends in two nutrient parameters (bioactive nitrogen and total nitrogen), and no significant trends in response parameters (total phytopigments and dissolved oxygen). Since the break, trends of increased dissolved inorganic nitrogen and bioactive nitrogen suggest continued nutrient enrichment but trends of decreased total phytopigments and increased dissolved oxygen indicate that any increase in nutrient enrichment has not translated to worsening ecosystem conditions. Analysis of other physical factors affecting algal growth and dissolved oxygen (pH, light, water clarity, tidal flushing, etc.) may provide insight into why response parameters have improved despite increased nutrient levels.

Discussion and Conclusions

Trend analysis results underscore the variability of conditions and complexity of water quality relationships throughout Pleasant Bay. Varied conditions throughout the Bay are reflected in differences in the direction and presence of trends among monitoring stations, while the lack of consistent trends between parameters reflects the complexity of relationships between nutrient inputs, nutrient cycling, and ecosystem responses to nutrient enrichment. Overall, trend analysis results do not show that eutrophication has improved or worsened at any one location or bay-wide. However, some stations have trends in individual parameters that suggest increased or decreased nutrient loading and these can be reviewed in conjunction with information on recent restoration efforts to gauge their effectiveness or to highlight areas as future restoration priorities. Furthermore, the presence of opposing trends in nutrient and response parameters (e.g., increasing nutrient concentrations but decreasing total phytopigment concentrations) merits further investigation of nutrient inputs, nutrient cycling, and ecosystem responses to changing nutrient levels in Pleasant Bay.

When interpreting trend analysis results, note that trends do not explicitly depict water quality as “good” or “bad”. Such classifications are typically made by evaluating whether sample data are above or below a numeric target. Trend analysis instead describes the relationship between water quality and time during the period of analysis, specifically whether concentrations have increased or decreased. Targets for water quality parameters analyzed in this study include dissolved oxygen concentrations above 6 milligrams per liter, total phytopigment concentrations below 5 micrograms per liter, and bioactive nitrogen concentrations between 0.098 and 0.405 milligrams per liter (bioactive nitrogen targets vary by station). Although trend analysis results show improved conditions for some parameters in portions of Pleasant Bay, sample data show that numeric targets were consistently not achieved in recent years. For example, the Namequoit-South station (PBA-12) has improving trends in five of the six eutrophication-related parameters analyzed (the exception is dissolved inorganic nitrogen) but 80% of samples collected in 2014 (eight of ten samples) do not meet the dissolved oxygen target. Such results illustrate continued effort is needed to restore the Pleasant Bay ecosystem and why trend analysis results should be one of several pieces of information used to guide restoration planning.

The trend analysis results presented in this report are <u>not</u> intended to be used to draw conclusions on the role of the 2007 break as a driver of water quality change in Pleasant Bay. Trend analysis showed a significant post-break change for some station-parameter pairs and for all parameters in the bay-wide analysis. In some cases, the post-break change is consistent with the expected effect of the break (e.g., the increase in bay-wide salinity concentrations following the break, possibly due to increased exchange of open ocean water). However, increased or decreased concentrations in samples collected after the 2007 break alone do not supply definitive evidence that the break caused a change in a water quality parameter. Analysis of other potential drivers of change (e.g., trends in nutrient loads from Pleasant Bay tributaries) are needed in order to determine the influence of the 2007 break and such analyses were beyond the scope of this study. Finally, trend analysis results are also not intended to be used for prediction of future conditions. Pleasant Bay is a dynamic system, and conditions in future years may drastically differ from the conditions that contributed to observed trends from 2000-2014. Continued monitoring is needed to characterize water quality in the coming years and additional sample data may allow for the identification of trends not detected in the 2000-2014 dataset.

Introduction

Pleasant Bay is an estuarine system located on Cape Cod in the Towns of Orleans, Chatham, Harwich, and Brewster, Massachusetts. Pleasant Bay was designated as an Area of Critical Environmental Concern (ACEC) by the Massachusetts Executive Office of Environmental Affairs in 1987. The Pleasant Bay Alliance (Alliance) was formed in 1998 to oversee the implementation of a resource management plan developed by the four towns. A key component of the resource management plan has been a bay-wide water quality monitoring plan.

In 2007, the Massachusetts Department of Environmental Protection established nitrogen Total Maximum Daily Loads (TMDLs) for Pleasant Bay. The TMDLs define the maximum nitrogen loads that Pleasant Bay can receive while still meeting threshold concentrations for bioactive nitrogen defined in the 2006 Massachusetts Estuaries Project (MEP) technical report for Pleasant Bay. Both the MEP technical report and nitrogen TMDLs incorporated water quality data collected by the Pleasant Bay Alliance under the bay-wide monitoring plan.

Fifteen consecutive years of water quality data have now been collected, at the time of this analysis, at sites throughout Pleasant Bay and its sub-embayments. In an effort to better understand these data, the Alliance retained The Cadmus Group, Inc. in February of 2015 to update the statistical analysis of monitoring data previously completed in 2010 (The Cadmus Group, 2010) to include results of 2010-2014 sampling. In addition to overall water quality trends, the Alliance is particularly interested in the effects of the April 16, 2007 “break” in the barrier beach (Nauset Beach), on water quality. This storm caused the formation of a second inlet connecting Pleasant Bay to the Atlantic Ocean. As a result of the break, tidal range in Pleasant Bay has increased by 0.7 feet and the volume of water exchanged with the Atlantic Ocean has increased by 14.9 percent (Applied Coastal Research and Engineering, Inc., 2008). The increase in the volume of water exchange between the bay and the open ocean would be expected to influence water quality in Pleasant Bay.

The statistical analysis of 2000-2014 water quality data described in this report includes a bay-wide trend analysis, as well as station-specific trend analyses. A class of statistical methods, called mixed effects models, was used to evaluate bay-wide trends. Multiple linear regression was used to evaluate station-specific trends. Both methods allow for the inclusion of multiple explanatory variables to isolate trends over time from other factors affecting water quality, with mixed effects models applied to further isolate bay-wide trends when samples from multiple monitoring stations are analyzed together.

This report is intended for a broad audience. As such, the main body of the report provides a general description of study methods and results. The appendices provide information for readers interested in detailed descriptions of the methods applied and results. Appendix A describes the data preparation steps and statistical methods applied. Appendix B contains tables of summary statistics for each sampling site. Appendix C contains tables that summarize the number of samples exceeding target concentrations for bioactive nitrogen, total phytopigments, and dissolved oxygen at each station by year. Appendix D and Appendix E contain tables of station-specific and bay-wide trend analysis results. Appendix F contains plots of station-specific trendlines for each parameter analyzed.

Methods

Dataset Description

The objective of this study is to evaluate trends over time in water quality parameters that are associated with nutrient loading and eutrophication in Pleasant Bay. These parameters include concentrations of dissolved inorganic nitrogen (DIN), bioactive nitrogen (DIN plus particulate organic nitrogen), total nitrogen, total algal pigments (phytopigments), phosphate, and dissolved oxygen. Trends in salinity concentrations were also analyzed. Although salinity is not directly related to eutrophication, salinity is an important physical water quality parameter and salinity trends provide information on changes in the relative amount of freshwater versus ocean water in Pleasant Bay.

Water quality samples used in this study were collected by members of the Alliance and Chatham Water Watchers volunteer monitoring programs using methods described in the *Quality Assurance Project Plan 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. Approximately 3,500 samples collected at 34 stations over the period 2000 through 2014 are used in the analysis. Table 1 lists total nitrogen sample counts by station and year as an example of the distribution of sample data. A similar number of samples by station and year are available for each of the other water quality parameters included in trend analysis. The duration of Pleasant Bay water quality monitoring to date (15 years) and sampling frequency (two times per month during July and August and once in early September) provides a dataset that is well suited for analysis of long-term trends.

Sample data acquired from the Alliance were reviewed prior to trend analysis to identify suspect data points and to characterize the prevalence of outliers. Some suspect data points were confirmed as entry errors based on original sample records maintained by the Alliance and were corrected prior to analysis. Outliers are samples with atypical low or high values and a large number of outliers can skew trend analysis results. The number of outliers for each water quality parameter included in trend analysis amounted to 1% or less of the total sample count.

The Pleasant Bay monitoring dataset intentionally includes “duplicate” samples. Duplicate samples are two samples collected at the same time and location for quality control purposes. Duplicate samples were averaged for trend analysis except where one result differed by more than 150% of the average of the duplicate pair (an indication of collection, handling, or measurement error), in which case both samples were discarded for analysis. Very few duplicate pairs had a large difference and nearly all were included in the analysis.

The Pleasant Bay monitoring dataset also includes paired “surface-bottom” samples. Surface-bottom samples are two samples collected at the same time and location from different depths. Most water quality parameters show a significant difference between surface and bottom concentrations. For this reason, sample depth was included as a potential predictor of parameter concentrations as part of trend analysis.

A complete description of dataset review methods is provided in Appendix A.

Table 1 Number of total nitrogen samples collected at each monitoring site by year.

Site ID	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
CM-13	20	16	14	14	14	14	12	10	10	10	10	10	8	10	10	182
CM-14	12	7	7	7	7	7	0	0	0	0	0	0	0	0	0	47
PBA-1	20	16	14	14	14	14	10	0	0	0	0	0	0	5	8	115
PBA-2	18	8	7	6	6	7	0	0	0	0	0	0	0	0	0	52
PBA-3	20	16	14	14	14	14	8	10	10	8	10	10	8	10	10	176
PBA-4	20	16	14	14	14	14	10	10	10	10	8	10	10	10	10	180
PBA-5	12	8	6	6	8	7	5	4	5	4	5	5	5	5	5	90
PBA-5A	0	0	6	7	7	7	6	5	5	5	5	5	5	4	5	72
PBA-6	10	10	10	12	14	14	0	0	0	0	6	10	8	10	10	114
PBA-7	12	12	14	14	14	14	0	0	0	0	0	0	0	0	0	80
PBA-8	10	12	14	14	15	14	12	10	10	10	10	10	8	8	8	165
PBA-9	12	12	12	14	14	14	12	10	10	10	10	10	10	10	10	170
PBA-10	12	12	14	14	14	14	12	8	10	10	10	10	10	10	10	170
PBA-11	12	12	14	12	12	14	12	7	10	10	10	10	10	10	10	165
PBA-12	12	12	14	14	14	14	8	10	10	10	10	10	10	10	10	168
PBA-13	12	12	14	12	12	14	12	10	10	10	10	10	10	10	8	166
PBA-14	12	12	14	14	14	14	11	0	0	0	10	10	10	10	10	141
PBA-15	12	12	12	14	14	14	10	10	10	10	10	10	10	10	10	168
PBA-16	12	12	14	14	14	14	7	0	0	0	10	10	10	10	10	137
PBA-17A	0	0	0	0	0	0	0	0	0	0	6	5	6	4	8	29
PBA-18	0	0	10	12	10	14	0	0	0	0	0	0	0	0	0	46
PBA-19	0	0	10	12	12	12	0	0	0	0	0	0	0	6	5	57
PBA-20	0	0	10	12	12	14	0	0	0	0	0	0	0	4	10	62
PBA-21	0	0	10	12	14	14	0	0	0	0	0	0	0	6	10	66
WMO-2	0	15	13	18	14	0	0	0	0	0	0	0	0	0	0	60
WMO-3	0	17	12	14	10	0	6	5	5	4	5	5	5	5	4	97
WMO-4	0	10	11	16	6	0	0	0	0	0	0	0	0	0	0	43
WMO-5	0	10	8	16	6	6	6	5	5	5	5	5	5	5	5	92
WMO-6	0	18	18	18	16	0	6	4	10	5	5	5	5	5	5	120
WMO-7	0	18	18	18	18	0	0	0	0	0	0	0	0	0	0	72
WMO-8	0	14	6	6	18	0	0	0	0	0	0	0	0	3	4	51
WMO-9	0	14	6	6	18	6	0	0	0	0	0	0	0	0	1	51
WMO-10	0	6	12	6	8	0	12	8	10	10	10	10	10	10	10	122
WMO-12	0	14	8	8	8	0	0	0	0	0	5	4	5	5	5	62
Total	250	353	380	404	405	304	177	126	140	131	170	174	168	195	211	3,588

Overview of Trend Analysis Techniques

Coastal and embayment water quality is influenced by many factors, including rainfall, temperature, ocean currents, human activity within the waterbody and its inland drainage area, chemical and biological processes, and other factors. Since these drivers are dynamic and constantly changing, so too is water quality. When a water quality sample is collected, it represents a snapshot of water quality at a specific location and moment in time. It is not unusual to collect a sample immediately adjacent to, or immediately following, another sample and measure different results. Trend analysis attempts to differentiate between random variation in sample data versus a consistent change in water quality over time.

Trend analysis can be used to identify two types of trends. A monotonic trend is a sustained, gradual change over time, as represented by a linear trendline (Figure 1; top). A step change trend is an abrupt shift in conditions at a specific point in time and usually corresponds to the occurrence of a discrete event (Figure 1; bottom).

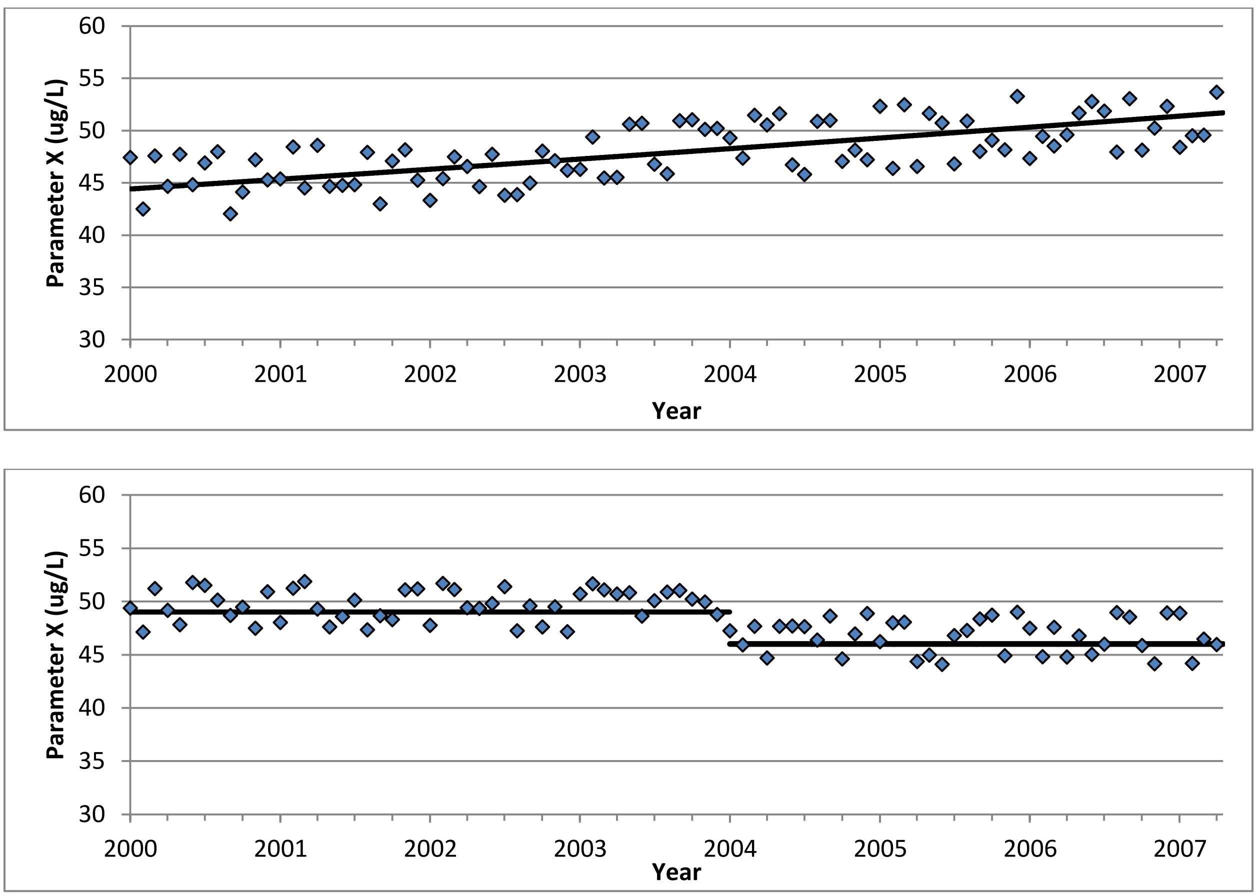


Figure 1. Example of a monotonic trend (top) and step change trend (bottom).

The variability of water quality in coastal systems can present a challenge for evaluating trends. Statistical methods must be applied to explicitly account for variable conditions. For example, simple linear regression can be used to fit a trendline to a set of total nitrogen concentrations observed over time (e.g., Figure 1; top) using the equation:

$$Total\ Nitrogen = aDate + z \quad \text{(Equation 1)}$$

where coefficient a is the trendline slope and coefficient z is the trendline intercept. Concluding that there is a positive or negative trend in total nitrogen based on the slope of the fitted line alone is not appropriate since that slope can result from random chance rather than from a true trend. A statistical test is therefore applied to determine whether the slope of the fitted trend line is significantly different from zero (i.e., no trend). Judgment of whether a trend is statistically significant is based on a calculated probability that the trend line slope is the result of random chance (instead of a true relationship between water quality and time) and whether this probability is sufficiently low.

The preceding example of trend analysis focuses on the use of simple linear regression to describe the relationship between water quality and time. Multiple linear regression, an extension of simple linear regression, can be a much more powerful tool for trend analysis. While simple linear regression examines the relationship between one response variable and one predictor variable, multiple linear regression includes multiple predictor variables in the analysis. This can be advantageous in complex systems where multiple drivers are influencing the response.

An example of the use of multiple linear regression is analysis of trends in dissolved oxygen concentrations over time. Dissolved oxygen concentrations are known to be influenced by water temperature and salinity. Trend analysis of dissolved oxygen concentrations therefore becomes more powerful when temperature and salinity are included as predictor variables in a multiple linear regression along with time:

$$Dissolved\ Oxygen = aDate + bTemperature + cSalinty + z \qquad \text{(Equation 2)}$$

This approach has the potential to better characterize how dissolved oxygen changes over time since variation due to temperature and salinity is explicitly accounted for.

Note that although the use of multiple predictor variables in a regression can be beneficial, it is not good practice to add as many predictors as possible. A simpler regression with fewer predictor variables is always preferable to a complex regression with many predictor variables given equal performance. This is because a complex regression is more likely to be describing random noise in the data rather than true relationships between the predictors and the response variable. Therefore, a predictor variable should only be included in a regression when its explanatory power outweighs the corresponding increase in complexity.

Equations 1 and 2 both involve the detection of a gradual (monotonic) trend. A step change trend can be evaluated using an “event” categorical variable that describes whether a sample was collected before or after the event of interest. For the case of a total nitrogen, a linear regression equation for evaluating a step change following an event is:

$$Total\ Nitrogen = aEvent + z \qquad \text{(Equation 3)}$$

In equation 3, coefficient a is the difference in means between total nitrogen concentrations before the event and after the event.

Monotonic trends can also be influenced by a discrete event and analysis of pre-event and post-event trends can be evaluated in tandem using multiple linear regression. Doing so requires the use of a continuous "Date" term, a categorical "Event" term, and a "Date-Event" interaction term in the regression equation:

$$Total\ Nitrogen = aDate + bEvent + cDate{:}Event + z \qquad \text{(Equation 4)}$$

In equation 4, coefficient a represents the monotonic trend before the event and coefficient c represents the effect of the event on the monotonic trend.

A third type of regression commonly used for trend analysis is mixed effects regression (also termed "mixed effects modeling"[2]). A mixed effects model is an extension of multiple linear regression that is applied to a sample dataset made up of several distinct groups of observations, such as a dataset with multiple observations from different monitoring stations. Like multiple linear regression, a mixed effects model describes the relationship between a response variable and multiple predictor variables. The model is considered mixed because it considers both "fixed effects" (predictors with a systematic and predictable influence on the response, such as time) and "random effects" (predictors with a non-systematic or idiosyncratic influence on the response, such as monitoring location).

[2] The use of the term "model" throughout this report refers to a statistical model. A statistical model is a mathematical expression derived from observational data that describes the relationship between two or more variables. A statistical model is distinct from a process-based water quality model, which uses a series of equations to represent the various physical, chemical, and biological processes occurring within a waterbody.

Detecting Trends in Water Quality Parameters

Trends in water quality parameters in Pleasant Bay over the period 2000-2014 were analyzed using multiple linear regression and mixed effects models. Multiple linear regression was used to evaluate station-specific trends in water quality parameters, while mixed effects modeling was used to evaluate bay-wide trends in water quality parameters. Seven water quality parameters were analyzed for station-specific and bay-wide trends:

- Dissolved Inorganic Nitrogen (DIN)
- Bioactive Nitrogen
- Total Nitrogen (TN)
- Total Phytopigments
- Phosphate (PO_4)
- Dissolved Oxygen (DO)
- Salinity

Station-Specific Trend Analysis

Trends in water quality parameters were evaluated individually at 20 monitoring stations in Pleasant Bay. Although there are 34 monitoring stations in the 2000-2014 dataset, 14 stations are either not actively sampled or contain large data gaps that preclude meaningful analysis of trends. Table 2 lists the stations excluded from stations-specific trend analysis and the reasons for exclusion.

Table 2. Pleasant Bay monitoring stations excluded from station-specific trend analysis.

Station	Reason for Exclusion From Station-Specific Trend Analysis
CM-14	Not sampled since 2005
PBA-1	Not sampled from 2007-2012
PBA-2	Not sampled since 2005
PBA-7	Not sampled since 2005
PBA-17A	Not sampled before 2010
PBA-18	Not sampled since 2005
PBA-19	Not sampled from 2006-2012
PBA-20	No sampled from 2006-2012
PBA-21	Not sampled from 2006-2012
WMO-2	Not sampled since 2004
WMO-4	Not sampled since 2004
WMO-7	Not sampled since 2004
WMO-8	Not sampled from 2005-2012
WMO-9	Not sampled from 2006-2013

Analysis of station-specific trends involved fitting various regression equations to sample data for each station-parameter pair, evaluating which regression equation provided the best fit, and assessing the statistical significance of terms of the best regression equation.

Nine candidate regression equations were fit to each station-parameter pair. The candidate regression equations described one of three trend types:

1. Gradual (monotonic) change over the period 2000-2014 that is not affected by the 2007 Nauset Beach break (Figure 2; top-left);
2. Step change following the 2007 Nauset Beach break (Figure 2; top-right);
3. Gradual (monotonic) change from 2000 to 2014 that changes in magnitude or direction following the 2007 break (Figure 2; bottom).

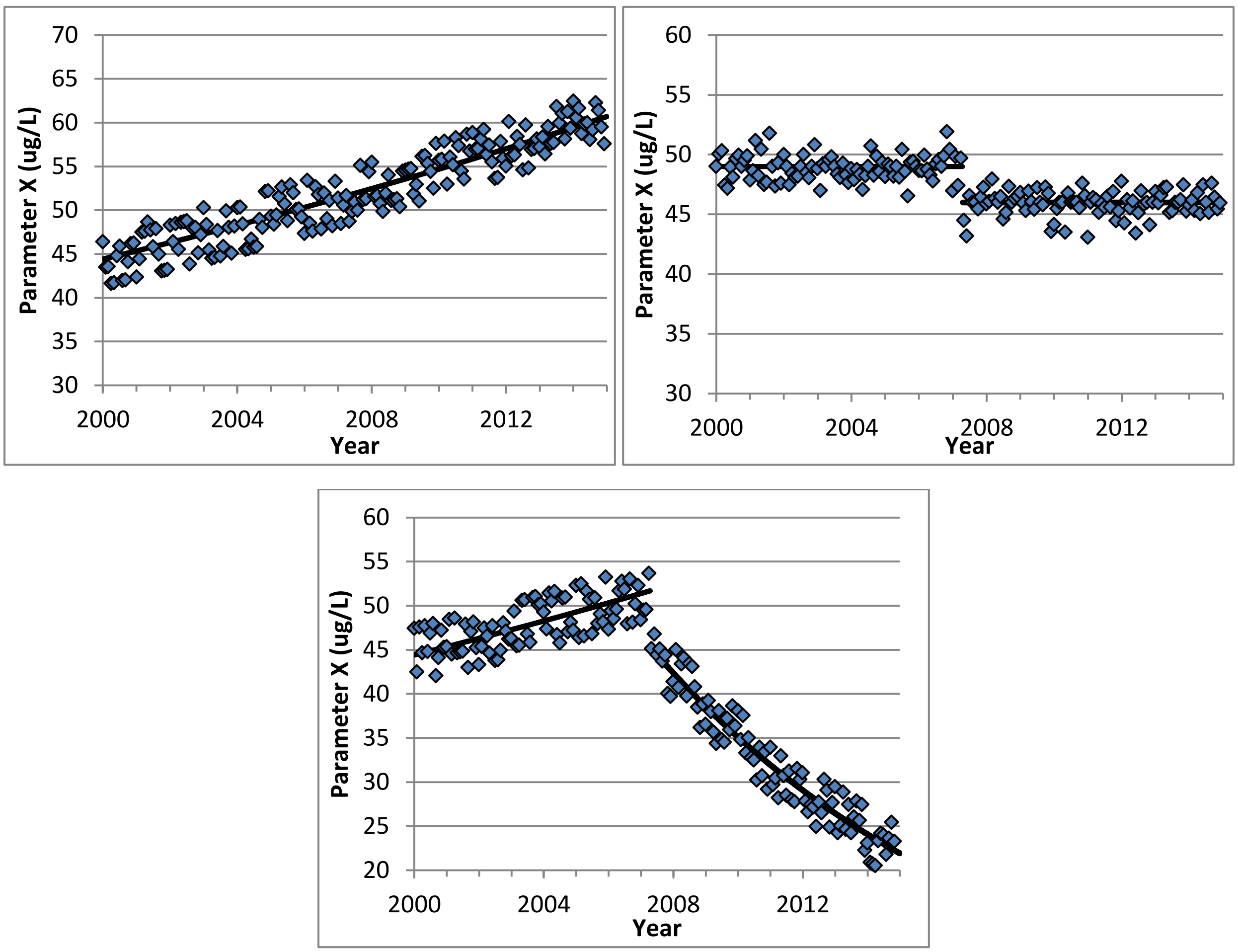


Figure 2. Graphical examples of the three trend types evaluated as part of station-specific and bay-wide trend analysis. Trend type 1 (top-left) is a gradual trend over 2000-2014 that is not affected by the 2007 Nauset Beach break. Trend type 2 (top-right) is a step change after the 2007 break. Trend type 3 (bottom) is a gradual change from 2000-2014 that changes in magnitude or direction after the break.

Table 3. Summary of the three trend types evaluated as part of station-specific and bay-wide trend analysis.

Name	Description	Regression Equation Form
Trend Type 1	Monotonic trend from 2000-2014 that is not affected by the 2007 break.	$y = aDate + z$
Trend Type 2	Step change after the 2007 break.	$y = aBreak + z$
Trend Type 3	Monotonic trend from 2000-2014 with a slope change after the 2007 break.	$y = aDate + bBreak + cDate{:}Break + z$

The candidate regression equations for each station-parameter pair further differ in whether they include sample depth, water temperature, recent rainfall, and salinity at the time of sample collection as additional predictor variables.

The "best" regression equation for each parameter out of the nine candidates was identified using Akaike's Information Criterion (AIC) (Hirotugu, 1974), a measure of relative quality within a collection of regression models. This approach identifies the model that provides the most explanatory power while minimizing the number of predictor variables. The simplest possible model is preferred unless an additional predictor variable provides significantly more explanatory power. Identification of the best model also considered the number of sample data points available for analysis. The rule of thumb in multiple linear regression is that one predictor variable per 20 samples should be included in the model. After selecting the best regression equation for each of the site-parameter pair, the statistical significance of the trend over time was evaluated using the p-value for coefficients related to changes over time and a significance level of 0.05. A significance level of 0.05 corresponds to a 5% likelihood of a "false positive" result (i.e., a trend is characterized as statistically significant even though no trend over time actually exists). The interpretation of statistical significance varies for each of the three trend types described in Table 3:

- Trend type 1 (monotonic trend with no effect of the 2007 break). The p-value for the "Date" term describes whether the trendline slope is statically significant.
- Trend type 2 (step change trend after the 2007 break). The p-value for the "Break" term describes whether the upward/downward shift after the 2007 break is statistically significant.
- Trend type 3 (monotonic trend with slope change after the 2007 break).
    - The p-value for the "Date" term describes whether the pre-break trendline slope is statically significant.
    - The p-value for the "Date:Break" interaction term describes whether the post-break trendline slope is statistically significant.

Bay-Wide Trend Analysis

Bay-wide water quality trends were evaluated using sample data from the 34 monitoring stations listed in Table 1. Similar to analysis of station-specific trends, analysis of bay-wide trends involved fitting various regression equations to sample data for each parameter, evaluating which regression equation provided the best fit, and assessing the statistical significance of terms of the best regression equation. The bay-wide analysis used mixed effects regression models with station ID as a random effect on trend slope and intercept. Mixed effects models are robust to missing data (Baayen et al. 2008) and the 14 stations with incomplete monitoring records listed in Table 2 were included in bay-wide trend analysis in order to maximize the number of samples analyzed.

Six candidate regressions were fit for each parameter. Like the station-specific analysis, candidate bay-wide regressions described trends over time as either monotonic with no effect of the 2007 break (Figure 2; top-left), a step change trend following the 2007 break (Figure 2; top-right), or a monotonic trend with a slope change following the 2007 Nauset Beach break (Figure 2; bottom). For each of these three trend types, one regression equation was fit with salinity, temperature, and recent rainfall at the time of sample collection as additional predictors and one regression equation was fit without salinity, temperature, and recent rainfall. All six candidate regressions included sampling depth as an additional predictor.

As with station-specific trend analysis, the "best" bay-wide regression equation for each water quality parameter was selected from the six candidates using AIC values. After selecting the best model for each water quality parameter, the statistical significance of the trend over time was evaluated using the p-value for coefficients related to changes over time ("Date", "Break", and/or "Date:Break" interaction) and a significance level of 0.05.

Further details of trend analysis methods can be found in Appendix A.

Results & Discussion

Station-Specific Trends

Station-specific trends are summarized for each station-parameter pair in Table 4 and are mapped in Figure 3 through Figure 8. In Table 4 and Figure 3 through Figure 8, the statistical significance and direction of trends are conveyed with the following symbols:

- Upward arrows (▲,▲,▲) indicate that the concentration of the water quality parameter increased over time and that the increase is statistically significant;
- Downward arrows (▼,▼,▼) indicate that the concentration of the water quality parameter decreased over time and that the decrease is statistically significant;
- Squares (■) indicate that the change in water quality over time is not statistically significant.

Table 4 and Figure 3 through Figure 8 also express whether the trend is associated with improved or worsened conditions based on the color of the symbol:

- Green arrows (▲ or ▼) indicate that the trend is associated with improved conditions. For dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, phosphate, and total pigments, decreased concentrations are associated with improved conditions. For dissolved oxygen, increased concentrations over time are associated with improved conditions;
- Red arrows (▲ or ▼) indicate that the trend is associated with worsened conditions. For dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, phosphate, and total pigments, increased concentrations over time are associated with worsened conditions. For dissolved oxygen, decreased concentrations over time are associated with worsened conditions;
- Salinity trends are not associated with improved or worsened conditions because they are not directly related to eutrophication.

Table 4. Station-specific trend analysis results. DIN=Dissolved Inorganic Nitrogen, TN=Total Nitrogen, BioN=Bioactive Nitrogen, PO4=Phosphate, Pigment=Total Phytopigments, DO=Dissolved Oxygen,

Station	DIN	BioN	TN	PO4	Pigment	DO	Salinity
Outer Ryder's Cove (CM-13)	▲	■	▲	▲	▼	▲	■
Inner Ryders Cove (PBA-3)	▲	■	■	■	▼	▲	▲
Crow's Pond (PBA-4)	■	▼	▼	▲	▼	▲	▲
Muddy Creek (PBA-5)	▲	■	■	■	■	■	▲
Muddy Creek-Upper (PBA-5A)	▼	■	■	■	▲	■	▲
Big Bay-SW (PBA-6)	■	■	▼	▼	▼	▲	▲
Big Bay-NE (PBA-8)	▲	■	▲	▼	▼	■	■
Round Cove (PBA-9)	▲	▼	▼	■	▼	▼	■
Quanset Pond (PBA-10)	▲	▲	▲	▼	▼	■	■
Paw Wah Pond (PBA-11)	■	▼	▼	■	▼	■	▲
Namequoit-South (PBA-12)	■	▼	▼	▼	▼	▲	▲
Namequoit-North (PBA-13)	▲	■	■	■	▼	■	■
Arey's Pond (PBA-14)	■	■	■	■	▼	▼	■
Kescayogansett Pond (PBA-15)	■	▼	▼	▲	▼	■	■
Meetinghouse Pond (PBA-16)	■	▼	■	■	▼	■	■
Pochet Mouth (WMO-3)	■	▼	▼	■	▼	■	■
Pochet Upper (WMO-5)	■	■	■	▲	▼	▲	■
Namequoit River Mid (WMO-6)	■	▼	▼	■	▼	■	■
River at Rattles Dock (WMO-10)	■	▼	▼	■	▼	▲	▲
Little Quanset Pond (WMO-12)	▲	▲	▲	■	■	▼	▲

Figure 3. Direction of trends in bioactive nitrogen (BioN) concentrations at each water quality monitoring station in Pleasant Bay.

Figure 4. Direction of trends in dissolved inorganic nitrogen (DIN) concentrations at each water quality monitoring station in Pleasant Bay.

Figure 5. Direction of trends in total nitrogen concentrations at each water quality monitoring station in Pleasant Bay.

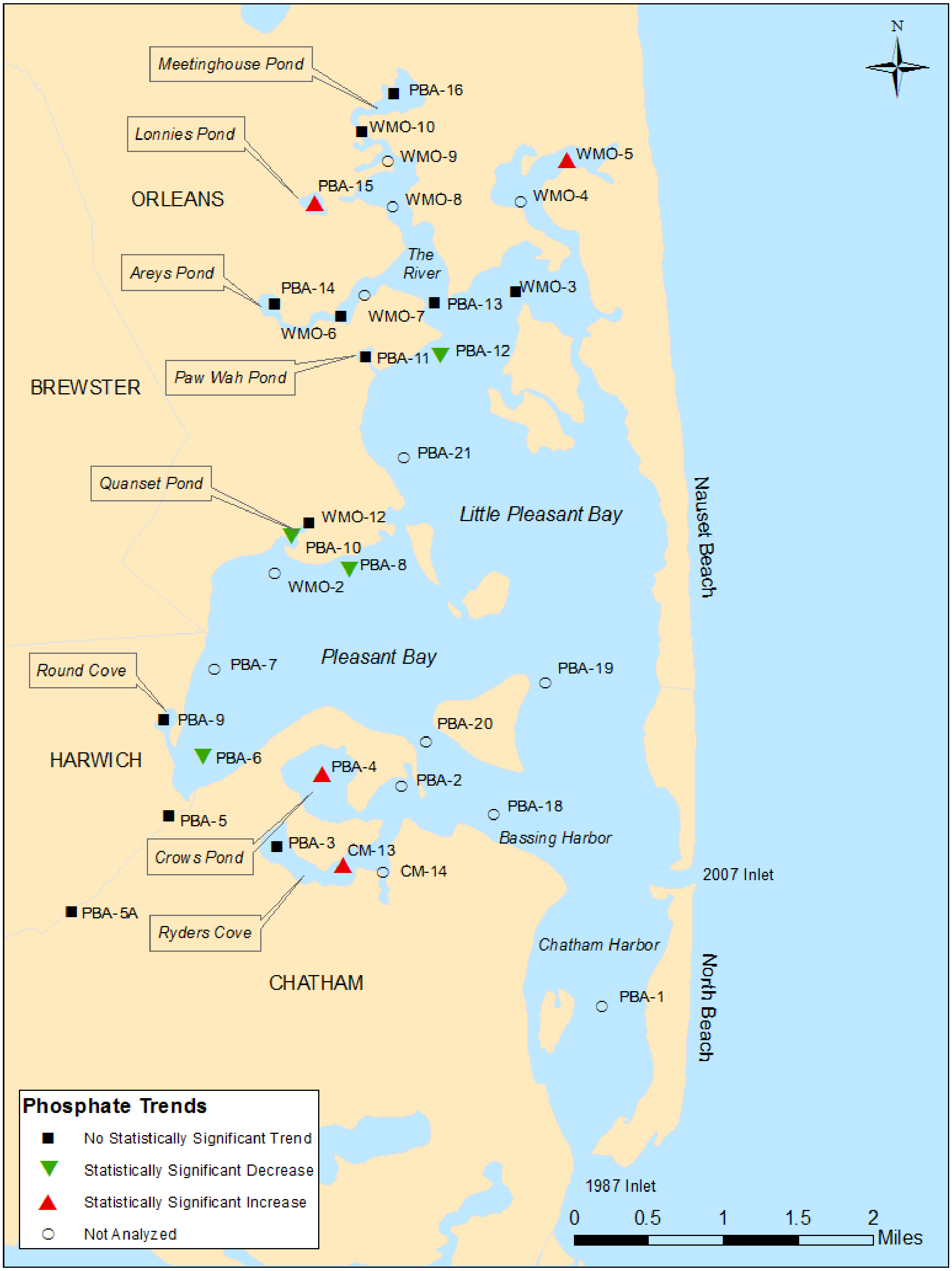


Figure 6. Direction of trends in phosphate concentrations at each water quality monitoring station in Pleasant Bay.

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

Figure 8. Direction of trends in dissolved oxygen (DO) concentrations at each water quality monitoring station in Pleasant Bay.

Figure 9. Direction of trends in salinity concentrations at each water quality monitoring station in Pleasant Bay.

Most station-specific trends are best characterized as either a gradual change over time that was not affected by the 2007 Nauset Beach break or a step-change following the 2007 break (trend types 1 and 2 in Table 3). Of the 140 different station-parameter pairs (20 stations and 7 water quality parameters), 67 pairs used trend type 1 (monotonic trend that was not affected by the 2007 break) and 55 pairs used trend type 2 (step change after the 2007 break). Note that step change trends should not be interpreted as being caused by the 2007 Nauset Beach break since other factors not related to the break could also have driven differences between pre-break and post-break concentrations. The remaining 18 pairs used trend type 3 (monotonic trend with a slope change after the 2007 break) and all 18 of these describe trends in dissolved oxygen or salinity. For these pairs, Table 4 and Figure 3 through Figure 8 list the direction and statistical significance of the post-break trend only. Refer to Appendix D for further details of each station-specific regression and Appendix F for station-specific trendline plots.

Station-specific trend analysis results demonstrate that Pleasant Bay is a highly variable and complex system. Varied conditions throughout the Bay are reflected in differences in the direction and presence of trends among monitoring stations for each water quality parameter. None of the seven parameters analyzed have consistent trends across all twenty monitoring stations. Total nitrogen trends, for example, are increasing at four stations, decreasing at nine stations, and are not statistically significant at seven stations.

The complexity of water quality relationships in Pleasant Bay is reflected in the lack of consistent trends between parameters at a given station. None of the twenty stations included in trend analysis show improvements across all six eutrophication-related parameters and none show worsened conditions across all six parameters. Seven stations (Big Bay-SW, Paw Wah Pond, Namequoit-South, Meetinghouse Pond, Pochet Mouth, Namequoit River Mid, and River at Rattles Dock) have improving trends in bioactive nitrogen and/or total nitrogen, no significant trend or an improving trend in phosphate, and improving total phytopigment trends. Three of these seven also have trends of improved dissolved oxygen concentrations (Big Bay-SW, Namequoit-South, and River at Rattles Dock). Of the twenty stations included in trend analysis, these seven have results that are most in line with overall improvements in nutrient enrichment and ecosystem responses. However, the lack of dissolved inorganic nitrogen trends and consistent dissolved oxygen improvements preclude definitive statements on an overall decline in eutrophication at these stations. One station (Little Quanset Pond) has trends of increasing dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen concentrations and decreasing dissolved oxygen. While these trends are consistent with continued nutrient enrichment and declining ecosystem conditions, no significant trend was found for phosphate and total phytopigments at Little Quanset Pond.

Results for the remaining twelve stations (Outer Ryder's Cove, Inner Ryders Cove, Crow’s Pond, Muddy Creek, Muddy Creek-Upper, Big Bay-NE, Round Cove, Quanset Pond, Namequoit-North, Arey’s Pond, Kescayogansett Pond, and Pochet Upper) are more variable between parameters. Most show improved total phytopigment concentrations but increasing concentrations of at least one nitrogen parameter. For example, Quanset Pond (PBA-10) has trends of increased dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen but decreased total phytopigment concentrations and no significant trend in dissolved oxygen. Such inconsistencies illustrate the potential influence of factors in addition to nutrient inputs on algal growth and dissolved oxygen concentrations (e.g., pH, light, water clarity, or tidal flushing).

The following summary paragraphs describe trend analysis results for each monitoring station. When reviewing results for an individual station, note that trends of decreased nutrient concentrations, decreased total phytopigment concentrations, and increased dissolved oxygen concentrations are indicative of improved conditions because they describe a system with lower nutrient enrichment, less algal growth, and higher oxygen levels for aquatic biota. Conversely, trends of increased nutrient concentrations, increased total phytopigment concentrations, and decreased dissolved oxygen concentrations are indicative of worsened conditions and continued eutrophication. Also note that trends do not explicitly depict water quality as “good” or “bad”. Such classifications are typically made by evaluating whether sample data are above or below a numeric target. Targets for water quality parameters analyzed in this study include dissolved oxygen concentrations above 6 milligrams per liter, total phytopigment concentrations below 5 micrograms per liter, and bioactive nitrogen concentrations between 0.098 and 0.405 milligrams per liter (bioactive nitrogen targets vary by station). Appendix C contains tables summarizing the number of samples not meeting targets for bioactive nitrogen, dissolved oxygen, and total phytopigments at each station by year.

CM-13 (Outer Ryder's Cove)

- *Nutrients*: Concentrations of dissolved inorganic nitrogen, total nitrogen, and phosphate have increased since 2000. No statistically significant trend was found for bioactive nitrogen.
- *Total Phytopigments*: Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen*: Dissolved oxygen concentrations show no significant trend prior to the 2007 break and an increasing trend after the break.
- *Salinity*: No significant trend was found for salinity concentrations.

PBA-3 (Inner Ryders Cove)

- *Nutrients:* Concentrations of dissolved inorganic nitrogen have increased since 2000. No statistically significant trend was found for the remaining nutrient parameters (bioactive nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show no significant trend prior to the 2007 break and an increasing trend after the break.
- *Salinity:* Salinity concentrations show an increasing trend since 2000.

PBA-4 (Crow’s Pond)

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000 while phosphate concentrations have increased. No significant trend was found for dissolved inorganic nitrogen.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show no significant trend before the 2007 break and an increasing trend after the break.
- *Salinity:* Salinity concentrations show an increasing trend since 2000.

PBA-5 (Muddy Creek)

- *Nutrients:* Concentrations of dissolved inorganic nitrogen have increased since 2000. No significant trend was found for the remaining nutrient parameters (bioactive nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* No significant trend was found for total phytopigments.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show a decreasing trend before the 2007 break and no significant trend after the break.
- *Salinity:* Salinity concentrations show a decreasing trend before the 2007 break and an increasing trend after the break.

<u>PBA-5A (Muddy Creek-Upper)</u>

- *Nutrients:* Concentrations of dissolved inorganic nitrogen have decreased since 2000. No significant trend was found for the remaining nutrient parameters (bioactive nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* Total phytopigment concentrations show an increasing trend since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* Salinity concentrations show a decreasing trend before the 2007 break and an increasing trend after the break.

<u>PBA-6 (Big Bay-SW)</u>

- *Nutrients:* Concentrations of total nitrogen and phosphate have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen and bioactive nitrogen.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have increased since 2000.
- *Salinity:* Salinity concentrations have increased since 2000.

<u>PBA-8 (Big Bay-NE)</u>

- *Nutrients:* Concentrations of dissolved inorganic nitrogen and total nitrogen have increased since 2000 while concentrations of phosphate have decreased. No significant trend was found for bioactive nitrogen.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show an increasing trend prior to the 2007 break and no significant trend after the break.
- *Salinity:* No significant trend was found for salinity concentrations.

<u>PBA-9 (Round Cove)</u>

- *Nutrients:* Concentrations of dissolved inorganic nitrogen have increased since 2000 while concentrations of bioactive nitrogen and total nitrogen have decreased. No significant trend was found for phosphate concentrations.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have decreased since 2000.
- *Salinity:* No significant trend was found for salinity concentrations.

<u>PBA-10 (Quanset Pond)</u>

- *Nutrients:* Concentrations of dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen have increased since 2000 while concentrations of phosphate have decreased.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* No significant trend was found for salinity concentrations.

PBA-11 (Paw Wah Pond)

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen and phosphate.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* Salinity concentrations have increased since 2000.

PBA-12 (Namequoit-South)

- *Nutrients:* Concentrations of bioactive nitrogen, total nitrogen, and phosphate have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have increased since 2000.
- *Salinity:* Salinity concentrations have increased since 2000.

PBA-13 (Namequoit-North)

- *Nutrients:* Concentrations of dissolved inorganic nitrogen have increased since 2000. No significant trend was found for the remaining nutrient parameters (bioactive nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* No significant trend was found for salinity concentrations.

PBA-14 (Arey's Pond)

- *Nutrients:* No significant trend was found for all four nutrient parameters (dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* Concentrations of total phytopigments have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show no significant trend before the 2007 break and a decreasing trend after the break.
- *Salinity:* No significant trend was found for salinity concentrations.

PBA-15 (Kescayogansett Pond)

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000 while phosphate concentrations have increased. No significant trend was found for dissolved inorganic nitrogen.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* No significant trend was found for salinity concentrations.

PBA-16 (Meetinghouse Pond)

- *Nutrients:* Concentrations of bioactive nitrogen have decreased since 2000. No significant trend was found for the remaining nutrient parameters (dissolved inorganic nitrogen, total nitrogen, and phosphate).
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have decreased since 2000.
- *Salinity:* No significant trend was found for salinity concentrations.

WMO-3 (Pochet Mouth)

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen and phosphate.

- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* No significant trend was found for salinity concentrations.

<u>WMO-5 (Pochet Upper)</u>

- *Nutrients:* Concentrations of phosphate have decreased since 2000. No significant trend was found for the remaining nutrient parameters (dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen).
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations show no significant trend before the 2007 break and an increasing trend after the break.
- *Salinity:* No significant trend was found for salinity concentrations.

<u>WMO-6 (Namequoit River Mid)</u>

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen and phosphate.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* No significant trend was found for dissolved oxygen concentrations.
- *Salinity:* No significant trend was found for salinity concentrations.

<u>WMO-10 (River at Rattles Dock)</u>

- *Nutrients:* Concentrations of bioactive nitrogen and total nitrogen have decreased since 2000. No significant trend was found for dissolved inorganic nitrogen and phosphate.
- *Total Phytopigments:* Total phytopigment concentrations have decreased since 2000.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have increased since 2000.
- *Salinity:* Salinity concentrations show a decreasing trend before the 2007 break and an increasing trend after the break.

<u>WMO-12 (Little Quanset Pond)</u>

- *Nutrients:* Concentrations of dissolved inorganic nitrogen, bioactive nitrogen, and total nitrogen have decreased since 2000. No significant trend was found for phosphate.
- *Total Phytopigments:* No significant trend was found for total phytopigment concentrations.
- *Dissolved Oxygen:* Dissolved oxygen concentrations have decreased since 2000.
- *Salinity:* Salinity concentrations have increased since 2000.

Bay-Wide Trends

All seven of the water quality parameters evaluated demonstrate significant bay-wide trends. Trends for each parameter are summarized below and in Table 5. Six of the seven parameters were best described using a regression equation for trend type 3 (monotonic trend with a slope change after the 2007 break; the exception was salinity). Plots of regression output are provided in Figure 10 through Figure 13. Note that the trendlines displayed in Figure 10 through Figure 13 are for surface concentrations. Trendlines for middle and bottom concentrations have the same shape and significance levels but are shifted upward or downward to account for average differences between depths.

- *Dissolved Inorganic Nitrogen*: Concentrations of dissolved inorganic nitrogen show a significant increasing trend from 2000 to the 2007 Nauset Beach break. The increasing trend has continued after the break.
- *Bioactive Nitrogen*: Bioactive nitrogen concentrations show a significant decreasing trend from 2000 to the 2007 Nauset Beach break. Since the break concentrations are increasing (i.e., the pre-break trend has reversed).
- *Total Nitrogen*: Concentrations of total nitrogen show a significant decreasing trend from 2000 to the 2007 Nauset Beach break. Since the break there is no significant trend in total nitrogen concentrations.
- *Phosphate*: Concentrations of phosphate show a significant increasing trend from 2000 to the 2007 Nauset Beach break. Since the break there is no significant trend in phosphate concentrations.
- *Total Phytopigments*: Total phytopigment concentrations show no significant trend from 2000 to the 2007 Nauset Beach break. Since the break, total phytopigment concentrations have been decreasing.
- *Dissolved Oxygen*: No significant trend in dissolved oxygen concentrations is apparent from 2000 to the 2007 Nauset Beach break. Since the break, dissolved oxygen concentrations have been increasing.
- *Salinity*: The salinity trend was best characterized as a “step-change” type trend, with a statistically significant increase in salinity concentrations after the 2007 break relative to pre-break concentrations.

Table 5. Results of bay-wide trend analysis. The direction of statistically significant trends is indicated by the arrow direction (▲, ▲, ▲ = increase; ▼, ▼, ▼ = decrease). Arrow colors are used to convey whether the trend is associated with improved or worsened conditions (green = improved; red = worsened). Station-parameter pairs with no significant trend are symbolized with a black square (■). The salinity trend was characterized as a step-change type trend, with a statistically significant increase in salinity concentrations after the 2007 break, and is not associated with improved or worsened conditions because it is not directly related to eutrophication.

Parameter	Pre-Break Trend	Post-Break Trend
Dissolved Inorganic Nitrogen	▲	▲
Bioactive Nitrogen	▼	▲
Total Nitrogen	▼	■
Phosphate	▲	■
Total Phytopigments	■	▼
Dissolved Oxygen	■	▲
Salinity	-	▲

Like the station-specific trend analysis results, bay-wide trend analysis results demonstrate the complexity of the relationships between nutrient enrichment and ecosystem responses. Pre-break trends show a system with increased trends in two nutrient parameters (dissolved inorganic nitrogen and phosphate), decreased trends in two nutrient parameters (bioactive nitrogen and total nitrogen), and no significant trends in response parameters (total phytopigments and dissolved oxygen). Since the break, trends of increased dissolved inorganic nitrogen and bioactive nitrogen suggest continued nutrient enrichment but trends of decreased total phytopigments and increased dissolved oxygen indicate that any increase in nutrient enrichment has not translated to worsening ecosystem conditions. Additional analysis of other physical factors affecting algal growth and dissolved oxygen (pH, light, water clarity, tidal exchange, etc.) may provide insight into why response parameters have improved despite increased nutrient levels.

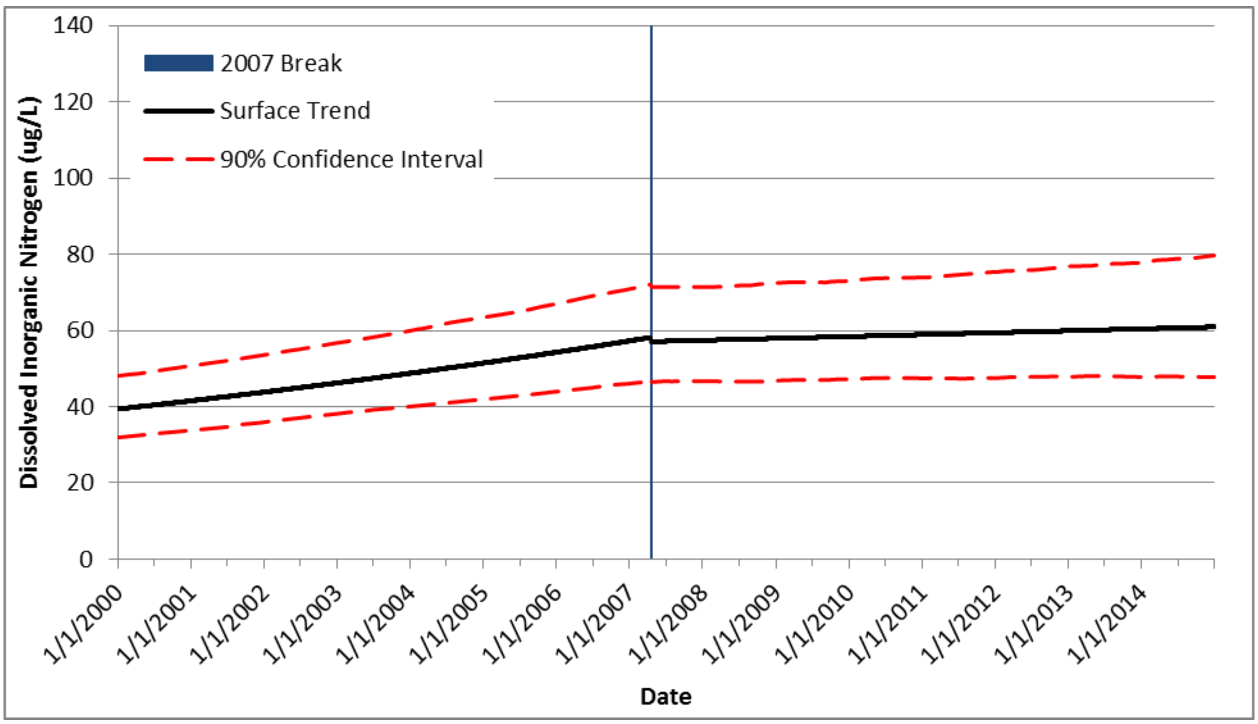


Figure 10. Bay-wide trends in dissolved inorganic nitrogen (DIN) concentrations over 2000-2014. Both the pre-break and post-break trends are statistically significant.

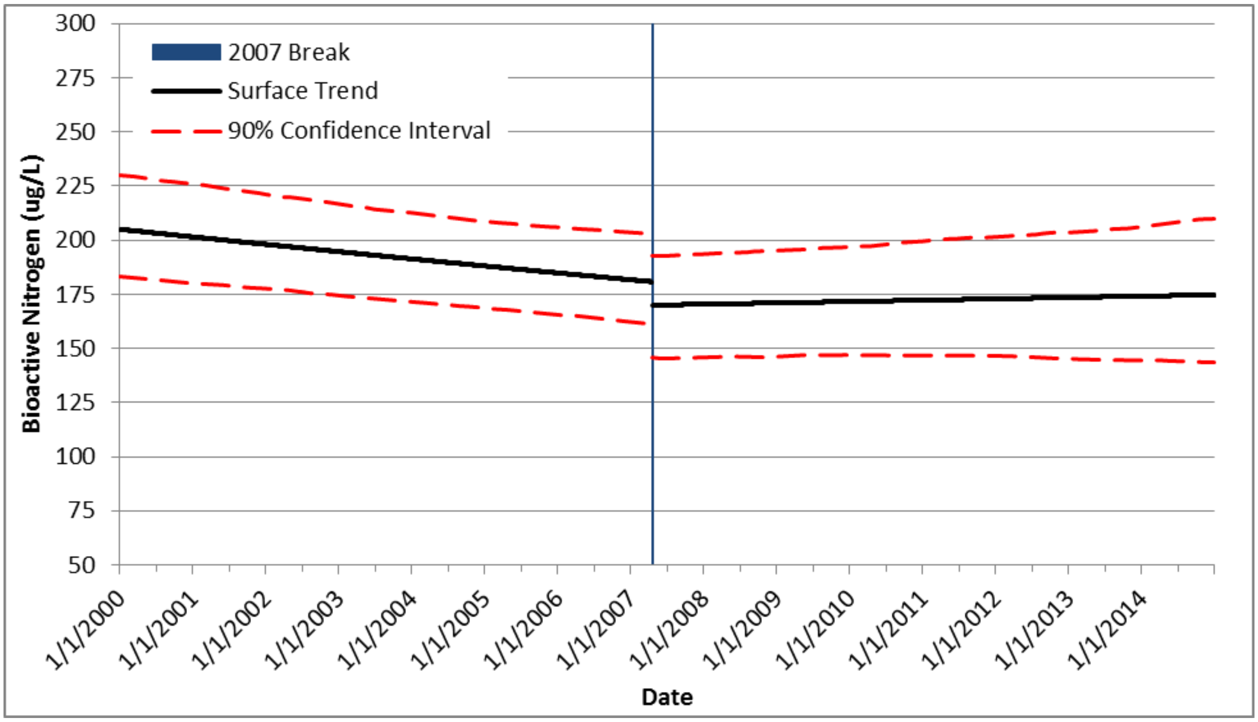


Figure 11. Bay-wide trends in bioactive nitrogen concentrations over 2000-2014. Both the pre-break trend and post-break trend are statistically significant.

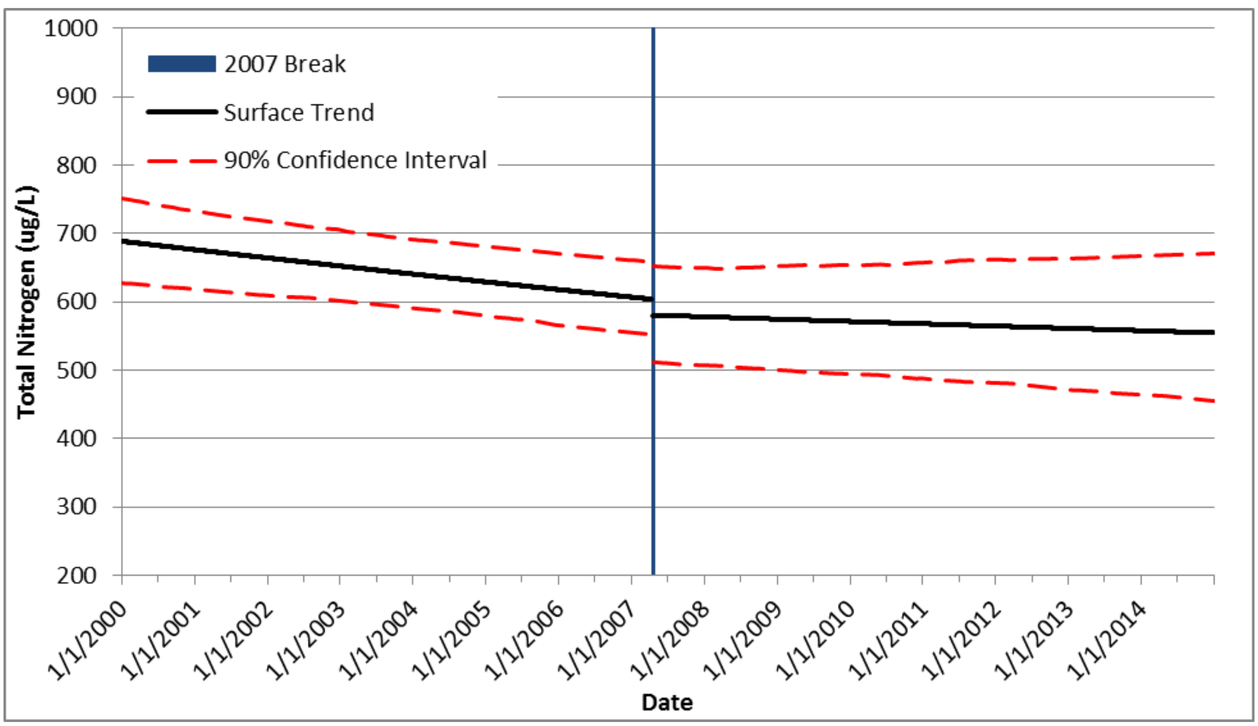


Figure 12. Bay-wide trends in total nitrogen concentrations over 2000-2014. Only the pre-break trend is statistically significant.

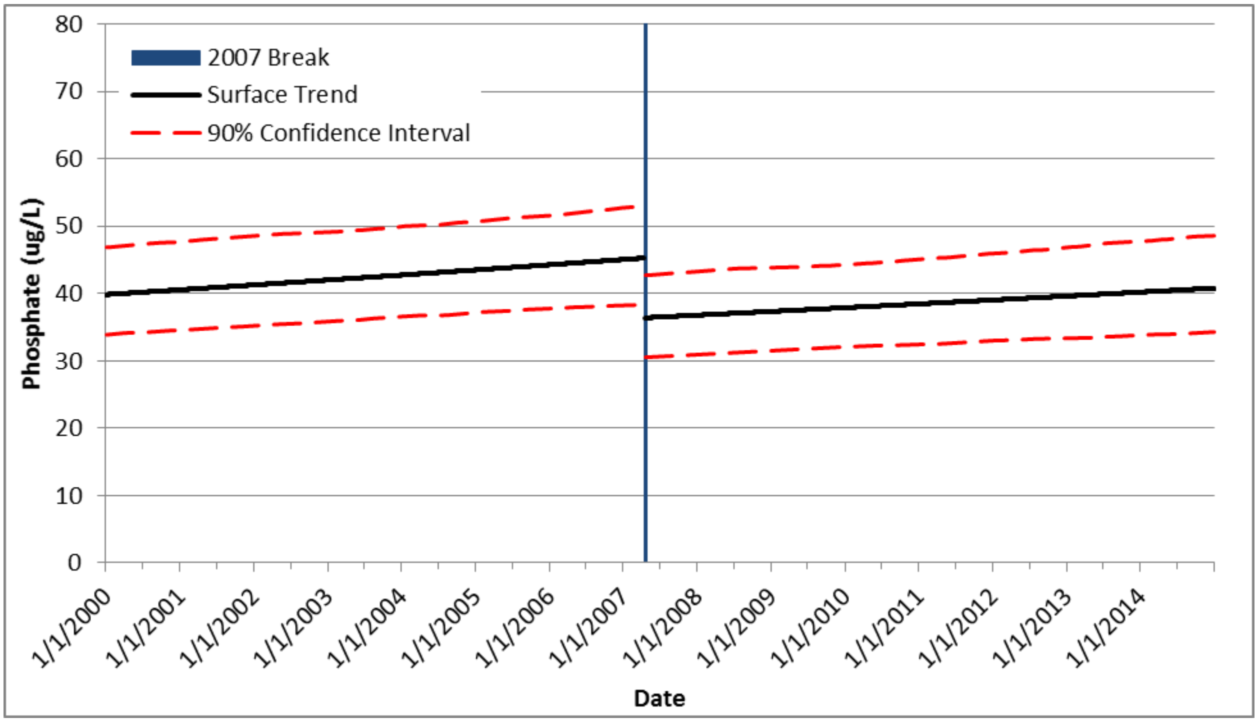


Figure 13. Bay-wide trends in phosphate concentrations over 2000-2014 period. Only the pre-break trend is statistically significant.

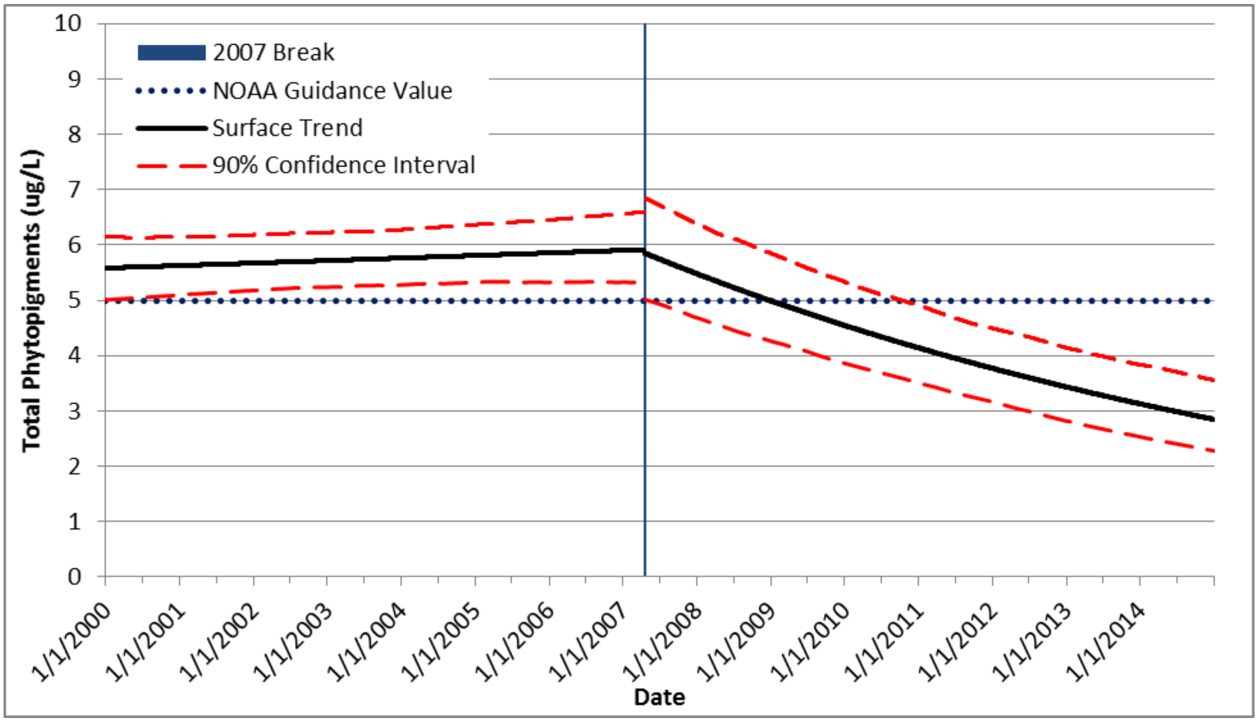


Figure 14. Bay-wide trends in total phytopigment concentrations over 2000-2014. Only the post-break trend is statistically significant.

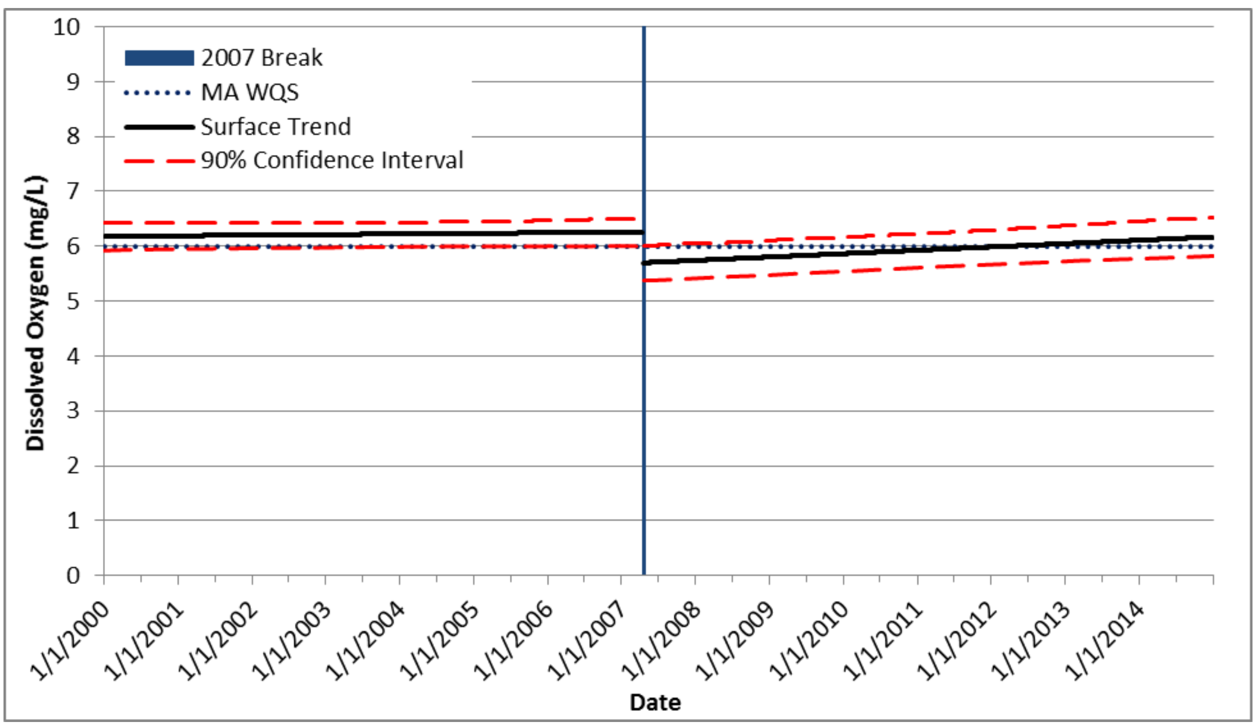


Figure 15. Bay-wide trends in dissolved oxygen concentrations over 2000-2014. Only the post-break trend is statistically significant.

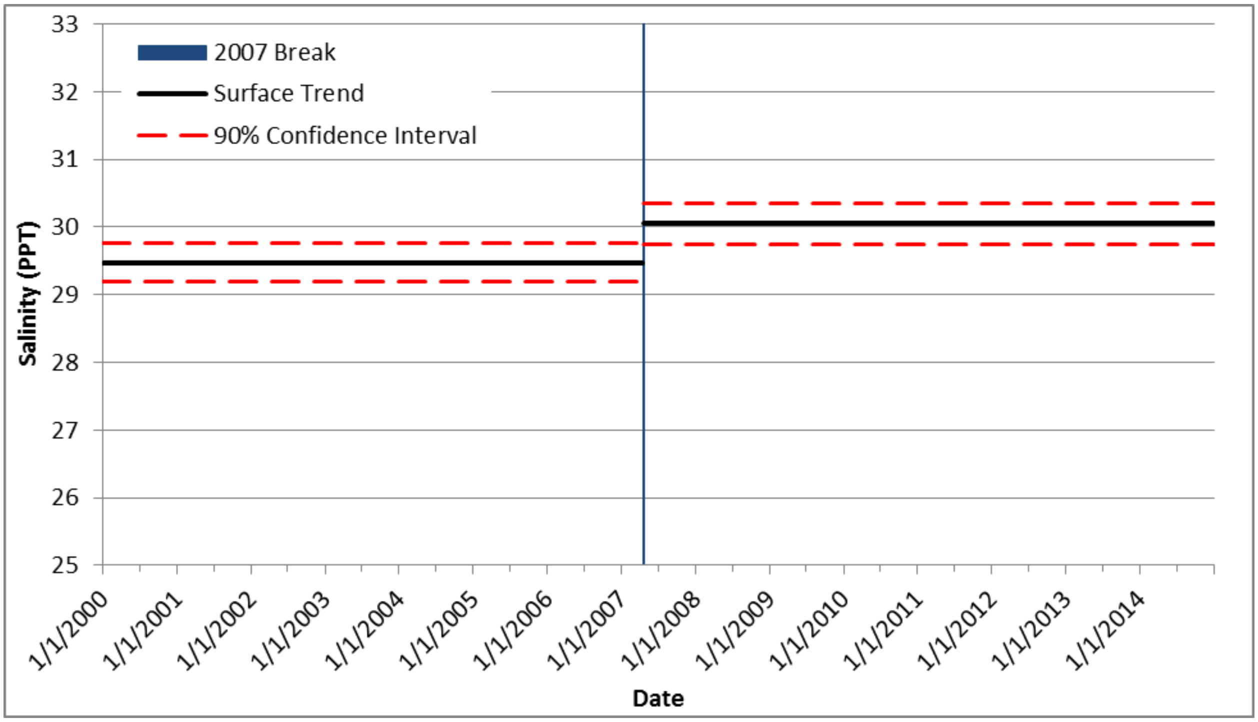


Figure 16. Bay-wide trends in salinity concentrations over 2000-2014. The post-break step change is statistically significant.

Conclusions

Trend analysis results underscore the variability of conditions and complexity of water quality relationships throughout Pleasant Bay. Varied conditions throughout the Bay are reflected in differences in the direction and presence of trends among monitoring stations, while the lack of consistent trends between parameters reflect the complexity of relationships between nutrient inputs, nutrient cycling, ecosystem responses to nutrient enrichment. Overall, trend analysis results do not show that eutrophication has improved or worsened at any one location or bay-wide. However, some stations have trends in individual parameters that suggest increased or decreased nutrient loading and these can be reviewed in conjunction with information on recent restoration efforts to gauge their effectiveness or to highlight areas as future restoration priorities. Furthermore, the presence of opposing trends in nutrient and response parameters (e.g., increasing nutrient concentrations but decreasing total phytopigment concentrations) merits further investigation of nutrient inputs, nutrient cycling, and ecosystem responses to changing nutrient levels in Pleasant Bay.

The trends presented in this report do not explicitly depict water quality as “good” or “bad”. Such classifications are typically made by evaluating whether sample data are above or below a numeric target. Trend analysis instead describes the relationship between water quality and time during the period of analysis, specifically whether concentrations have increased or decreased. Targets for water quality parameters analyzed in this study include dissolved oxygen concentrations above 6 milligrams per liter, total phytopigment concentrations below 5 micrograms per liter, and bioactive nitrogen concentrations between 0.098 and 0.405 milligrams per liter (bioactive nitrogen targets vary by station). Although trend analysis results show improved conditions for some parameters in portions of Pleasant Bay, sample data show that numeric targets were consistently not achieved in recent years. For example, the Namequoit-South station (PBA-12) has improving trends in five of the six eutrophication-related parameters analyzed (the exception is dissolved inorganic nitrogen) but 80% of samples collected in 2014 (eight of ten samples) do not meet the dissolved oxygen target. Such results illustrate continued effort is needed to restore the Pleasant Bay ecosystem and why trend analysis results should be one of several pieces of information used to guide restoration planning.

The trend analysis results presented in this report are <u>not</u> intended to be used to draw conclusions on the role of the 2007 break as a driver of water quality change in Pleasant Bay. Trend analysis showed a significant post-break change for some station-parameter pairs and for all parameters in the bay-wide analysis. In some cases, the post-break change is consistent with the expected effect of the break (e.g., the increase in bay-wide salinity concentrations following the break, possibly due to increased exchange of open ocean water). However, increased or decreased concentrations in samples collected after the 2007 break alone do not supply definitive evidence that the break caused a water quality change. Analysis of other potential drivers of change (e.g., trends in nutrient loads from Pleasant Bay tributaries) are needed in order to determine the influence of the 2007 break but such analyses were beyond the scope of this study. Finally, trend analysis results are also <u>not</u> intended to be used for prediction of future conditions. Pleasant Bay is a dynamic system, and conditions in future years may drastically differ from the conditions that contributed to observed trends from 2000-2014. Continued monitoring is needed to characterize water quality in the coming years and additional sample data may allow for the identification of trends not detected in the 2000-2014 dataset.

References

Applied Coastal Research and Engineering, Inc. (2008). Memo to U.S. Army Corps of Engineers. *Hydrodynamic Model of Chatham Harbor/Pleasant Bay including 2007 North Breach*.

Baayen, R., Davidson, D., & Bates, D. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of memory and language, 59*(4), 390-412.

Bates, D., & Maechler, M. (2010). *Linear mixed-effects models using S4 classes*. Retrieved from http://lme4.r-forge.r-project.org/

Burnham, K., & Anderson, D. (2002). *Model selection and multimodel inference: a practical information-theoretic approach.* Springer-Verlag: New York, New York.

Draper, N., & Smith, H. (1998). *Applied Regression Analysis.* New York: John Wiley and Sons.

Hirotugu, A. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control* , 716-723.

Howes, B., Samimy, R., Schlezinger, D., Kelley, S., Ramsey, J., & Eichner, E. (2006). *Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster and Harwich, Massachusetts.* Boston, MA: Massahusetts Estuaries Project, Massachusetts Department of Environmental Protection.

Iglewicz, B., & Hoaglin, D. (1993). Volume 16: How to Detect and Handle Outliers. In E. Mykytka, *The ASQC Basic References in Quality Control: Statistical Techniques.*

Pleasant Bay Resource Management Alliance. (2001). *QAPP for the Pleasant Bay Citizen Water Quality Monitoring Program.* Brewster, Chatham, Harwich, and Orleans.

The Cadmus Group. (2010). *Pleasant Bay Alliance Water Quality Monitoring Program: Statistical Analysis of Multi-year Water Quality Monitoring Data.*

Appendix A. Detailed Methods

Data Compilation

Water quality data files were provided to Cadmus by the Pleasant Bay Alliance (PBA). These files included a Microsoft Access database containing 2000-2009 monitoring results compiled as part of the previous water quality data analysis project (The Cadmus Group, 2010) and Microsoft Excel spreadsheets containing 2010-2014 monitoring results.

The 2010-2014 spreadsheets were combined into a single spreadsheet and edited so that field (column) names and formats matched field names and formats in the "All_data" table in the Access database. Some fields were not present in the original 2010-2014 spreadsheets and were either filled using information from other fields or left blank. These included:

- ID (filled by concatenating "Program"-"Station" fields)
- SDID (filled by concatenating "ID"-"Date" fields)
- SDDID (filled by concatenating "ID"-"Date"-"Depth" fields)
- Year (filled with year from "Date" field)
- Analysis_Site (filled using list of monitoring sites in Pleasant Bay provided by PBA)
- TP (left blank)
- Serial (left blank)
- Sample (left blank)
- Location_description (left blank)

Notes fields were added for each water quality parameter to store non-numeric entries in results fields. For samples reported as "BDL" (below detection limit) or "<X" (where X is the detection limit), the numeric value was entered as one-half the detection limit. 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).

The combined 2010-2014 spreadsheet was imported into the Access database and stored in a table named "All_data_2010_2014". Access generates a list of import errors that primarily indicate data type mismatches between the source 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.

Data Review

Identifying Suspect Data Points and Outliers

The 2010-2014 dataset was reviewed to identify potential measurement or data entry errors and to characterize the prevalence of outliers for the following parameters:

- Water Temperature
- Dissolved Oxygen
- Salinity (lab measured *not* field measured values)
- Secchi Depth
- Phosphate (PO_4)
- Dissolved Organic Nitrogen (DON)
- Total Dissolved Nitrogen (TDN)
- Particulate Organic Nitrogen (PON)
- Total Nitrogen (TN)
- Particulate Organic Carbon (POC)

- Ammonium (NH_4)
- Nitrate Plus Nitrite (NO_x)
- Dissolved Inorganic Nitrogen (DIN)
- Chlorophyll-a (Chla)
- Phaeophyton
- Total Pigments

Methods applied to identify suspect data points and outliers in the 2010-2014 dataset are consistent with those previously applied to the 2000-2009 dataset (The Cadmus Group, 2010). Minimum and maximum values of each parameter were initially examined to identify values that fell outside of typical ranges. This step identified one water temperature value entered as 82.5°C, one NO_x value entered as 0, and one DO concentration entered as 62 mg/L.

Modified z-scores (Iglewicz & Hoaglin, 1993) were then calculated for each variable. With the exception of water temperature, dissolved oxygen, and salinity, all parameters were log-transformed before calculating modified z-scores because their histograms demonstrated a log-normal distribution. Absolute values of modified z-scores >3.5 were flagged as outliers. Outliers were reviewed and shared with PBA to compare to original monitoring logs. This step identified two additional DO concentrations of 19.6 mg/L and 19.0 mg/L as entry errors. All entry errors were replaced with corrected values in the Access database.

A large number of outliers in a dataset can inhibit the detection of trends over time. Most parameters in the 2010-2014 dataset have few outliers (≤2% of observations; Table 6). Parameters with higher outlier counts include chlorophyll-a and salinity. Chlorophyll-a is not included in trend analysis (see *Analysis of Water Quality Trends* in this Appendix). Salinity is included in trend analysis and the prevalence of outliers was determined not to be problematic because most outliers were collected from freshwater monitoring sites, which are excluded from station-specific and bay-wide analysis of salinity trends.

Table 7. Number of outliers in the 2010-2014 dataset for each parameter (based on modified z-scores).

Parameter	No. of Observations	No. of Outliers	Percent Outliers
Water Temperature	1,039	13	1%
Salinity (Lab)	1,090	63	6%
Dissolved Oxygen	1,019	8	1%
Secchi Depth	585	3	1%
PO_4	1,097	1	<1%
NH_4	1,096	1	<1%
NO_x	1,097	5	<1%
DIN	1,096	2	<1%
DON	1,096	1	<1%
TDN	1,096	1	<1%
PON	1,101	19	2%
TN	1,095	2	<1%
POC	1,101	23	2%
Chlorophyll-a	1,097	14	1%
Phaeopytin	1,097	102	9%
Total Pigments	1,097	15	1%

Review of Duplicate Samples

Duplicate samples are samples collected at the same time and location for quality control purposes. Most trend analysis methods assume that each observation in a dataset is independent of any other observation. Duplicate samples with values that are similar (e.g., sample 1 equal to sample 2) violate this assumption. Conversely, duplicate samples with different values suggest that collection, handling, or equipment error occurred for that sample pair.

The 2010-2014 monitoring dataset includes approximately 185 duplicate samples for a given parameter (the exact number varies by parameter). The similarity of duplicate samples was evaluated by reviewing scatterplots and Pearson correlation coefficients between paired values. All parameters show moderate to high correlation between duplicates (correlation coefficients > 0.5; Table 8). PO_4 duplicates were the most consistently similar (correlation coefficient = 0.99) and phaeophytin duplicates were the most variable (correlation coefficient = 0.57).

To address the lack of independence of duplicate samples, values were combined into a single result (the average of the two samples) for statistical and trend analysis. Duplicate pairs with one value differing by more than 150% of the average were assumed to contain measurement errors and were discarded from statistical and trend analysis. Both approaches are consistent with methods previously applied to the 2000-2009 monitoring dataset (The Cadmus Group, 2010).

Table 8. Summary of duplicate samples in the 2010-2014 dataset.

Parameter	Number of Duplicate Pairs	Correlation Coefficient	Number of Pairs to Remove
Salinity (Lab)	183	0.79	0
PO_4	185	0.99	0
NH_4	185	0.87	1
NO_x	185	0.94	2
DIN	185	0.88	1
DON	185	0.53	1
TDN	185	0.64	0
PON	186	0.95	0
TN	184	0.73	0
POC	186	0.93	0
Chlorophyll-a	186	0.93	1
Phaeophytin	186	0.57	18
Total Pigments	186	0.95	1

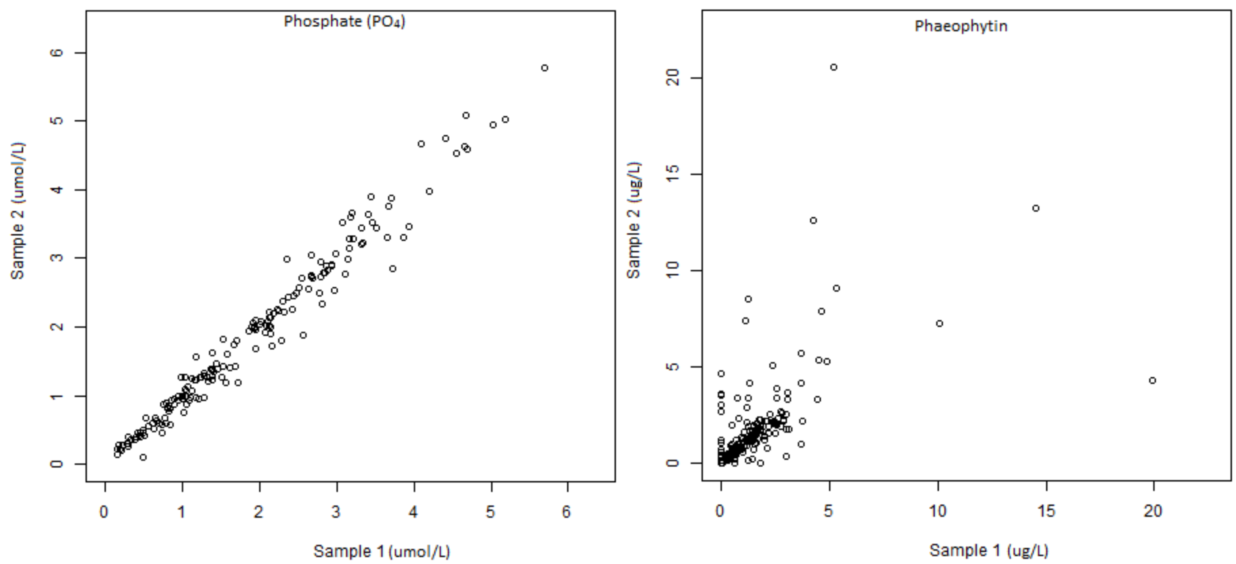


Figure 17. Example scatterplots for duplicate samples displaying high correlation (phosphate; left) and moderate correlation (phaeophytin; right) between pairs.

Review of Paired Surface-Bottom Samples

Paired surface-bottom samples are samples collected from different depths at the same time and monitoring site. Like duplicate samples, surface-bottom samples can violate the independence assumption of trend analysis techniques.

The 2000-2014 monitoring dataset includes approximately 1,470 paired surface-bottom samples for a given parameter (the exact number varies by parameter). The similarity of surface-bottom samples was evaluated by reviewing scatterplots and Pearson correlation coefficients between paired values. Additionally, Student's t-test for paired samples was used to test whether the mean of surface samples significantly differed the mean of bottom samples. With the exception of water temperature, salinity, and dissolved oxygen, all parameters were log-transformed for comparing surface and bottom samples. This was completed because one assumption of Student's t-test is that variables are normally distributed and histograms indicated that most parameters were log-normally distributed.

All parameters except for dissolved oxygen show moderate to high correlation between surface and bottom samples (correlation coefficients > 0.5; Table 9). Differences between surface and bottom means are statistically significant (at $p < 0.05$) for twelve parameters. Of these, surface samples were greater in magnitude than bottom samples for salinity, PO_4, NH_4, DIN, PON, POC, phaeophytin, and total pigments while bottom samples were greater than surface samples for water temperature, dissolved oxygen, NO_x, and DON. No significant difference was found between surface and bottom samples for TDN, TN, and chlorophyll-a.

One method to account for differences between surface and bottom conditions in Pleasant Bay is to perform separate trend analyses on surface and bottom samples. However, this approach reduces the sample size in each analysis and smaller sample size corresponds to reduced statistical power to detect true trends. An alternative is to include both surface and bottom samples in a single trend analysis and to use sample depth as a predictor variable in regression models. This approach was followed for analysis of trends in the 2000-2014 monitoring dataset.

Table 9. Results of t-tests comparing 2000-2014 paired surface-bottom samples. P-values less than 0.05 indicate a statistically significant difference between surface and bottom values. Note that t-tests were applied to log-transformed sample data for all parameters except water temperature, dissolved oxygen, and salinity. Log-transformed means were back-transformed to original units for reporting.

Parameter	No. Surface-Bottom Pairs	Pearson Correlation	Mean Surface	Mean Bottom	p-value for Mean Difference
Water Temperature (^oC)	1,494	0.93	21.2	21.7	$2.5x10^{-52}$
Salinity (ppt)	1,463	0.71	30.0	29.7	$1.8x10^{-21}$
Dissolved Oxygen (mg/L)	1,469	0.68	5.4	6.0	$3.5x10^{-67}$
PO_4 (µmol/L)	1,471	0.86	1.4	1.3	$1.9x10^{-19}$
NH_4 (µmol/L)	1,471	0.66	3.3	2.6	$1.6x10^{-23}$
NO_x (µmol/L)	1,469	0.67	0.5	0.5	$1.7x10^{-7}$
DIN (µmol/L)	1,468	0.68	4.1	3.5	$1.8x10^{-14}$
DON (µmol/L)	1,463	0.60	27.3	28.7	$7.6Ex10^{-6}$
TDN (µmol/L)	1,463	0.62	33.0	33.4	0.35
PON (µmol/L)	1,449	0.55	8.6	7.9	$3.3x10^{-11}$
TN (µmol/L)	1,443	0.57	43.3	42.6	0.09
POC (µmol/L)	1,456	0.53	57.0	51.3	$1.5x10^{-18}$
Chlorophyll a (µg/L)	1,461	0.60	3.6	3.6	0.89
Phaeophytin (µg/L)	1,461	0.56	0.9	0.8	$1.5x10^{-7}$
Total Pigments (µg/L)	1,461	0.65	5.4	5.1	$1.2x10^{-4}$

Calculating Summary Statistics

Annual means and confidence intervals around the mean were calculated by year across the range of available data for the following water quality parameters:

- Dissolved Oxygen
- Phosphate
- Dissolved Inorganic Nitrogen
- Bioactive Nitrogen (Dissolved Inorganic Nitrogen + Particulate Organic Nitrogen)
- Total Nitrogen
- Total Pigments

The geometric mean (mean of log-transformed values, back-transformed to the original scale) was used for dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, phosphate, and total pigments because histograms indicated these variables are log-normally distributed. The arithmetic mean was used for dissolved oxygen because histograms indicated they are normally distributed.

Confidence intervals for annual means were calculated at the 90% confidence level. This means that if the same methods were applied to select different samples and compute new confidence intervals, we would expect the true annual mean to fall within the computed interval 90% of the time. Confidence intervals were calculated as:

$$\bar{Y} \pm t^* \frac{s}{\sqrt{N}}$$

where $\bar{Y}$ is the sample mean, s is the sample standard deviation, N is the sample size, and t^* is the 95th percentile of the t-distribution with N-1 degrees of freedom.

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 site) were also calculated for each site-year pair.

Tables of annual means and confidence intervals are provided in Appendix B. Tables of exceedance frequencies are provided in Appendix C.

Analysis of Water Quality Trends

Station-Specific Trends

Multiple linear regression was used to evaluate trends in seven water quality parameters at 20 monitoring sites in Pleasant Bay. Although there are 34 monitoring stations in the 2000-2014 dataset, 14 stations are either not actively sampled or contain large data gaps and were excluded from station-specific analysis. These stations are: CM-14, PBA-1, PBA-2, PBA-7, PBA-18, PBA-19, PBA-20, PBA-21, WMO-2, WMO-4, WMO-7, WMO-8, WMO-9, PBA-17A. The seven water quality parameters analyzed were:

- Dissolved Inorganic Nitrogen
- Bioactive Nitrogen
- Total Nitrogen
- Phosphate
- Total Phytopigments
- Dissolved Oxygen
- Salinity

Station-specific trends were analyzed using the "lm" package in the R statistical language. Nine candidate multiple linear regression models were created for each site-parameter pair using different combinations of the following predictor variables:

- Sample date
- "Break" term denoting whether the sample was collected before or after the 2007 Nauset Beach break (coded as 0 if sample was collected before break and 1 if sample was collected after break)
- "Date-Break" interaction term representing the combined effect sample date and the 2007 Nauset Beach break
- Logarithm of 7-day rainfall prior to sample collection measured at Chatham Municipal Airport
- Lab-measured sample salinity[3]
- Field-measured water temperature at the time of sample collection
- Sample depth

[3] Salinity was included as a predictor variable for dissolved oxygen, phosphate, dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, and total phytopigments. Salinity was not included as a predictor variable for models with salinity as the response variable.

Table 10 lists the different combinations of predictor variables used in the nine candidate models. The "best" model for each parameter out of the nine candidates was identified using Akaike's Information Criterion (AIC) (Hirotugu, 1974), a measure of relative quality within a collection of regression models. This approach identifies the model that provides the most explanatory power while minimizing the number of predictor variables. The simplest possible model is preferred unless an additional predictor variable provides significantly more explanatory power. Identification of the best model also considered the number of sample data points available for analysis. The rule of thumb in multiple linear regression is that one predictor variable per 20 samples should be included in the model. After selecting the best model for each of the site-parameter pair, the statistical significance of the trend over time was evaluated using the p-value for the slope of sample date, break, and the date-break interaction term (if included in the best model) and a significance level of 0.05.

The candidate regression equations described one of three trend types:

1. Monotonic change over time that is not affected by the 2007 Nauset Beach break (equations 1 through 3 in Table 10);
2. Step change following the 2007 Nauset Beach break (equations 4 through 6 in Table 10);
3. Monotonic change over time with a slope change following the 2007 Nauset Beach break (equations 7 through 9 in Table 10).

Results of station-specific trend analysis are presented in Appendix D and Appendix F.

Table 10. Nine candidate multiple linear regression models evaluated for analysis of station-specific trends. Models differ in the predictor variables used (variables on the right-hand side of each equation). Predictor variables included sample date (Date), "Break" term denoting whether the sample was collected before or after the 2007 Nauset Beach break, Date-Break interaction term representing the combined effect sample date and the 2007 break (Date:Break), logarithm of 7-day rainfall prior to sample collection (Rain), lab-measured sample salinity (Salinity), field-measured water temperature at the time of sample collection (Temp), and sample depth (Depth).

Model Equations
1) Response = Date
2) Response = Date + Depth
3) Response = Depth + Depth + Temp + Rain + Salinity
4) Response = Break
5) Response = Break + Depth
6) Response = Break + Depth + Temp + Rain + Salinity
7) Response = Date + Break + Date:Break
8) Response = Date + Break + Date:Break + Depth
9) Response = Date + Break + Date:Break + Depth + Temp + Rain + Salinity

Bay-Wide Trends

Mixed effects models were used to evaluate bay-wide trends in dissolved oxygen, salinity, phosphate, dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, and total phytopigments using the "lmer" function (Bates & Maechler, 2010) in the R programming language. Six candidate models were created for each parameter using different combinations of the following predictor variables:

- Sample date

- “Break” term denoting whether the sample was collected before or after the 2007 Nauset Beach break (coded as 0 if sample was collected before break and 1 if sample was collected after break)
- “Date-Break” interaction term representing the combined effect sample date and the 2007 Nauset Beach break
- Logarithm of 7-day rainfall prior to sample collection measured at Chatham Municipal Airport
- Lab-measured sample salinity[4]
- Field-measured water temperature at the time of sample collection
- Sample depth

All candidate models included sample depth as a predictor variable with a fixed effect on the response variable. All candidate models also included site ID as a predictor with a random effect on the intercept, Date slope, Break slope, and Date-Break interaction slope. Candidate regression equations are shown in Table 11.

Like the station-specific trend analysis, the candidate regression equations described one of three trend types:

1. Monotonic change over time that is not affected by the 2007 Nauset Beach break (equations 1 and 1C in Table 11);
2. Step change following the 2007 Nauset Beach break (equations 2 and 2C in Table 11);
3. Monotonic change over time with a slope change following the 2007 Nauset Beach break (equations 3 and 3C in Table 11).

For each of the above, two separate candidate models were developed, one with no additional predictor variables and one including salinity, temperature, and 7-day rainfall as additional predictors.

Table 11. Six candidate mixed effects models evaluated for analysis of bay-wide trends. Models differ in the predictor variables used (variables on the right-hand side of each equation). Predictor variables included sample date (Date), “Break” term denoting whether the sample was collected before or after the 2007 Nauset Beach break, “Date-Break” interaction term representing the combined effect sample date and the 2007 break (Date:Break), logarithm of 7-day rainfall prior to sample collection (Rain), lab-measured sample salinity (Salinity), field-measured water temperature at the time of sample collection (Temp), and sample depth (Depth).

Model Number	Model Equation
1	Response = Date + Depth
1C	Response = Date + Depth + Salinity + Temp + Rain
2	Response = Break + Depth
2C	Response = Break + Depth + Salinity + Temp + Rain
3	Response = Date + Break + Date:Break + Depth
3C	Response = Date + Break + Date:Break + Depth + Salinity + Temp + Rain

The “best” bay-wide model for each water quality parameter from the six candidates was selected using AIC values to find the model that provided the most explanatory power while minimizing the number of predictor variables.

[4] Salinity was included as a predictor variable for dissolved oxygen, phosphate, dissolved inorganic nitrogen, bioactive nitrogen, total nitrogen, and total phytopigments. Salinity was not included as a predictor variable for models with salinity as the response variable.

After selecting the best model for each of the seven water quality parameters, the statistical significance of the trend over time was evaluated using the p-value for the slope of sample date, break, and the date-break interaction term (if included in the best model) and a significance level of 0.05. P-values for model coefficients were estimated using the "summary" function of the "lmerTEST" package in R.

Results of bay-wide trend analysis are presented in Appendix E.

Appendix B. Summary Statistics Tables

The following tables present summary statistics for each site 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.

Dissolved Inorganic Nitrogen

Site		Dissolved Inorganic Nitrogen (µg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	32	19	25	32	36	23	39	53	68	58	64	79	153	88	76
	90% CI	23	15	18	15	27	16	27	47	52	50	52	55	116	69	57
		45	25	33	69	48	34	57	60	89	67	79	115	201	113	100
CM-14	Mean	124	91	112	151	131	123									
	90% CI	67	25	61	69	85	57									
		230	325	206	331	203	263									
PBA-1	Mean	19	12	20	20	12	20	29							42	53
	90% CI	14	7	16	10	7	13	18							33	38
		27	21	25	39	22	31	47							53	74
PBA-2	Mean	37	15	26	35	23										
	90% CI	23	7	19	28	12										
		61	30	36	46	43										
PBA-3	Mean	39	35	40	67	111	51	92	101	102	92	112	145	106	29	64
	90% CI	25	25	27	38	70	26	51	53	65	29	81	78	77	22	48
		60	49	61	120	175	100	166	191	158	287	155	270	146	38	86
PBA-4	Mean	70	40	58	80	80	57	73	67	43	52	92	51	90	42	33
	90% CI	42	20	40	46	57	43	40	43	31	31	58	34	74	34	28
		115	83	82	138	112	75	131	103	60	89	145	75	110	52	39
PBA-5	Mean	30	12	51	25	64	64	252	81	30	73	89	74	69	21	46
	90% CI	16	5	18	4	40	25	127	12	7	8	48	43	38	9	14
		56	24	147	148	105	165	498	527	135	667	165	126	123	50	153
PBA-5A	Mean			156	328	313	544	370	149	351	462	303	305	60	116	205
	90% CI			46	150	192	260	273	30	222	290	143	148	32	68	102
				525	718	512	1,139	503	740	556	735	640	627	112	198	413
PBA-6	Mean	23	27	22	39	18	22					17	28	47	18	32
	90% CI	12	13	13	24	11	15					11	17	38	10	22
		45	54	38	64	30	31					29	46	58	31	46
PBA-7	Mean	41	15	22	34	20	20									
	90% CI	23	7	17	20	12	10									
		74	32	29	56	33	37									
PBA-8	Mean	41	11	20	34	20	18	45	29	17	27	33	73	94	100	31
	90% CI	35	7	16	21	13	13	29	20	10	22	24	44	78	60	21
		48	17	25	55	32	25	69	43	30	33	47	121	114	166	45
PBA-9	Mean	46	27	29	51	63	24	88	54	28	51	57	74	111	43	43
	90% CI	34	19	18	34	49	17	58	35	12	43	37	51	96	31	26

		61	39	46	77	83	36	135	84	66	60	86	108	129	60	71
PBA-10	Mean	21	23	30	52	41	37	50	53	34	34	59	61	60	38	43
	90% CI	12	15	24	40	28	26	33	33	21	19	46	48	50	26	27
		37	37	38	68	61	53	77	85	55	58	75	77	72	56	69
PBA-11	Mean	42	46	50	35	43	33	75	68	28	33	51	35	70	34	35
	90% CI	25	28	30	15	32	23	33	43	17	21	38	22	46	14	18
		71	76	84	85	58	48	171	107	46	52	67	56	108	83	71
PBA-12	Mean	107	35	74	97	74	45	53	87	43	40	51	52	92	49	60
	90% CI	51	24	49	71	56	38	37	64	38	32	46	37	78	38	47
		226	51	111	133	97	53	76	118	50	51	57	71	108	64	76
PBA-13	Mean	72	43	76	73	76	43	77	95	73	63	103	65	132	87	105
	90% CI	46	28	56	48	56	26	60	66	55	49	90	47	115	66	83
		111	67	103	111	102	72	99	137	97	82	116	89	153	114	133
PBA-14	Mean	126	88	98	76	99	88	150				113	113	147	101	118
	90% CI	99	66	60	45	77	57	103				69	87	104	72	84
		160	116	158	130	127	136	220				184	147	209	142	165
PBA-15	Mean	104	69	124	125	141	126	91	121	185	94	118	119	144	58	96
	90% CI	79	51	81	73	113	98	47	92	148	70	91	87	110	36	68
		137	93	189	213	177	162	173	161	231	126	152	163	189	93	135
PBA-16	Mean	151	125	128	224	92	97	106				201	130	142	126	128
	90% CI	103	41	55	97	48	47	40				144	92	113	98	102
		222	385	295	515	179	199	285				280	185	178	161	161
PBA-17A	Mean											34	41	41	24	21
	90% CI											23	17	25	13	12
												49	98	65	42	36
PBA-18	Mean			18	26	13	20									
	90% CI			15	19	9	15									
				22	37	18	26									
PBA-19	Mean			37	13	47	101								24	57
	90% CI			15	4	28	52								20	35
				90	43	78	198								28	95
PBA-20	Mean			31	31	17	24								17	72
	90% CI			16	20	9	19								9	52
				59	47	29	31								32	101
PBA-21	Mean			44	53	39	31								34	38
	90% CI			30	40	30	24								26	27
				66	70	50	39								45	54
WMO-2	Mean		15	20	45	32										

	90% CI		8	10	26	18										
			28	40	78	56										
WMO-3	Mean		44	71	68	62		77	95	55	44	83	73	129	61	57
	90% CI		31	40	48	42		48	71	37	24	68	66	97	40	37
			63	124	96	92		126	125	81	80	100	81	171	93	87
WMO-4	Mean		63	132	106	101										
	90% CI		41	88	56	73										
			97	197	201	138										
WMO-5	Mean		79	136	173	132	112	122	128	105	135	94	123	188	74	89
	90% CI		46	58	115	103	57	70	74	79	92	68	93	136	55	66
			137	319	260	168	220	214	222	140	199	130	163	260	99	120
WMO-6	Mean		205	112	83	109		160	124	103	83	148	117	136	79	101
	90% CI		110	69	44	83		110	48	83	38	76	79	104	59	67
			380	184	153	142		234	319	127	183	288	174	178	105	154
WMO-7	Mean		153	103	84	93										
	90% CI		70	55	53	73										
			337	191	132	118										
WMO-8	Mean		64	111	127	98									68	117
	90% CI		22	68	71	74									58	69
			188	180	228	131									78	200
WMO-9	Mean		115	114	130	146	77									121
	90% CI		97	56	81	107	38									
			136	233	207	199	152									
WMO-10	Mean		69	95	143	125		119	125	151	101	130	114	152	109	109
	90% CI		25	56	84	65		71	68	137	82	106	90	132	88	84
			195	159	241	239		197	227	167	124	159	146	175	136	143
WMO-12	Mean		46	43	72	89						102	150	125	99	99
	90% CI		23	16	41	64						56	99	57	52	68
			89	120	126	124						187	228	273	190	144

Bioactive Nitrogen

Site		Bioactive Nitrogen (µg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	166	137	189	163	164	122	125	141	155	141	132	208	255	163	152
	90% CI	148	127	174	139	149	99	100	122	137	126	115	185	205	143	128
		185	149	205	192	179	150	155	162	177	158	151	234	316	187	179
CM-14	Mean	367	244	273	294	270	227									
	90% CI	295	120	197	190	190	126									
		457	497	376	455	384	411									
PBA-1	Mean	133	92	124	98	91	84	72							93	128
	90% CI	119	81	115	83	79	77	64							88	106
		148	104	134	116	106	93	81							99	153
PBA-2	Mean	151	106	134	106	101										
	90% CI	126	93	103	88	88										
		180	121	174	127	115										
PBA-3	Mean	190	174	251	290	331	256	227	272	225	241	223	315	258	143	171
	90% CI	165	143	222	217	267	211	167	182	183	155	190	249	208	126	148
		219	212	282	386	410	311	308	407	277	374	262	399	322	163	196
PBA-4	Mean	217	190	226	219	191	159	171	161	129	176	166	140	183	130	121
	90% CI	180	131	195	182	158	136	122	134	117	117	120	118	166	117	116
		263	275	261	264	231	187	241	192	142	263	229	166	202	145	126
PBA-5	Mean	225	232	238	270	234	221	403	325	276	265	228	351	246	322	232
	90% CI	163	183	178	202	172	189	291	225	185	114	164	244	202	263	173
		311	295	317	362	319	259	559	471	410	616	318	506	300	394	312
PBA-5A	Mean			531	617	576	824	591	795	702	674	756	436	834	637	577
	90% CI			244	462	441	522	465	536	558	520	535	280	627	589	392
				1,156	823	754	1,300	751	1,179	883	872	1,067	677	1,109	689	848
PBA-6	Mean	221	198	214	181	158	175					138	264	148	159	162
	90% CI	156	150	190	148	142	159					110	184	116	139	146
		313	263	241	221	176	194					173	378	190	182	179
PBA-7	Mean	179	141	172	149	146	147									
	90% CI	149	115	142	126	125	109									
		214	173	207	177	171	197									
PBA-8	Mean	169	135	191	164	132	138	147	114	114	127	98	216	172	224	133
	90% CI	137	114	155	131	119	113	112	98	91	87	89	159	155	182	112
		208	160	235	205	147	169	194	132	142	187	107	294	192	276	158
PBA-9	Mean	254	236	286	247	216	214	252	204	231	180	222	194	251	243	252
	90% CI	198	185	243	221	203	191	223	183	197	140	197	163	235	207	223

		325	302	338	276	229	239	285	226	272	233	251	232	268	286	286
PBA-10	Mean	171	162	186	208	179	161	174	150	210	150	186	221	215	223	228
	90% CI	127	133	170	182	159	137	150	124	175	130	165	185	195	191	192
		229	198	205	238	202	190	203	182	252	173	209	264	238	260	271
PBA-11	Mean	192	248	237	356	251	211	262	142	119	164	160	163	228	274	210
	90% CI	146	152	196	208	181	155	143	112	91	104	122	143	153	154	133
		254	405	288	608	349	287	482	180	155	259	209	186	340	488	329
PBA-12	Mean	254	126	198	183	168	135	128	170	115	134	119	260	166	112	151
	90% CI	177	110	162	148	157	119	101	136	102	107	109	160	148	97	140
		364	143	242	226	181	154	163	212	130	167	129	423	187	130	162
PBA-13	Mean	170	135	193	206	168	147	155	170	134	135	174	149	199	156	174
	90% CI	137	117	170	174	152	134	129	139	108	116	158	133	178	133	148
		212	156	218	244	184	162	186	207	167	158	191	168	222	183	205
PBA-14	Mean	305	255	328	290	334	313	325				289	227	375	319	302
	90% CI	239	213	270	250	307	281	246				266	184	340	254	254
		390	305	399	337	363	350	430				313	279	413	402	361
PBA-15	Mean	272	190	348	320	335	302	294	274	312	201	247	308	265	199	218
	90% CI	199	177	263	253	274	271	233	228	282	183	230	270	242	174	192
		372	205	460	404	411	337	370	329	345	221	266	352	290	228	246
PBA-16	Mean	300	350	340	460	288	345	291				307	263	300	256	252
	90% CI	233	189	248	296	263	279	226				243	215	256	226	234
		387	646	465	716	315	428	374				386	321	351	291	270
PBA-17A	Mean											105	118	113	95	102
	90% CI											86	81	92	91	83
												130	170	138	99	125
PBA-18	Mean			158	108	122	101									
	90% CI			138	91	109	90									
				180	128	138	114									
PBA-19	Mean			200	109	141	188								78	143
	90% CI			125	90	113	123								69	110
				321	133	176	288								87	185
PBA-20	Mean			194	128	120	118								110	172
	90% CI			163	116	98	104								75	144
				232	142	145	134								160	205
PBA-21	Mean			165	149	116	109								114	120
	90% CI			142	128	101	95								104	106
				192	173	133	125								125	135
WMO-2	Mean		150	200	177	147										

	90% CI		123	177	148	128										
			182	227	211	168										
WMO-3	Mean		163	193	185	158		146	157	116	103	146	147	210	122	134
	90% CI		130	166	162	125		114	134	86	67	133	136	180	104	118
			204	224	213	199		187	184	156	159	160	159	246	144	152
WMO-4	Mean		212	270	257	198										
	90% CI		148	223	210	148										
			303	327	315	264										
WMO-5	Mean		240	262	345	248	235	235	231	214	245	219	243	342	182	222
	90% CI		144	158	240	166	163	167	164	182	152	170	207	280	145	180
			401	433	495	371	340	331	326	253	395	282	285	418	227	273
	Mean		342	242	277	305		293	307	212	209	282	268	252	195	213
WMO-6	90% CI		238	182	214	240		208	229	166	163	224	237	227	164	175
			491	322	358	389		412	411	271	267	355	302	281	232	260
WMO-7	Mean		285	216	218	206										
	90% CI		188	140	207	175										
			431	333	230	242										
WMO-8	Mean		203	210	242	212									138	196
	90% CI		153	159	185	175									120	149
			270	278	317	256									158	257
WMO-9	Mean		200	237	237	287	240									185
	90% CI		129	167	209	244	180									
			310	337	268	336	321									
WMO-10	Mean		213	241	308	322		289	281	263	200	234	241	259	212	217
	90% CI		175	198	221	251		246	255	236	178	214	220	248	187	197
			260	295	431	414		340	309	293	225	257	265	271	240	238
WMO-12	Mean		206	185	206	196						208	282	291	277	248
	90% CI		153	123	171	159						138	232	190	212	211
			276	277	248	243						315	344	445	362	293

Total Nitrogen

Site		Total Nitrogen (µg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	442	410	468	456	425	365	424	435	446	554	672	571	750	719	534
	90% CI	403	371	377	396	387	329	384	367	418	504	527	510	633	553	453
		485	452	581	524	467	405	468	516	476	609	857	639	887	936	630
CM-14	Mean	1,176	706	1,359	1,144	1,000	1,113									
	90% CI	980	346	1,139	961	723	723									
		1,412	1,438	1,621	1,362	1,382	1,714									
PBA-1	Mean	528	503	454	405	340	273	419							364	519
	90% CI	440	363	366	319	264	234	328							268	427
		633	695	563	514	439	318	535							493	630
PBA-2	Mean	512	445	500	518	450										
	90% CI	406	381	315	401	309										
		646	519	793	669	657										
PBA-3	Mean	502	761	686	879	854	724	820	739	658	556	641	710	634	621	617
	90% CI	420	634	583	696	683	614	702	580	561	441	580	642	512	511	525
		601	914	808	1,111	1,067	854	959	943	771	702	710	785	785	754	726
PBA-4	Mean	772	963	1,128	660	642	678	574	727	514	560	700	702	955	607	548
	90% CI	585	786	1,052	548	536	579	492	561	449	425	563	661	860	489	490
		1,021	1,180	1,209	795	769	795	670	943	589	738	869	747	1,060	754	611
PBA-5	Mean	556	623	880	695	610	558	1,540	1,196	1,139	620	869	1,005	578	809	591
	90% CI	480	521	412	508	391	462	900	547	388	247	655	727	483	664	435
		645	745	1,881	950	950	674	2,635	2,615	3,341	1,559	1,155	1,389	693	986	802
PBA-5A	Mean			1,318	1,297	1,277	1,225	1,292	1,308	1,472	1,231	1,433	1,323	1,301	1,037	1,030
	90% CI			638	998	991	867	886	868	1,361	1,135	1,174	889	1,040	991	780
				2,724	1,684	1,646	1,730	1,884	1,970	1,593	1,336	1,748	1,969	1,627	1,085	1,361
PBA-6	Mean	576	578	539	514	474	408					433	587	416	399	344
	90% CI	430	498	438	459	366	375					404	450	356	359	325
		773	672	663	575	613	444					464	765	486	444	365
PBA-7	Mean	707	399	381	413	452	429									
	90% CI	596	366	329	380	376	370									
		839	436	441	449	544	499									
PBA-8	Mean	578	410	446	498	388	381	499	436	394	349	356	733	798	942	359
	90% CI	461	364	384	438	346	337	440	309	362	292	327	618	680	860	316
		725	461	518	565	435	431	565	615	429	417	387	871	936	1,032	409
PBA-9	Mean	742	661	811	882	555	513	753	558	546	500	530	543	615	584	588
	90% CI	628	561	665	759	507	470	672	491	506	423	485	491	557	521	523

		876	779	989	1,024	607	561	844	634	589	590	579	602	679	656	661
PBA-10	Mean	413	502	577	767	604	505	645	449	570	450	549	586	614	627	762
	90% CI	349	453	480	622	536	461	588	334	511	400	484	498	528	538	679
		488	556	692	946	680	553	707	603	636	507	622	689	714	730	855
PBA-11	Mean	524	1,081	694	884	773	634	789	596	457	465	534	529	564	677	566
	90% CI	452	720	588	650	678	546	533	456	396	364	459	443	451	470	453
		606	1,621	818	1,201	881	736	1,167	780	528	594	621	631	707	974	707
PBA-12	Mean	718	664	770	1,081	787	517	547	850	439	436	463	615	553	447	451
	90% CI	606	552	603	939	657	456	470	659	415	399	430	471	486	403	414
		852	800	982	1,245	941	587	637	1,097	465	476	497	804	631	495	491
PBA-13	Mean	588	581	619	601	528	535	591	524	533	484	619	587	683	651	498
	90% CI	501	466	521	547	471	475	526	433	430	401	519	503	521	536	406
		690	725	736	661	591	603	663	634	662	584	738	685	895	789	612
PBA-14	Mean	669	716	929	768	731	741	962				819	754	781	976	688
	90% CI	579	660	762	683	669	681	777				731	653	670	854	617
		772	778	1,133	864	800	806	1,192				917	871	909	1,116	768
PBA-15	Mean	705	647	1,059	903	807	732	839	883	871	650	613	815	977	566	663
	90% CI	556	617	858	775	667	663	709	707	775	585	587	724	858	534	589
		895	679	1,307	1,053	975	809	993	1,102	980	722	640	917	1,113	599	747
PBA-16	Mean	684	838	796	914	661	761	731				915	690	944	911	858
	90% CI	497	560	658	673	608	669	663				818	626	791	811	783
		941	1,253	963	1,241	718	865	807				1,023	761	1,127	1,024	940
PBA-17A	Mean											380	331	348	323	305
	90% CI											340	304	287	287	284
												425	361	421	362	327
PBA-18	Mean			540	568	452	319									
	90% CI			422	470	385	279									
				692	685	531	364									
PBA-19	Mean			962	640	614	881								321	605
	90% CI			621	477	557	666								262	433
				1,490	861	676	1,164								394	846
PBA-20	Mean			599	566	525	604								420	676
	90% CI			476	433	416	421								225	581
				752	739	664	865								785	786
PBA-21	Mean			573	614	568	480								557	456
	90% CI			415	526	480	399								486	392
				792	716	673	579								638	529
WMO-2	Mean		483	775	568	515										

	90% CI		389	563	481	408										
			599	1,067	670	650										
WMO-3	Mean		613	823	675	680		914	858	561	407	600	549	655	557	585
	90% CI		484	607	575	543		751	692	442	291	505	456	514	514	510
			776	1,115	793	851		1,111	1,063	711	569	714	661	835	604	670
WMO-4	Mean		695	847	780	692										
	90% CI		476	651	618	524										
			1,015	1,101	984	913										
WMO-5	Mean		787	799	947	825	630	786	770	701	684	690	727	754	767	804
	90% CI		515	575	745	554	536	737	683	626	582	620	665	622	654	674
			1,202	1,110	1,203	1,228	740	837	868	785	803	768	795	914	898	959
WMO-6	Mean		1,016	848	837	747		972	1,109	732	608	889	826	538	650	615
	90% CI		672	678	609	558		709	1,042	678	529	697	639	460	549	550
			1,534	1,062	1,150	998		1,333	1,179	791	698	1,133	1,067	630	771	688
WMO-7	Mean		973	764	748	583										
	90% CI		647	584	564	529										
			1,463	999	992	642										
WMO-8	Mean		821	978	794	659									679	633
	90% CI		545	799	622	479									490	515
			1,236	1,198	1,014	906									940	777
WMO-9	Mean		841	865	785	907	756									675
	90% CI		668	681	658	734	517									
			1,060	1,099	937	1,120	1,106									
WMO-10	Mean		907	878	1,419	970		787	635	666	518	622	610	559	617	563
	90% CI		561	764	906	737		663	595	627	483	595	572	496	573	524
			1,468	1,010	2,222	1,278		935	677	707	555	651	651	630	664	606
WMO-12	Mean		665	652	596	575						707	883	730	875	753
	90% CI		470	459	549	431						461	741	521	785	645
			943	925	648	766						1,083	1,054	1,023	976	878

Phosphate

Site		Phosphate (µg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	25	30	23	24	25	30	48	34	31	30	37	30	46	41	40
	90% CI	19	22	18	20	18	21	37	31	24	24	32	23	39	39	35
		33	40	29	29	36	44	61	38	38	39	43	37	53	44	45
CM-14	Mean	40	67	38	41	42	46									
	90% CI	30	17	29	32	26	24									
		55	262	50	52	69	86									
PBA-1	Mean	17	15	13	15	14	9	17							18	25
	90% CI	14	11	10	11	11	7	13							13	20
		20	20	17	21	18	13	22							23	31
PBA-2	Mean	24	27	24	24	26										
	90% CI	17	17	15	18	14										
		34	43	39	34	46										
PBA-3	Mean	32	38	25	29	24	30	44	32	34	27	39	27	44	40	39
	90% CI	24	31	19	21	16	19	27	24	27	20	35	21	38	35	34
		43	47	34	40	38	47	72	42	41	37	43	33	50	46	45
PBA-4	Mean	25	33	21	25	27	30	38	34	25	22	33	28	37	37	30
	90% CI	19	24	15	19	19	23	26	29	23	19	31	22	31	35	25
		32	45	28	33	37	39	55	39	29	26	35	35	42	39	35
PBA-5	Mean	30	17	30	16	27	27	62	38	27	28	51	33	53	12	17
	90% CI	24	8	16	4	14	15	40	19	3	21	38	22	45	5	6
		39	39	55	71	54	49	98	77	226	37	68	51	62	27	45
PBA-5A	Mean			41	29	41	15	20	22	26	57	32	51	35	14	18
	90% CI			20	15	27	7	9	12	14	45	21	37	14	5	7
				86	55	62	32	45	40	48	73	49	68	84	39	43
PBA-6	Mean	30	40	26	31	27	20					18	21	24	27	15
	90% CI	22	25	22	24	23	13					14	17	19	23	13
		40	64	31	42	31	33					24	27	31	31	18
PBA-7	Mean	31	32	25	31	27	25									
	90% CI	24	23	22	26	23	16									
		40	46	28	38	32	38									
PBA-8	Mean	31	31	23	30	26	28	48	24	17	20	23	22	26	28	14
	90% CI	26	21	18	24	20	21	40	20	13	17	21	19	22	27	12
		36	47	28	36	34	36	59	28	21	22	25	26	30	30	17
PBA-9	Mean	26	34	27	29	29	20	46	28	23	21	27	27	37	30	19
	90% CI	21	26	22	22	24	13	37	23	20	17	23	20	29	27	14

		33	45	33	39	35	29	57	34	26	27	32	37	46	35	27
PBA-10	Mean	31	42	36	35	35	34	51	31	24	25	27	27	42	37	31
	90% CI	25	32	32	29	31	26	41	29	22	21	21	21	37	33	24
		37	54	41	44	41	44	64	34	26	30	34	35	49	40	40
PBA-11	Mean	49	61	57	76	59	68	109	63	44	44	51	56	74	83	62
	90% CI	37	44	50	49	43	53	59	53	38	36	45	43	63	51	51
		66	85	65	116	82	86	202	76	51	53	58	74	87	135	75
PBA-12	Mean	53	68	55	53	50	57	73	51	38	36	43	42	64	64	53
	90% CI	40	50	47	39	33	44	53	47	32	30	36	34	57	54	49
		71	93	65	72	76	74	101	57	46	44	50	50	71	76	58
PBA-13	Mean	51	79	66	67	74	65	93	69	55	50	69	65	79	84	68
	90% CI	36	60	54	46	59	47	75	67	48	43	59	60	73	69	65
		71	103	79	98	92	89	114	70	62	59	80	72	85	102	70
PBA-14	Mean	63	108	83	91	87	90	126				105	78	88	95	90
	90% CI	48	82	65	66	65	68	96				89	68	81	77	84
		83	143	106	126	116	118	166				124	90	97	117	96
PBA-15	Mean	61	89	100	89	98	93	132	107	98	77	97	82	114	109	100
	90% CI	46	66	79	63	72	73	108	94	87	61	88	72	104	94	97
		81	120	127	127	135	119	162	122	110	97	107	93	125	126	104
PBA-16	Mean	84	182	104	181	90	111	131				120	81	108	122	100
	90% CI	43	79	73	98	73	74	95				90	69	95	106	93
		163	417	148	333	112	165	180				160	94	123	141	106
PBA-17A	Mean											11	13	9	15	10
	90% CI											8	10	7	8	8
												15	17	12	27	12
PBA-18	Mean			27	22	20	23									
	90% CI			19	17	14	18									
				38	29	28	29									
PBA-19	Mean			22	24	19	18								24	13
	90% CI			19	17	13	12								18	9
				26	35	30	29								33	20
PBA-20	Mean			27	27	24	27								27	10
	90% CI			23	21	18	20								25	8
				32	35	33	36								29	13
PBA-21	Mean			39	34	41	40								40	30
	90% CI			35	24	35	30								33	24
				43	50	48	53								49	37
WMO-2	Mean		26	29	33	26										

	90% CI		21	25	27	19										
			34	35	41	35										
WMO-3	Mean		69	85	62	43		99	69	61	49	59	59	77	84	66
	90% CI		54	73	39	24		76	53	48	29	49	52	66	66	65
			89	99	97	78		128	89	78	81	70	68	91	106	68
WMO-4	Mean		97	86	102	96										
	90% CI		73	62	54	58										
			130	120	193	157										
WMO-5	Mean		118	112	138	119	126	167	168	167	162	131	145	187	138	142
	90% CI		79	87	75	79	86	113	126	140	124	107	107	159	123	124
			176	144	256	178	184	246	223	200	211	162	198	219	155	162
WMO-6	Mean		89	77	89	84		123	102	81	75	95	77	98	98	98
	90% CI		65	53	48	50		89	89	62	50	73	55	88	71	94
			121	110	165	142		172	117	106	111	122	107	109	135	102
WMO-7	Mean		73	79	88	74										
	90% CI		38	49	52	42										
			139	125	147	129										
WMO-8	Mean		79	72	74	77									77	85
	90% CI		50	48	39	45									57	75
			127	110	141	132									103	95
WMO-9	Mean		69	76	81	86	85									83
	90% CI		33	50	43	55	50									
			148	116	153	136	145									
WMO-10	Mean		64	78	91	87		132	103	93	66	90	81	105	107	101
	90% CI		30	60	49	58		112	94	82	51	80	69	94	93	96
			137	102	167	130		155	113	106	87	101	95	116	124	106
WMO-12	Mean		51	48	43	53						42	35	54	43	46
	90% CI		41	39	32	40						37	27	47	37	40
			64	58	56	70						47	45	61	50	53

Total Phytopigments

Site		Total Phytopigments (µg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	6.0	5.3	6.5	4.0	6.9	5.4	4.5	5.4	3.7	5.2	3.3	3.6	3.7	2.1	1.9
	90% CI	5.1	4.9	5.1	3.2	5.3	4.2	3.6	4.7	3.0	3.3	2.7	3.1	2.9	1.6	1.7
		7.2	5.7	8.2	4.9	9.1	7.0	5.6	6.2	4.5	8.1	4.0	4.2	4.7	2.6	2.1
CM-14	Mean	9.6	5.4	6.1	4.7	5.9	5.7									
	90% CI	6.1	4.3	4.8	3.5	4.5	3.2									
		14.9	6.9	7.7	6.2	7.7	10.0									
PBA-1	Mean	5.4	3.9	4.4	2.1	3.6	3.1	1.6							1.2	1.8
	90% CI	4.6	3.4	3.8	1.5	2.5	2.6	1.2							0.9	1.5
		6.4	4.4	5.1	3.0	5.1	3.7	2.2							1.5	2.0
PBA-2	Mean	5.5	4.2	5.3	2.8	4.1										
	90% CI	4.5	3.4	4.3	1.9	3.1										
		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	4.6	5.6	6.8	4.0	2.8
	90% CI	4.7	5.7	7.2	7.1	9.3	7.0	5.4	7.2	4.5	5.0	3.6	4.5	5.2	3.0	2.3
		7.1	8.6	11.4	9.8	16.5	11.4	10.0	11.8	6.3	11.4	5.8	7.0	8.8	5.2	3.4
PBA-4	Mean	5.7	5.5	8.2	5.1	6.1	5.3	5.7	5.4	3.2	5.4	2.5	4.1	3.9	2.8	2.8
	90% CI	5.0	4.4	6.6	4.1	5.1	4.4	4.5	4.4	2.5	2.7	2.0	3.5	3.3	2.4	2.3
		6.5	6.8	10.2	6.4	7.3	6.3	7.1	6.7	4.2	10.6	3.2	4.7	4.5	3.2	3.4
PBA-5	Mean	8.8	9.8	7.3	8.0	9.1	6.6	7.7	10.6	22.1	14.1	4.5	10.4	5.9	9.4	4.5
	90% CI	5.9	5.9	4.5	4.2	6.9	3.9	2.8	2.2	12.7	4.7	3.1	6.2	3.3	5.9	3.1
		13.1	16.3	11.9	15.1	11.8	11.2	21.0	52.3	38.5	42.1	6.4	17.6	10.7	14.8	6.5
PBA-5A	Mean			20.5	9.2	11.5	9.1	11.6	30.0	18.7	16.6	16.0	17.8	46.8	15.7	10.3
	90% CI			12.1	4.9	5.2	5.3	5.4	8.1	13.7	8.2	5.8	7.5	25.4	11.8	8.9
				34.7	17.1	25.4	15.7	24.6	111.8	25.6	33.8	44.3	42.2	86.3	20.8	11.9
PBA-6	Mean	8.5	7.7	8.5	6.0	7.4	8.5					4.8	8.1	4.2	4.6	3.6
	90% CI	5.7	5.0	7.2	4.5	5.6	7.3					3.9	6.3	3.5	4.1	3.0
		12.6	12.0	10.0	8.1	9.8	10.0					5.9	10.4	5.1	5.2	4.3
PBA-7	Mean	5.8	5.3	7.1	4.1	6.0	6.5									
	90% CI	4.7	3.9	6.1	3.5	4.2	5.0									
		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	2.1	3.1	3.3	3.1	2.7
	90% CI	3.9	5.0	5.1	3.4	4.6	4.8	4.0	3.2	2.7	2.4	1.5	2.5	2.8	2.3	2.3
		6.0	7.5	7.6	5.0	7.1	6.6	6.0	5.5	3.9	6.1	2.9	4.0	3.8	4.0	3.1
PBA-9	Mean	7.5	10.9	11.5	8.2	9.1	11.8	9.3	10.0	8.5	8.5	6.2	7.9	7.1	6.6	5.5
	90% CI	5.1	8.0	10.1	6.7	7.2	9.4	7.2	7.8	6.7	4.9	5.0	6.2	6.3	5.6	4.0

		11.1	14.8	13.0	10.2	11.5	14.8	12.1	12.7	11.0	14.5	7.7	10.1	7.9	7.8	7.3
PBA-10	Mean	6.3	6.8	7.1	5.3	7.1	6.0	6.6	5.7	6.3	4.7	3.4	5.7	6.6	5.7	4.3
	90% CI	4.1	4.7	5.5	4.6	5.6	4.6	5.5	5.0	3.5	2.9	2.7	4.6	5.5	4.6	3.3
		9.8	9.9	9.2	6.2	9.0	7.8	7.8	6.7	11.5	7.7	4.4	7.0	8.0	7.1	5.5
PBA-11	Mean	6.6	8.7	6.8	9.9	10.3	8.9	11.7	4.6	4.0	5.2	4.6	10.7	8.4	6.6	4.8
	90% CI	3.8	4.8	5.4	5.6	6.0	5.7	6.1	2.7	2.1	2.7	3.5	5.1	5.0	3.6	2.8
		11.5	15.5	8.6	17.6	17.8	13.8	22.3	7.7	7.8	9.9	6.0	22.1	14.2	12.1	8.3
PBA-12	Mean	3.6	4.2	4.9	3.8	4.2	4.6	3.7	2.9	1.9	2.9	2.2	3.3	2.8	1.6	1.7
	90% CI	2.6	2.9	3.9	2.9	3.3	3.7	2.4	2.4	1.4	1.5	1.8	2.5	2.5	1.4	1.3
		4.9	6.0	6.3	5.1	5.3	5.8	5.7	3.5	2.6	5.8	2.8	4.6	3.1	1.9	2.2
PBA-13	Mean	4.2	4.1	4.8	4.2	4.7	5.8	4.5	4.0	2.1	4.2	2.7	3.1	3.0	1.7	1.5
	90% CI	2.9	3.1	3.8	2.8	3.6	4.4	3.3	2.9	1.7	3.2	2.2	2.3	2.5	1.5	1.3
		6.1	5.3	6.0	6.4	6.2	7.7	6.2	5.6	2.7	5.6	3.3	4.1	3.6	1.9	1.8
PBA-14	Mean	6.5	9.8	9.6	10.1	16.5	12.4	10.0				6.9	11.3	9.3	6.1	4.2
	90% CI	4.2	7.2	7.4	8.1	12.7	9.2	6.9				4.8	9.8	7.8	4.9	3.3
		10.1	13.4	12.5	12.6	21.3	16.8	14.5				9.8	12.9	11.1	7.6	5.4
PBA-15	Mean	6.2	6.8	7.0	6.5	10.0	9.5	9.3	10.2	5.4	6.3	5.6	7.3	5.5	3.9	2.9
	90% CI	3.9	5.0	5.4	5.1	7.5	7.1	6.9	6.5	4.3	4.2	4.1	5.6	4.3	3.4	2.1
		9.7	9.3	8.9	8.4	13.3	12.8	12.5	16.1	6.9	9.5	7.6	9.5	6.9	4.6	4.1
PBA-16	Mean	4.9	7.7	5.9	6.2	8.3	9.6	10.4				3.1	7.6	9.0	4.4	3.3
	90% CI	3.1	5.5	4.3	4.0	6.2	6.3	6.5				2.4	6.2	6.4	3.6	2.4
		7.8	10.8	8.1	9.6	11.2	14.8	16.9				4.0	9.2	12.7	5.4	4.5
PBA-17A	Mean											5.4	5.4	4.0	2.4	2.9
	90% CI											4.2	3.3	2.5	1.4	2.3
												6.9	8.9	6.5	3.9	3.8
PBA-18	Mean			6.6	2.9	5.1	4.3									
	90% CI			5.9	2.1	3.7	3.6									
				7.5	4.1	7.0	5.1									
PBA-19	Mean			5.0	3.6	2.7	3.8								1.5	2.3
	90% CI			4.5	2.6	1.3	3.0								1.2	1.9
				5.5	5.0	5.6	4.9								1.7	2.7
PBA-20	Mean			7.2	3.8	5.4	5.5								3.1	2.9
	90% CI			6.3	3.0	3.9	5.0								2.5	2.3
				8.2	4.7	7.5	6.0								3.9	3.7
PBA-21	Mean			5.0	3.3	3.5	4.1								1.7	1.8
	90% CI			4.3	2.7	2.8	3.4								1.4	1.5
				5.7	4.1	4.3	4.9								2.1	2.2
WMO-2	Mean		7.1	5.4	5.4	7.4										

	90% CI		5.0	4.9	4.5	4.3										
			10.2	6.0	6.5	12.9										
WMO-3	Mean		3.9	4.1	3.9	3.9		4.5	3.1	2.8	2.8	1.9	4.3	3.6	1.5	1.6
	90% CI		2.3	2.9	2.7	2.5		3.1	1.8	1.5	1.2	1.4	2.5	2.7	1.1	0.9
			6.6	5.7	5.7	6.3		6.7	5.3	5.5	6.7	2.6	7.5	4.7	2.2	2.8
WMO-4	Mean		4.9	4.7	5.3	4.5										
	90% CI		2.3	3.6	2.9	1.9										
			10.7	6.0	10.0	10.3										
WMO-5	Mean		3.6	4.7	4.0	4.7	5.7	6.9	6.7	6.1	3.5	4.0	5.5	8.4	2.0	1.1
	90% CI		2.6	2.6	3.3	2.6	4.2	4.7	5.0	3.4	1.9	2.4	4.4	5.2	1.5	0.3
			5.0	8.6	4.8	8.3	7.9	10.1	9.1	10.7	6.5	6.7	6.8	13.6	2.6	4.5
WMO-6	Mean		5.1	4.7	6.1	10.1		9.5	13.9	6.8	4.8	4.8	8.0	6.1	4.2	1.1
	90% CI		3.7	2.9	3.6	7.1		5.7	6.5	2.9	2.0	3.5	6.4	4.7	2.9	0.2
			7.1	7.6	10.3	14.1		15.8	29.6	16.1	11.6	6.5	10.1	7.9	6.0	7.5
WMO-7	Mean		4.5	4.2	4.9	5.8										
	90% CI		2.5	2.7	3.0	4.0										
			8.0	6.4	8.0	8.5										
WMO-8	Mean		4.7	3.3	4.0	6.3									2.0	2.2
	90% CI		2.9	1.5	2.3	4.3									1.9	1.3
			7.6	6.9	7.0	9.1									2.0	3.6
WMO-9	Mean		5.2	3.8	5.3	7.6	9.6									1.4
	90% CI		3.6	1.4	3.9	6.2	6.5									
			7.3	10.4	7.2	9.4	14.1									
WMO-10	Mean		6.6	4.8	6.9	10.5		11.2	10.9	6.2	4.0	3.5	6.4	6.3	4.2	1.3
	90% CI		3.8	3.7	4.3	6.2		8.8	6.6	4.3	2.8	3.0	5.4	5.3	3.7	0.5
			11.5	6.4	11.2	17.9		14.4	17.9	8.8	5.9	4.0	7.5	7.6	4.7	3.6
WMO-12	Mean		5.9	6.2	4.2	3.9						2.6	4.7	5.6	5.1	3.2
	90% CI		3.7	3.2	3.3	2.6						1.9	3.7	4.2	4.2	2.1
			9.6	12.0	5.2	5.8						3.5	6.0	7.5	6.2	5.0

Dissolved Oxygen

Site		Dissolved Oxygen (mg/L)														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	Mean	6.5	6.8	6.4	6.4	6.3	6.0	6.3	5.7	4.2	4.7	6.2	6.5	4.9	6.9	5.9
	90% CI	6.0	6.3	6.0	5.7	6.0	5.7	5.7	5.2	3.8	4.5	5.6	6.2	4.8	6.3	5.6
		7.1	7.3	6.8	7.1	6.6	6.4	6.8	6.1	4.6	5.0	6.7	6.9	5.0	7.5	6.3
CM-14	Mean	5.5	5.1	5.3	5.7	5.8	7.2									
	90% CI	4.4	4.1	4.9	5.3	3.9	2.1									
		6.5	6.1	5.7	6.0	7.7	12.3									
PBA-1	Mean	6.4	8.1	7.8	8.7	8.0	9.0	7.7							7.4	6.4
	90% CI	6.2	7.8	7.3	8.2	7.6	8.8	7.5							6.8	6.0
		6.7	8.4	8.2	9.2	8.5	9.3	7.9							8.1	6.7
PBA-2	Mean	6.8	6.6	6.3	7.7	6.4										
	90% CI	6.3	6.1	6.0	4.4	5.0										
		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	5.9	5.7	6.1	6.0	8.2
	90% CI	5.5	6.1	4.9	5.5	5.4	4.8	4.7	4.8	4.4	2.7	5.5	5.0	5.7	4.8	7.5
		6.6	7.0	6.3	7.2	6.4	6.8	7.5	6.1	5.6	5.5	6.3	6.4	6.5	7.2	8.9
PBA-4	Mean	6.6	7.9	6.6	6.7	6.5	6.2	6.3	5.8	5.4	5.5	6.7	6.4	6.2	6.4	7.6
	90% CI	5.7	6.9	5.2	6.2	6.1	5.6	5.8	5.3	4.9	5.2	6.2	6.0	5.8	5.9	7.2
		7.5	8.8	7.9	7.2	7.0	6.8	6.7	6.2	5.8	5.7	7.2	6.8	6.7	6.9	8.0
PBA-5	Mean	6.5	5.9	5.8	6.8	6.2	3.8	5.0	6.1	4.8	5.7	5.3	5.2	5.6	5.0	5.4
	90% CI	5.6	4.9	5.0	5.5	5.1	2.1	3.5	0.5	3.6	3.2	4.3	3.6	4.4	4.1	3.8
		7.3	6.9	6.5	8.1	7.3	5.4	6.6	11.6	6.0	8.1	6.2	6.7	6.7	5.8	6.9
PBA-5A	Mean			4.8	8.0	6.2	7.4	4.9	7.7	6.2	5.6	5.9	8.2	6.1	7.1	5.0
	90% CI			2.7	2.8	4.6	5.8	2.5	4.5	3.1	3.7	3.7	5.1	3.9	3.3	2.3
				6.8	13.3	7.7	9.1	7.2	10.8	9.2	7.6	8.1	11.2	8.2	11.0	7.7
PBA-6	Mean	6.3	5.4	5.5	5.6	6.1	5.9					7.6	6.9	6.7	6.4	7.2
	90% CI	5.5	4.3	4.8	4.2	5.3	5.1					6.9	6.3	6.4	6.3	6.5
		7.0	6.5	6.2	7.0	6.9	6.6					8.4	7.5	7.0	6.6	7.9
PBA-7	Mean	6.8	6.5	7.4	6.3	6.5	5.7									
	90% CI	6.3	5.6	6.6	5.9	6.1	4.7									
		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	7.5	7.3	5.9	7.4	6.4
	90% CI	4.0	6.1	6.5	7.0	6.4	6.0	6.6	5.5	5.4	5.3	6.8	6.9	5.6	7.0	6.0
		6.7	7.2	7.5	8.2	7.2	7.4	7.9	6.7	8.0	6.0	8.3	7.6	6.1	7.9	6.9
PBA-9	Mean	6.2	7.0	6.2	7.0	7.0	5.9	5.5	6.7	4.7	5.2	6.4	6.4	5.1	5.6	5.4
	90% CI	5.0	6.6	5.7	6.4	6.6	5.5	4.5	6.0	4.4	5.0	5.8	5.9	4.6	4.9	4.8

		7.4	7.5	6.7	7.6	7.4	6.4	6.4	7.3	5.1	5.4	7.0	6.9	5.6	6.2	5.9
PBA-10	Mean	5.9	5.4	5.4	5.9	6.0	5.3	5.2	5.5	4.1	3.7	5.3	6.1	4.3	5.2	5.6
	90% CI	5.3	5.0	5.2	5.5	5.6	4.9	4.7	5.1	3.6	2.7	4.9	5.6	4.1	4.8	5.2
		6.6	5.8	5.6	6.3	6.3	5.8	5.6	5.8	4.5	4.7	5.7	6.6	4.5	5.6	5.9
PBA-11	Mean	5.2	4.6	4.1	5.2	4.7	4.6	4.6	5.2	4.1	3.7	5.9	4.6	3.8	4.7	5.0
	90% CI	4.4	3.4	3.2	3.0	3.2	3.5	3.5	4.5	4.0	2.7	5.3	3.1	2.9	3.5	4.3
		6.1	5.7	5.1	7.4	6.1	5.6	5.7	5.9	4.3	4.6	6.4	6.1	4.6	5.8	5.6
PBA-12	Mean	5.9	5.1	5.0	5.6	5.9	5.0	5.4	5.6	4.7	4.9	6.2	6.3	5.3	5.7	5.7
	90% CI	5.1	4.6	4.4	5.2	5.5	4.6	4.9	5.0	4.4	4.4	5.9	6.0	5.2	5.4	5.5
		6.7	5.5	5.5	6.0	6.2	5.5	6.0	6.3	5.1	5.3	6.6	6.7	5.5	6.0	5.9
PBA-13	Mean	5.4	5.0	4.5	5.5	5.1	5.0	5.5	6.0	4.6	4.8	5.4	5.5	4.3	4.8	5.1
	90% CI	4.8	4.7	4.2	4.8	4.7	4.2	5.1	5.5	4.2	4.4	5.0	5.2	4.1	4.4	4.9
		6.1	5.3	4.8	6.2	5.4	5.8	5.8	6.5	4.9	5.1	5.8	5.8	4.6	5.2	5.3
PBA-14	Mean	4.5	4.8	4.2	5.2	4.8	4.7	3.6				5.4	5.6	4.5	4.9	4.4
	90% CI	3.5	4.2	3.5	4.1	4.0	4.0	2.8				4.7	4.9	3.6	4.2	3.8
		5.5	5.4	4.8	6.2	5.5	5.5	4.3				6.2	6.2	5.3	5.5	4.9
PBA-15	Mean	5.5	4.7	4.7	5.0	4.5	4.7	4.8	5.5	4.9	3.6	5.1	5.6	4.5	5.4	4.9
	90% CI	4.8	4.3	4.3	4.2	4.1	4.1	4.2	4.4	4.1	3.0	4.6	5.3	3.9	4.8	4.5
		6.1	5.2	5.1	5.7	5.0	5.3	5.5	6.6	5.7	4.3	5.5	6.0	5.1	6.0	5.3
PBA-16	Mean	5.1	4.3	5.5	3.9	4.1	3.3	5.1				4.8	4.4	3.9	4.9	4.9
	90% CI	3.8	2.5	4.5	2.2	3.3	1.9	3.9				4.0	3.9	3.3	3.9	4.3
		6.5	6.1	6.4	5.6	4.9	4.7	6.3				5.7	4.9	4.5	5.9	5.5
PBA-17A	Mean															
	90% CI															
PBA-18	Mean			6.6	6.6	6.4	6.4									
	90% CI			6.4	6.3	6.3	5.9									
				6.8	6.8	6.6	6.9									
PBA-19	Mean			7.3	7.9	7.4	7.8								7.5	7.4
	90% CI			6.9	7.3	7.0	6.7								7.2	6.9
				7.7	8.6	7.8	8.9								7.9	7.8
PBA-20	Mean			6.7	6.3	6.7	6.5								7.8	6.5
	90% CI			6.5	6.0	6.5	6.1								7.3	5.4
				7.0	6.6	7.0	6.9								8.3	7.5
PBA-21	Mean			5.5	5.4	6.0	5.6								6.1	6.2
	90% CI			5.0	4.3	5.8	5.3								5.8	5.9
				6.0	6.5	6.2	6.0								6.5	6.5
WMO-2	Mean		8.2	6.7	7.4	7.2										

	90% CI		7.7	5.4	6.2	6.0										
			8.7	7.9	8.6	8.3										
WMO-3	Mean		6.2	4.9	7.2	6.4		5.2	4.9	4.1	4.0	5.6	5.4	4.5	5.4	4.2
	90% CI		5.6	3.9	5.8	6.1		4.3	3.7	3.6	2.9	4.9	4.8	4.2	4.2	3.5
			6.9	6.0	8.6	6.8		6.1	6.1	4.7	5.2	6.3	6.0	4.7	6.6	5.0
WMO-4	Mean		5.2	5.2	6.3	5.4										
	90% CI		4.9	4.6	5.7	4.3										
			5.6	5.8	6.8	6.6										
WMO-5	Mean		4.8	4.8	5.8	5.4	4.1	4.1	3.0	2.2	2.4	3.3	3.5	3.3	3.4	3.6
	90% CI		4.4	4.0	5.0	4.5	2.9	2.8	1.7	1.7	1.4	2.1	2.1	2.6	2.8	3.3
			5.2	5.5	6.5	6.3	5.3	5.5	4.4	2.7	3.5	4.5	4.9	4.1	3.9	3.9
WMO-6	Mean		5.1	4.6	5.7	5.8		4.7	4.6	3.7	4.5	6.2	5.5	3.7	4.8	3.9
	90% CI		4.7	4.3	4.7	5.2		3.9	2.7	3.0	3.3	5.5	4.4	3.2	3.8	3.6
			5.4	4.9	6.6	6.4		5.4	6.4	4.4	5.8	6.9	6.6	4.2	5.8	4.3
WMO-7	Mean		5.3	4.8	6.0	6.0										
	90% CI		5.0	4.5	5.4	5.6										
			5.6	5.2	6.6	6.4										
WMO-8	Mean		5.7	5.8	6.8	6.0									5.8	5.2
	90% CI		5.4	5.1	5.6	5.7									5.5	4.3
			5.9	6.6	8.0	6.4									6.2	6.0
WMO-9	Mean		5.0	5.1	6.0	5.2	5.5									5.1
	90% CI		4.7	4.2	4.7	4.9	3.8									
			5.4	5.9	7.2	5.5	7.2									
WMO-10	Mean					7.3		4.3	4.3	3.5	4.1	9.0	5.1	4.3	4.9	5.1
	90% CI					7.2		3.8	3.6	3.2	3.8	3.8	4.6	4.0	4.1	4.5
						7.4		4.7	5.0	3.8	4.5	14.1	5.5	4.6	5.7	5.6
WMO-12	Mean		5.3	5.8	5.6	5.5						5.2	5.3	4.1	5.3	4.6
	90% CI		5.2	5.2	4.8	4.3						4.6	4.5	3.7	4.8	4.0
			5.5	6.5	6.3	6.7						5.9	6.2	4.4	5.8	5.1

Appendix C. Exceedances of Targets and Thresholds

The following tables present the percent of samples exceeding thresholds/targets for bioactive nitrogen, dissolved oxygen, and total phytopigments by year. Bioactive nitrogen thresholds were established by the Massachusetts Estuaries Program (MEP) to support the development of the 2007 Pleasant Bay TMDL (Howes et al. 2006). The dissolved oxygen target is the Massachusetts water quality standard for coastal waters. The total phytopigment target is a guidance value established by the National Oceanic and Atmospheric Administration (NOAA).

Site ID	MEP Modeled Restoration Value (mg/L)[5]	Percent of Samples Exceeding MEP Restoration Target for Bioactive Nitrogen														
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	0.138	84%	44%	100%	75%	93%	36%	25%	30%	60%	60%	30%	100%	100%	70%	60%
CM-14	0.173	100%	67%	100%	100%	100%	50%									
PBA-1	0.102	90%	27%	86%	27%	17%	14%	0%							0%	75%
PBA-2	0.12	90%	13%	86%	20%	0%										
PBA-3	0.19	45%	25%	92%	85%	86%	93%	57%	50%	78%	71%	56%	80%	88%	20%	22%
PBA-4	0.149	80%	38%	100%	90%	69%	57%	50%	60%	20%	50%	75%	40%	100%	30%	0%
PBA-5	0.208	56%	63%	80%	83%	67%	57%	100%	100%	100%	75%	60%	80%	80%	100%	40%
PBA-5A	0.405			83%	100%	86%	100%	100%	100%	100%	100%	100%	60%	100%	100%	75%
PBA-6	0.169	78%	60%	90%	75%	42%	50%					50%	70%	13%	30%	40%
PBA-7	0.153	67%	33%	71%	43%	36%	42%									
PBA-8	0.139	78%	50%	79%	71%	43%	29%	33%	13%	22%	30%	0%	70%	100%	100%	38%
PBA-9	0.207	58%	58%	100%	79%	64%	62%	83%	40%	70%	10%	80%	50%	90%	70%	80%
PBA-10	None															
PBA-11	0.209	33%	36%	57%	75%	50%	43%	58%	0%	13%	30%	10%	10%	40%	60%	40%
PBA-12	0.16	75%	17%	86%	77%	64%	14%	25%	40%	0%	20%	0%	60%	50%	10%	20%
PBA-13	0.172	64%	17%	71%	67%	40%	23%	50%	30%	20%	20%	50%	20%	70%	30%	38%
PBA-14	0.253	58%	42%	85%	79%	100%	93%	83%				70%	30%	100%	80%	60%
PBA-15	0.208	92%	25%	100%	92%	100%	100%	100%	90%	100%	40%	90%	100%	100%	40%	60%
PBA-16	0.262	75%	33%	69%	85%	69%	71%	50%				60%	70%	70%	40%	30%
PBA-17A	0.098											33%	75%	67%	0%	43%
PBA-18	0.112			89%	50%	70%	21%									
PBA-19	0.113			100%	60%	64%	90%								0%	100%
PBA-20	0.118			100%	67%	64%	29%								33%	100%
PBA-21	0.148			70%	58%	8%	14%								0%	20%
WMO-2	0.147		73%	100%	78%	50%										
WMO-3	0.164		50%	63%	67%	50%		33%	40%	0%	0%	20%	0%	100%	0%	0%
WMO-4	0.179		67%	100%	100%	50%										
WMO-5	0.211		67%	75%	83%	33%	83%	67%	40%	60%	60%	60%	80%	100%	40%	80%
WMO-6	0.206		100%	67%	100%	100%		83%	100%	40%	40%	80%	100%	100%	40%	40%
WMO-7	0.188		83%	67%	100%	80%										
WMO-8	0.182		83%	67%	100%	80%									0%	50%
WMO-9	0.196		83%	83%	100%	100%	83%									0%
WMO-10	0.207		67%	73%	100%	100%		100%	100%	100%	40%	70%	90%	100%	60%	80%

[5] From Table VIII-6 in: Howes, Samimy, Schlezinger, Kelley, Ramsey, & Eichner, 2006.

Site ID	Percent of Samples Not Meeting Dissolved Oxygen Standard of 6 mg/L														
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	35%	6%	29%	33%	29%	42%	42%	70%	100%	100%	40%	20%	100%	20%	60%
CM-14	64%	86%	86%	100%	75%	83%									
PBA-1	20%	0%	0%	0%	0%	0%	0%							0%	25%
PBA-2	20%	13%	29%	20%	20%										
PBA-3	57%	21%	64%	38%	58%	50%	38%	80%	100%	100%	40%	50%	50%	50%	0%
PBA-4	40%	13%	21%	17%	21%	33%	20%	70%	75%	100%	25%	30%	50%	30%	0%
PBA-5	36%	38%	50%	33%	20%	83%	80%	67%	80%	50%	80%	75%	80%	80%	60%
PBA-5A			83%	33%	33%	29%	80%	40%	60%	50%	40%	20%	60%	25%	60%
PBA-6	30%	60%	60%	33%	33%	50%					0%	10%	13%	0%	20%
PBA-7	10%	33%	14%	36%	21%	50%									
PBA-8	50%	9%	7%	7%	13%	21%	17%	10%	50%	80%	0%	0%	75%	0%	38%
PBA-9	25%	8%	42%	7%	14%	38%	75%	25%	100%	100%	30%	30%	80%	60%	60%
PBA-10	58%	83%	100%	64%	64%	79%	92%	100%	100%	100%	90%	40%	100%	100%	80%
PBA-11	58%	91%	93%	67%	83%	79%	75%	100%	100%	90%	60%	60%	100%	70%	80%
PBA-12	58%	83%	86%	71%	50%	86%	75%	80%	100%	100%	30%	30%	100%	80%	80%
PBA-13	67%	100%	100%	60%	90%	71%	83%	60%	100%	100%	80%	70%	100%	90%	100%
PBA-14	75%	92%	100%	79%	86%	86%	100%				75%	80%	90%	80%	90%
PBA-15	80%	92%	100%	83%	100%	92%	90%	75%	88%	100%	90%	75%	100%	60%	90%
PBA-16	42%	67%	67%	75%	92%	86%	71%				88%	100%	100%	70%	80%
PBA-18			0%	0%	0%	43%									
PBA-19			0%	0%	0%	0%								0%	0%
PBA-20			0%	33%	0%	29%								0%	20%
PBA-21			90%	75%	42%	71%								33%	38%
WMO-2		0%	8%	17%	14%										
WMO-3		50%	75%	38%	20%		83%	100%	100%	100%	75%	80%	100%	80%	100%
WMO-4		100%	100%	38%	67%										
WMO-5		100%	100%	50%	67%	100%	83%	100%	100%	100%	100%	80%	100%	100%	100%
WMO-6		100%	100%	67%	53%		100%	75%	100%	100%	40%	80%	100%	80%	100%
WMO-7		100%	100%	61%	50%										
WMO-8		69%	67%	33%	61%									67%	75%
WMO-9		100%	100%	67%	89%	75%									100%
WMO-10					0%		100%	100%	100%	100%	80%	80%	100%	75%	60%
WMO-12		100%	50%	88%	75%						80%	75%	100%	100%	100%

Site ID	Percent of Samples Exceeding NOAA Pigment Guidance of 5 µg/L														
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CM-13	70%	63%	71%	17%	86%	67%	42%	60%	10%	70%	10%	10%	38%	0%	0%
CM-14	90%	71%	71%	57%	71%	50%									
PBA-1	55%	6%	29%	17%	17%	7%	0%							0%	0%
PBA-2	70%	25%	57%	0%	33%										
PBA-3	70%	87%	93%	100%	100%	93%	75%	100%	60%	75%	44%	70%	75%	50%	0%
PBA-4	65%	69%	93%	42%	57%	50%	60%	60%	0%	70%	0%	10%	25%	0%	10%
PBA-5	90%	88%	100%	83%	100%	71%	60%	50%	100%	100%	40%	100%	60%	80%	40%
PBA-5A			100%	71%	86%	86%	83%	80%	100%	100%	80%	80%	100%	100%	100%
PBA-6	80%	70%	100%	75%	92%	100%					50%	100%	25%	50%	20%
PBA-7	58%	36%	86%	31%	50%	75%									
PBA-8	60%	67%	71%	25%	64%	64%	42%	25%	0%	30%	10%	0%	0%	13%	0%
PBA-9	83%	100%	100%	93%	93%	93%	100%	100%	90%	80%	80%	80%	90%	90%	60%
PBA-10	58%	75%	79%	64%	79%	64%	75%	75%	50%	60%	20%	70%	80%	70%	40%
PBA-11	58%	64%	71%	75%	67%	86%	83%	50%	25%	30%	60%	60%	60%	50%	40%
PBA-12	25%	42%	50%	21%	36%	29%	25%	0%	0%	20%	0%	20%	0%	0%	10%
PBA-13	50%	25%	57%	33%	40%	57%	33%	40%	0%	40%	0%	20%	10%	0%	0%
PBA-14	67%	100%	100%	100%	100%	100%	100%				60%	100%	100%	80%	30%
PBA-15	75%	83%	75%	62%	100%	93%	100%	70%	60%	80%	60%	80%	60%	20%	10%
PBA-16	58%	67%	71%	62%	86%	86%	100%				10%	90%	80%	50%	30%
PBA-17A											67%	75%	33%	0%	0%
PBA-18			100%	20%	60%	21%									
PBA-19			40%	20%	25%	30%								0%	0%
PBA-20			100%	17%	64%	71%								0%	10%
PBA-21			40%	0%	17%	21%								0%	0%
WMO-2		67%	80%	60%	67%										
WMO-3		33%	38%	25%	38%		33%	0%	20%	0%	0%	20%	20%	0%	0%
WMO-4		33%	33%	17%	50%										
WMO-5		0%	50%	17%	50%	83%	83%	80%	80%	40%	40%	60%	80%	0%	0%
WMO-6		50%	67%	50%	100%		83%	100%	40%	40%	60%	100%	80%	20%	20%
WMO-7		67%	33%	50%	67%										
WMO-8		67%	50%	50%	83%									0%	0%
WMO-9		67%	50%	83%	100%	83%									0%
WMO-10		83%	55%	67%	100%		100%	88%	80%	30%	10%	80%	80%	20%	0%
WMO-12		50%	67%	17%	33%						0%	50%	40%	40%	20%

Appendix D. Station-Specific Trend Analysis Results

Table 12 Model coefficients and p-values for each of the statistically significant multiple linear regression models. Coefficients with statistically significant p-values (<0.05) are marked with an asterisk (*). Note that while some models included additional predictors (depth, water temperature, salinity, and recent rainfall) this table only displays coefficients for predictors related to changes over time.

Station	Parameter	Date Coefficient	Date p-value	Break Coefficient	Break p-value	Date:Break Coefficient	Date:Break p-value
CM-13	DIN	0.047*	7E-20				
CM-13	TN	0.014*	4E-11				
CM-13	Pigments	-0.029*	4E-18				
CM-13	DO	-0.039	0.339	-1.435*	5E-05	0.158*	0.009
CM-13	PO4	0.016*	2E-06				
PBA-10	DIN	0.019*	2E-04				
PBA-10	BioN	0.007*	1E-03				
PBA-10	TN	0.006*	9E-03				
PBA-10	Pigments			-0.093*	0.005		
PBA-10	DO	0.006	0.903	-1.486*	5E-05	0.113	0.083
PBA-10	PO4			-0.094*	1E-04		
PBA-10	Salinity	0.069	0.298	1.059*	0.033	-0.130	0.152
PBA-11	BioN			-0.122*	0.001		
PBA-11	TN			-0.135*	5E-06		
PBA-11	Pigments			-0.150*	0.002		
PBA-11	Salinity	0.066*	1E-03				
PBA-12	BioN	-0.008*	0.010				
PBA-12	TN	-0.018*	3E-11				
PBA-12	Pigments			-0.248*	5E-12		
PBA-12	DO	0.040*	8E-04				
PBA-12	PO4			-0.076*	0.007		
PBA-12	Salinity			0.641*	0.001		
PBA-13	DIN	0.017*	3E-04				
PBA-13	Pigments	-0.029*	9E-12				
PBA-13	Salinity	0.093	0.340	1.469*	0.042	-0.166	0.209
PBA-14	Pigments			-0.169*	9E-05		
PBA-14	DO	0.055	0.376	3.005*	0.002	-0.350*	0.004
PBA-15	BioN			-0.067*	0.003		
PBA-15	TN	-0.005*	0.040				
PBA-15	Pigments	-0.019*	2E-05				
PBA-15	PO4	0.007*	0.019				
PBA-15	Salinity	-0.113	0.201	1.406*	0.029	0.065	0.578
PBA-16	BioN	-0.010*	0.012				
PBA-16	Pigments			-0.161*	0.002		
PBA-3	DIN			0.204*	0.001		
PBA-3	Pigments	-0.020*	3E-08				
PBA-3	DO	0.012	0.853	-2.833*	5E-09	0.355*	5E-05
PBA-3	Salinity			0.552*	0.029		
PBA-4	BioN	-0.015*	2E-07				
PBA-4	TN	-0.010*	3E-04				
PBA-4	Pigments	-0.024*	3E-13				
PBA-4	DO	-0.061	0.352	-1.983*	1E-04	0.300*	0.001
PBA-4	PO4	0.008*	0.017				
PBA-4	Salinity	0.072*	2E-03				
PBA-5	DIN	0.024*	0.043				

PBA-5	DO	-0.293*	3E-03	-0.105	0.898	0.264	0.056
PBA-5	Salinity	-0.751*	5E-03	-4.438*	0.043	1.516*	9E-05
PBA-5A	DIN	-0.026*	0.039				
PBA-5A	Pigments			0.226*	0.005		
PBA-5A	Salinity	-2.008*	3E-03	-6.320*	0.038	3.161*	6E-05
PBA-6	TN	-0.010*	7E-05				
PBA-6	Pigments	-0.020*	9E-08				
PBA-6	DO			1.141*	1E-07		
PBA-6	PO4	-0.015*	3E-04				
PBA-6	Salinity	0.061*	9E-03				
PBA-8	DIN	0.036*	5E-08				
PBA-8	TN	0.008*	5E-03				
PBA-8	Pigments			-0.236*	6E-15		
PBA-8	DO	0.209*	2E-03	-0.781	0.116	-0.149	0.104
PBA-8	PO4			-0.150*	1E-07		
PBA-9	DIN	0.017*	5E-03				
PBA-9	BioN			-0.039*	0.029		
PBA-9	TN			-0.092*	9E-08		
PBA-9	Pigments	-0.015*	3E-05				
PBA-9	DO			-0.721*	1E-05		
WMO-10	BioN			-0.059*	0.002		
WMO-10	TN			-0.193*	7E-17		
WMO-10	Pigments	-0.034*	3E-05				
WMO-10	DO	0.167*	0.043				
WMO-10	Salinity	-0.492*	6E-03	0.232	0.788	0.515*	0.012
WMO-12	DIN	0.029*	9E-04				
WMO-12	BioN	0.012*	3E-03				
WMO-12	TN			0.100*	0.006		
WMO-12	DO	-0.093*	3E-04				
WMO-12	Salinity			0.575*	0.043		
WMO-3	BioN			-0.086*	0.001		
WMO-3	TN			-0.080*	0.005		
WMO-3	Pigments	-0.023*	5E-04				
WMO-5	Pigments	-0.019*	0.034				
WMO-5	DO	-0.183	0.059	-3.008*	5E-07	0.337*	0.005
WMO-5	PO4			0.074*	0.023		
WMO-6	BioN	-0.011*	9E-04				
WMO-6	TN	-0.013*	2E-04				
WMO-6	Pigments	-0.025*	0.022				

Appendix E. Bay-Wide Trend Analysis Results

Table 13. AIC values and coefficient estimates for each of the candidate mixed effects models. The best models (lowest AIC) are highlighted in yellow. Coefficient p-values are displayed for the best models in parentheses. Coefficients with statistically significant p-values (<0.05) are marked with an asterisk (*).

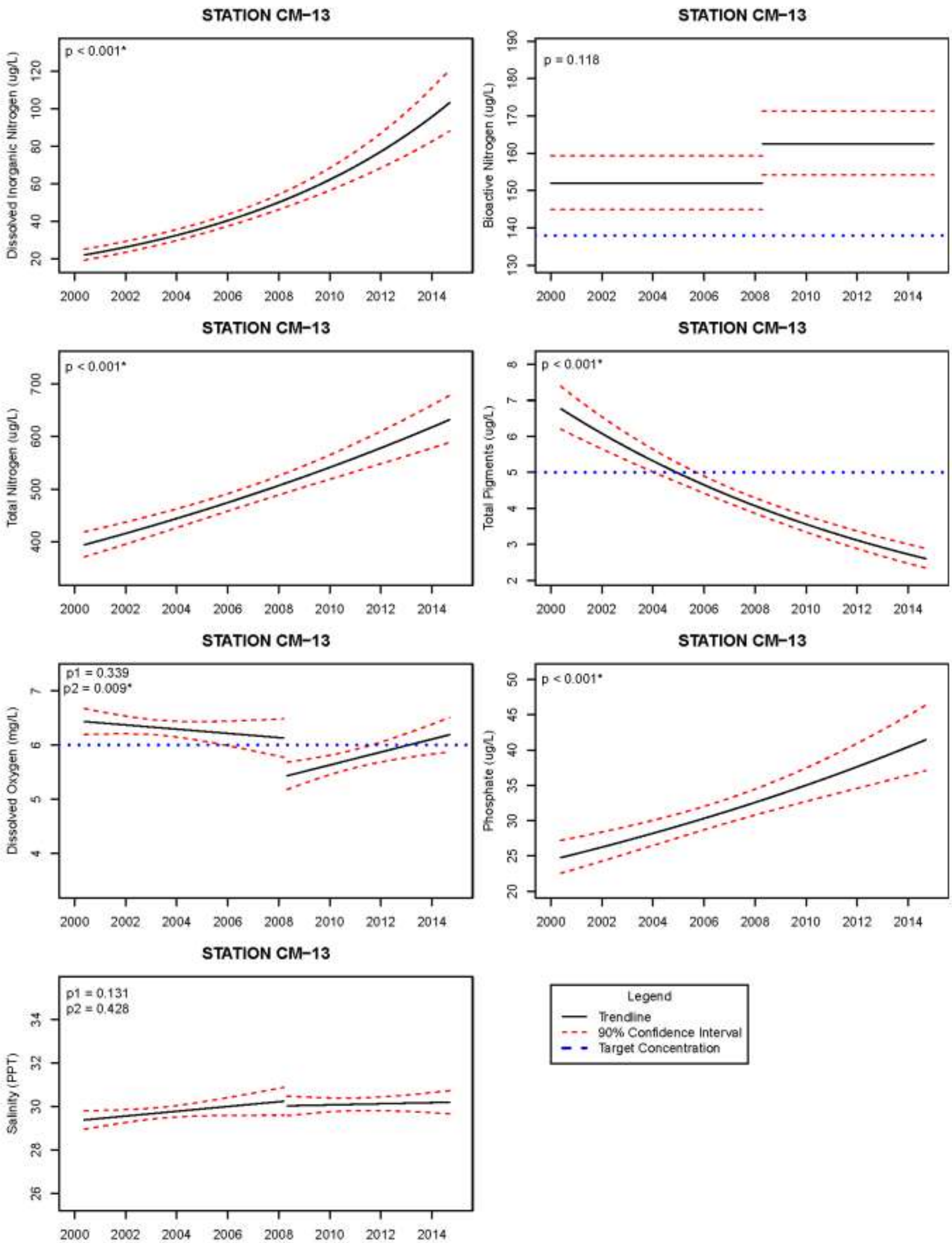
Model	AIC	Coefficient Estimates								
		Date	Break	Date:Break	DepthMid	DepthSurface	Salinity	Temp	LogRain7	Intercept
DIN1	2168.6	0.0091			0.0316	-0.0614				1.7484
DIN1C	2009.1	0.0124			0.0297	-0.0606	-0.0032	0.0009	0.0801	1.8608
DIN2	2197.0		0.0819		0.0470	-0.0609				1.7384
DIN2C	2049.7		0.1038		0.0510	-0.0598	-0.0030	0.0010	0.0747	1.8391
DIN3	2155.6	0.0204	0.0912	-0.0229	0.0303	-0.0616				1.7517
DIN3C	2000.5	0.0233* (7e-6)	0.0634 (0.07)	-0.0196* (0.003)	0.0289 (0.54)	-0.060* (3e-6)	-0.0014 (0.67)	0.0001 (0.98)	0.0793* (<2e-16)	1.8298* (<2e-16)
BioN1	-2750.6	-0.0040			-0.0617	-0.0536				2.3390
BioN1C	-2663.4	-0.0032			-0.0717	-0.0579	-0.0063	0.0035	0.0138	2.4580
BioN2	-2757.1		-0.0325		-0.0608	-0.0537				2.3407
BioN2C	-2669.9		-0.0248		-0.0691	-0.0577	-0.0060	0.0033	0.0145	2.4549
BioN3	-2790.5	-0.0075* (0.02)	-0.0599* (0.04)	0.0090* (0.04)	-0.0479* (0.03)	-0.0535* (<2e-16)				2.3381* (<2e-16)
BioN3C	-2701.1	-0.0081	-0.0684	0.0123	-0.0568	-0.0579	-0.0064	0.0036	0.0152	2.4575
TN1	-3286.6	-0.0058			0.0265	-0.0047				2.8118
TN1C	-3221.7	-0.0055			0.0274	-0.0072	0.0004	0.0058	0.0071	2.6815
TN2	-3263.0		-0.0390		0.0248	-0.0046				2.8125
TN2C	-3176.2		-0.0400		0.0236	-0.0073	0.0005	0.0060	0.0085	2.6763
TN3	-3340.6	-0.0078* (0.02)	-0.0362 (0.17)	0.0053 (0.21)	0.0301 (0.13)	-0.0044 (0.41)				2.8143* (<2e-16)
TN3C	-3247.3	-0.0087	-0.0429	0.0071	0.0296	-0.0071	0.0009	0.0060	0.0081	2.6657
Pig1	79.1	-0.0201			-0.0145	-0.0244				0.7801
Pig1C	2.9	-0.0197			-0.0463	-0.0404	-0.0101	0.0156	0.0025	0.7580
Pig2	125.4		-0.1753		-0.0196	-0.0246				0.7842
Pig2C	53.5		-0.1689		-0.0511	-0.0402	-0.0101	0.0147	0.0091	0.7837
Pig3	-73.7	0.0062	0.1675	-0.0495	-0.0147	-0.0252				0.7840
Pig3C	-119.5	0.0035 (0.38)	0.1570* (0.001)	-0.0441* (2e-8)	-0.0497 (0.10)	-0.0391* (2e-5)	-0.0088* (8e-5)	0.0134* (<2e-16)	-0.0016 (0.80)	0.7671* (<2e-16)
DO1	11549.6	-0.0219			0.2621	0.6102				5.5669
DO1C	10275.9	-0.0143			0.3273	0.7207	-0.0380	-0.1937	-0.1294	10.6573
DO2	11520.7		-0.2806		0.3043	0.6117				5.5891
DO2C	10250.8		-0.2364		0.3643	0.7230	-0.0349	-0.1921	-0.1397	10.5534
DO3	11505.8	-0.0350	-0.8501	0.1032	0.3460	0.6118				5.5761
DO3C	10237.8	0.0110 (0.53)	-0.7446* (2e-4)	0.0501* (0.046)	0.3989* (0.03)	0.7223* (<2e-16)	-0.0369* (0.003)	- 0.1927* (<2e-16)	-0.1199* (0.001)	10.6260* (<2e-16)
PO1	-818.8	-0.0005			-0.0140	-0.0383				1.6498
PO1C	-1248.7	-0.0020			-0.0269	-0.0492	0.0123	0.0295	0.0252	0.6958
PO2	-822.5		-0.0221		-0.0163	-0.0384				1.6561
PO2C	-1257.4		-0.0332		-0.0255	-0.0488	0.0131	0.0292	0.0237	0.6803
PO3	-861.2	0.0124	-0.0724	-0.0070	-0.0146	-0.0385				1.6590
PO3C	-1281.4	0.0076* (8e-3)	-0.0906* (3e-4)	-0.0012 (0.75)	-0.0237 (0.42)	-0.0486* (2e-10)	0.0134* (3e-12)	0.0289* (<2e-16)	0.0264* (4e-7)	0.6834* (<2e-16)
Sal1	11389.4	0.0680			-0.4367	-0.3165				29.8184
Sal1C	10935.8	0.0539			-0.3807	-0.3189		0.0155	-0.3712	29.2692
Sal2	11369.6		0.6723		-0.4229	-0.3160				29.7650

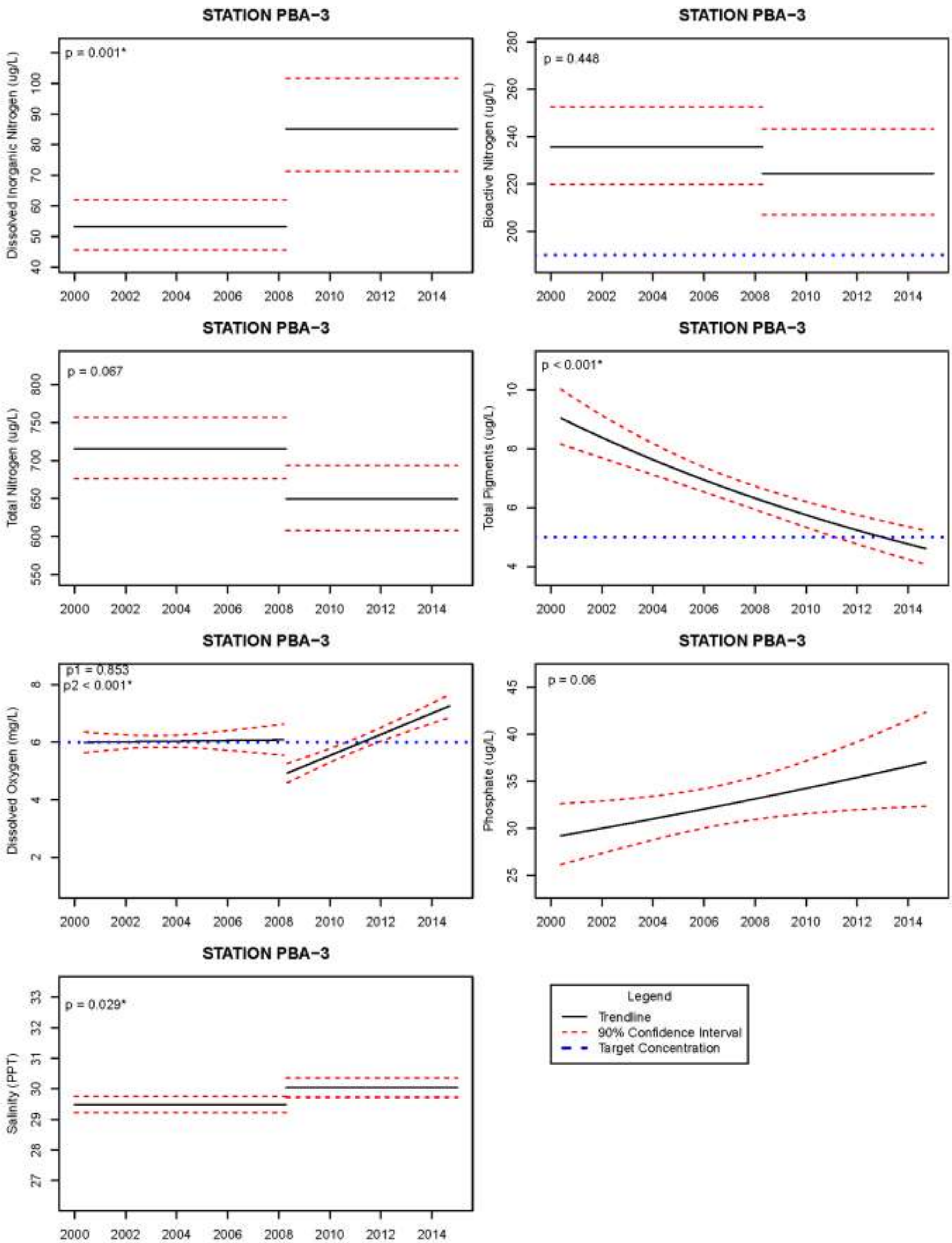
Model	AIC	Coefficient Estimates								
		Date	Break	Date:Break	DepthMid	DepthSurface	Salinity	Temp	LogRain7	Intercept
Sal2C	10909.0		0.5763* (3e-5)		-0.3835 (0.18)	-0.3193* (6e-6)		0.0174* (0.065)	-0.3746* (2e-16)	29.1774* (<2e-16)
Sal3	11376.3	0.0077	0.5096	0.0127	-0.4274	-0.3161				29.7664
Sal3C	10916.2	-0.0164	0.5757	0.0166	-0.3761	-0.3196		0.0185	-0.3759	29.1487

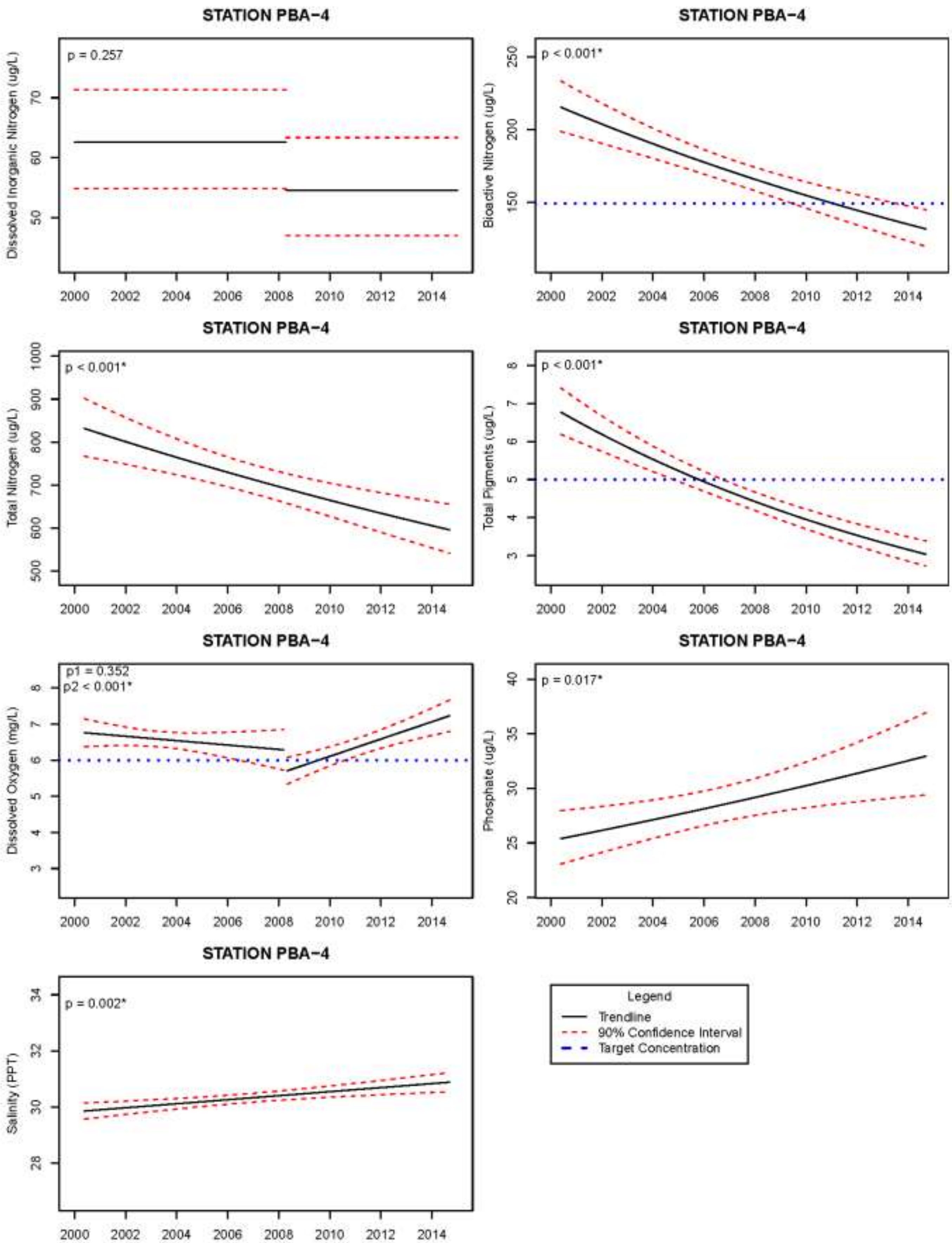
Appendix F. Station-Specific Trend Plots

This Appendix contains plots of station-specific trend analysis results. Each plot displays the trendline for a given station-parameter pair as a solid line. Plots also includes the following elements:

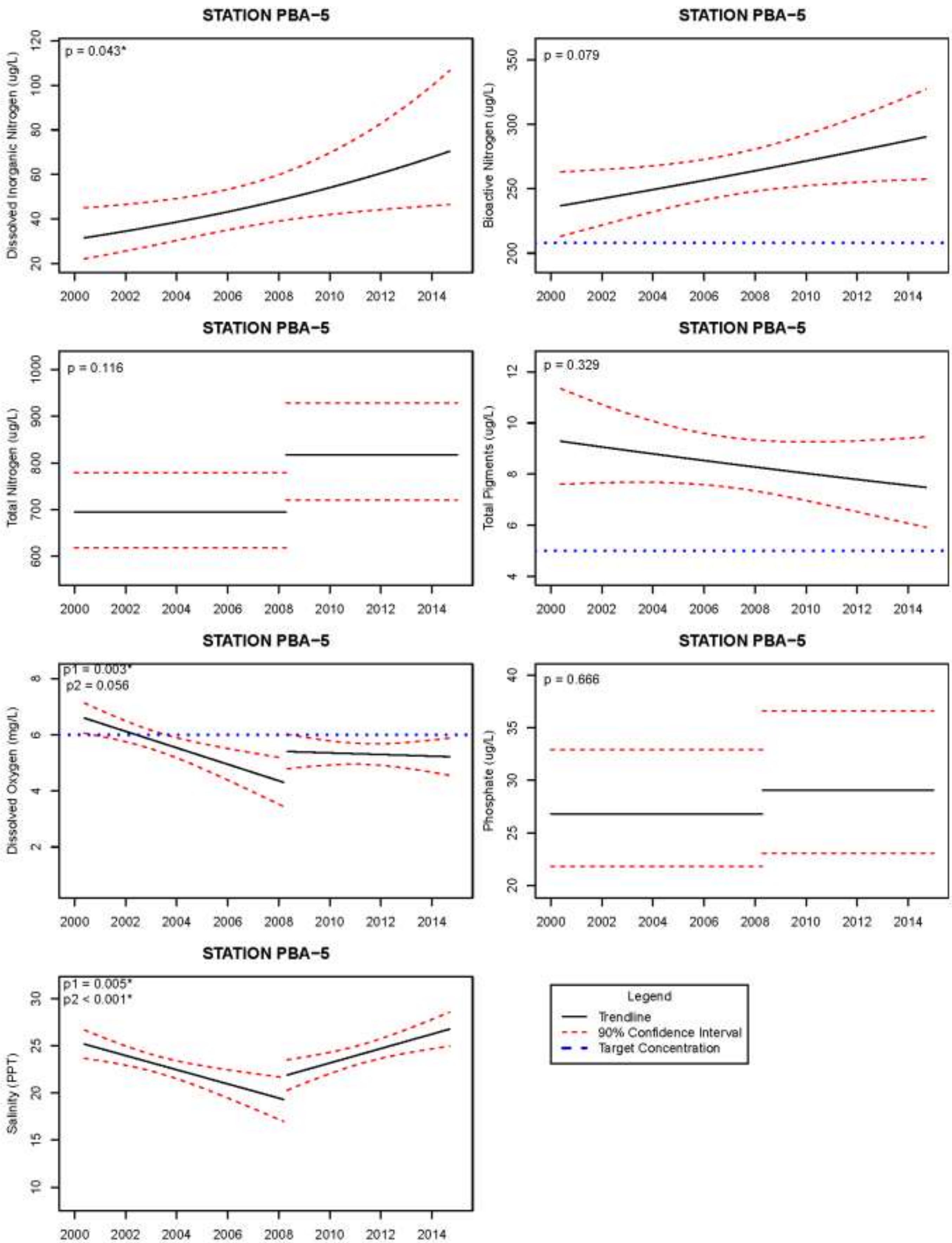
- 90% confidence interval for the trendline (red dashed lines).
- The p-value for the trendline. For station-parameter pairs with different pre-break and post-break trends, two p-values are listed. The first (p1) is the p-value for the pre-break trend slope. The second (p2) is the p-value for the post-break trend slope. Trends that are statistically significant at $p<0.05$ are denoted by an asterisk next to the p-value.
- Water quality target concentrations for dissolved oxygen, total phytopigment, and bioactive nitrogen plots (blue dotted lines). Bioactive nitrogen thresholds were established by the Massachusetts Estuaries Program to support the development of the 2007 Pleasant Bay TMDL and vary by station (Howes et al. 2006). The dissolved oxygen target of 6 mg/L is the Massachusetts water quality standard for coastal waters. The total phytopigment target of 5 µg/L is a guidance value established by the National Oceanic and Atmospheric Administration (NOAA).

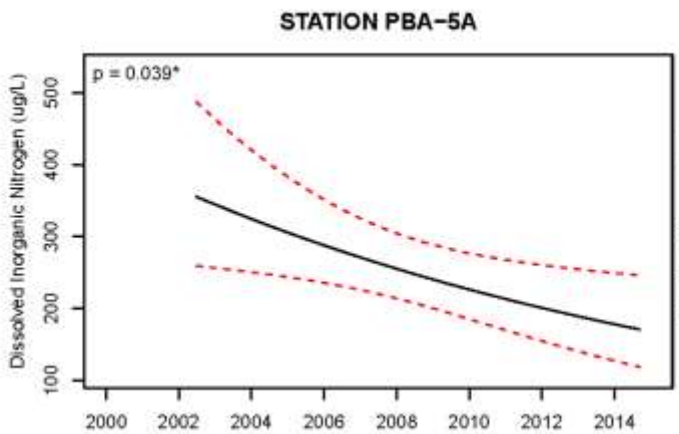

STATION CM−13
p < 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION CM−13
p = 0.118
Bioactive Nitrogen (ug/L)
STATION CM−13
p < 0.001*
Total Nitrogen (ug/L)
STATION CM−13
p < 0.001*
Total Pigments (ug/L)
STATION CM−13
p1 = 0.339
p2 = 0.009*
Dissolved Oxygen (mg/L)
STATION CM−13
p < 0.001*
Phosphate (ug/L)
STATION CM−13
p1 = 0.131
p2 = 0.428
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

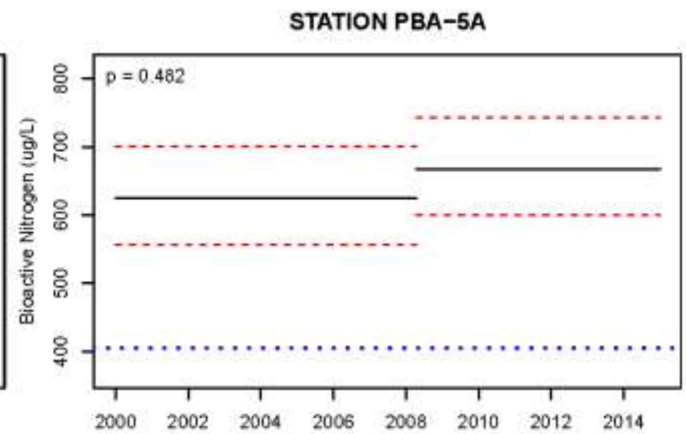

STATION PBA−3
p = 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−3
p = 0.448
Bioactive Nitrogen (ug/L)
STATION PBA−3
p = 0.067
Total Nitrogen (ug/L)
STATION PBA−3
p < 0.001*
Total Pigments (ug/L)
STATION PBA−3
p1 = 0.853
p2 < 0.001*
Dissolved Oxygen (mg/L)
STATION PBA−3
p = 0.06
Phosphate (ug/L)
STATION PBA−3
p = 0.029*
Salinity (PPT)
2000 2002 2004 2006 2008 2010 2012 2014
Legend
Trendline
90% Confidence Interval
Target Concentration

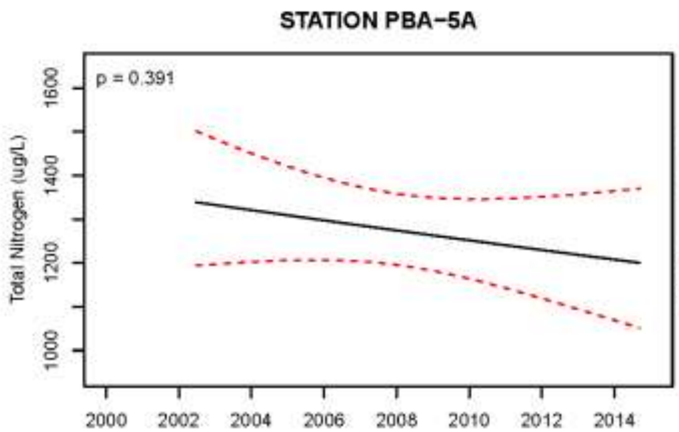


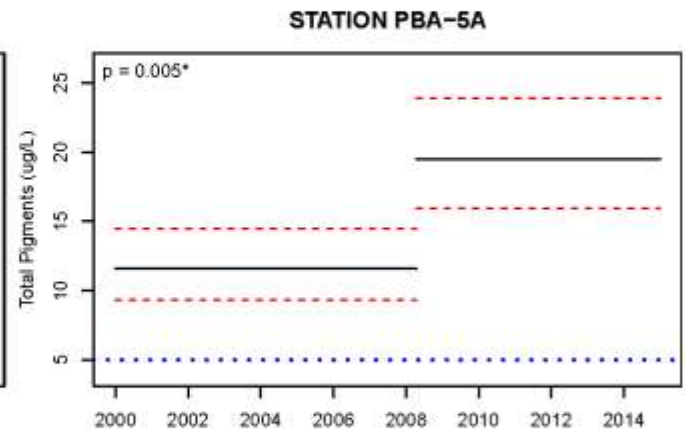
STATION PBA−4
Dissolved Inorganic Nitrogen (ug/L)
p = 0.257
STATION PBA−4
Bioactive Nitrogen (ug/L)
p < 0.001*
STATION PBA−4
Total Nitrogen (ug/L)
p < 0.001*
STATION PBA−4
Total Pigments (ug/L)
p < 0.001*
STATION PBA−4
Dissolved Oxygen (mg/L)
p1 = 0.352
p2 < 0.001*
STATION PBA−4
Phosphate (ug/L)
p = 0.017*
STATION PBA−4
Salinity (PPT)
p = 0.002*
Legend
Trendline
90% Confidence Interval
Target Concentration

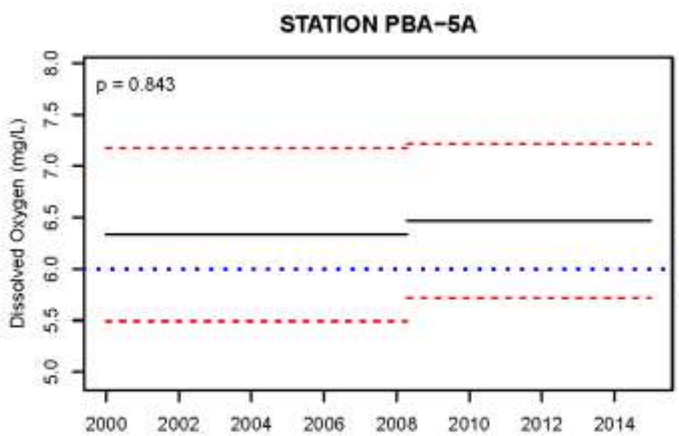

STATION PBA−5
p = 0.043*
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−5
p = 0.079
Bioactive Nitrogen (ug/L)
STATION PBA−5
p = 0.116
Total Nitrogen (ug/L)
STATION PBA−5
p = 0.329
Total Pigments (ug/L)
STATION PBA−5
p1 = 0.003*
p2 = 0.056
Dissolved Oxygen (mg/L)
STATION PBA−5
p = 0.666
Phosphate (ug/L)
STATION PBA−5
p1 = 0.005*
p2 < 0.001*
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

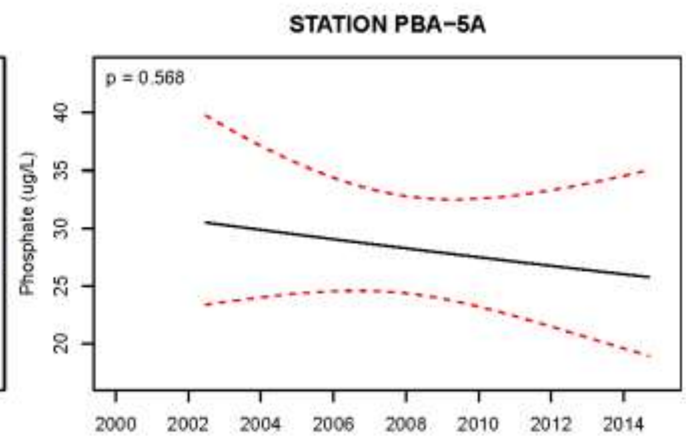

STATION PBA-5A
p = 0.039*
Dissolved Inorganic Nitrogen (ug/L)

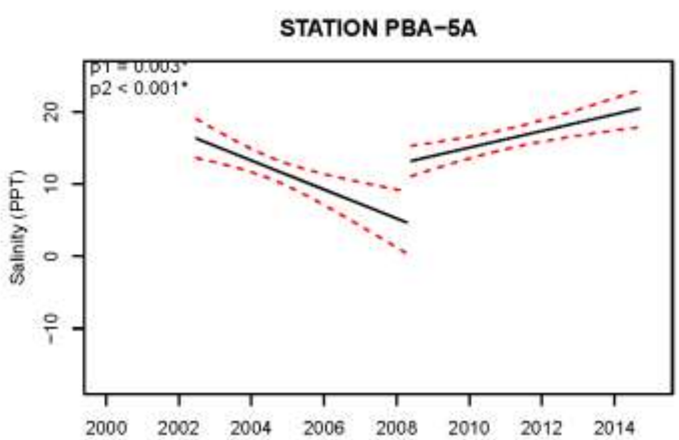

STATION PBA-5A
p = 0.482
Bioactive Nitrogen (ug/L)


STATION PBA-5A
p = 0.391
Total Nitrogen (ug/L)

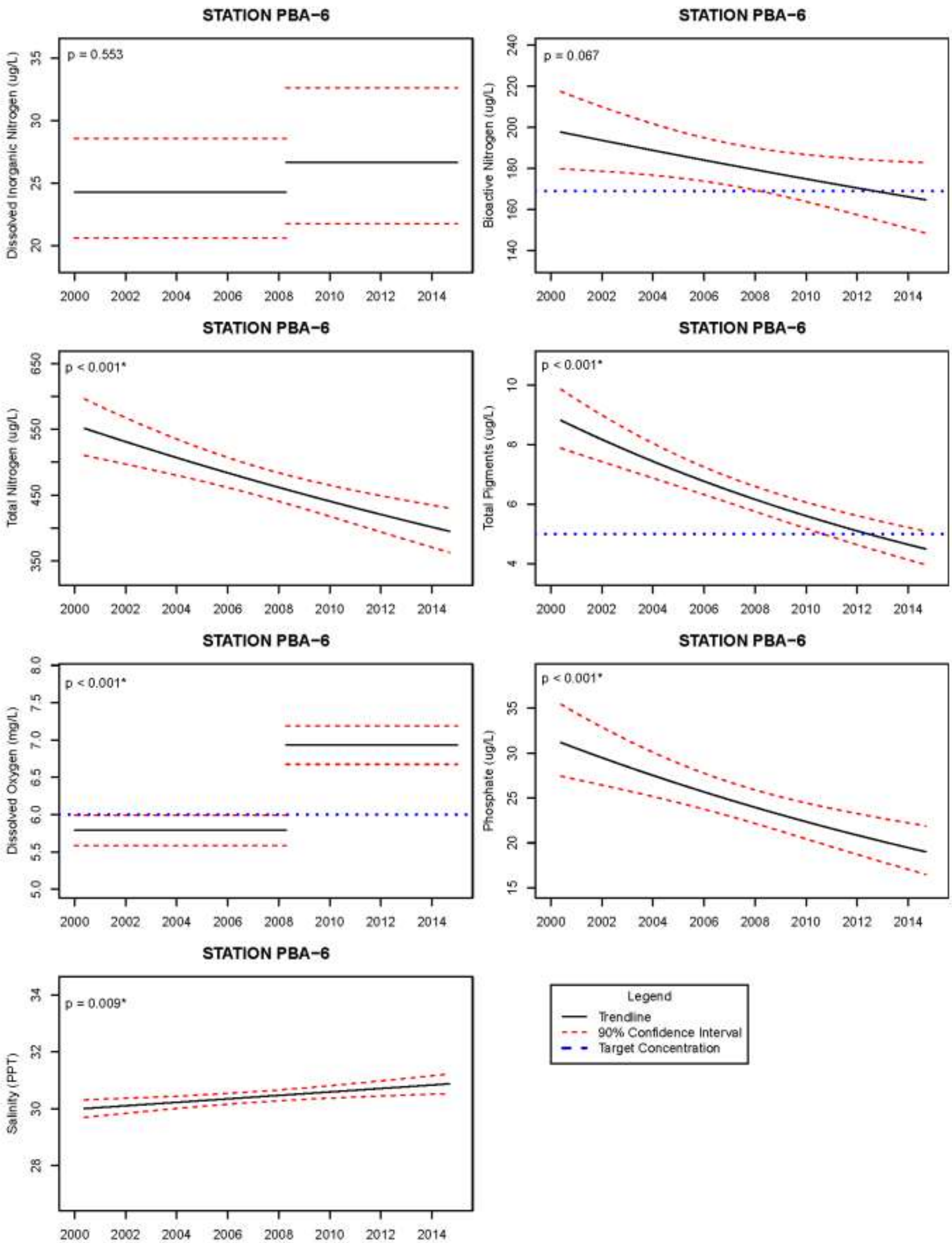

STATION PBA-5A
p = 0.005*
Total Pigments (ug/L)

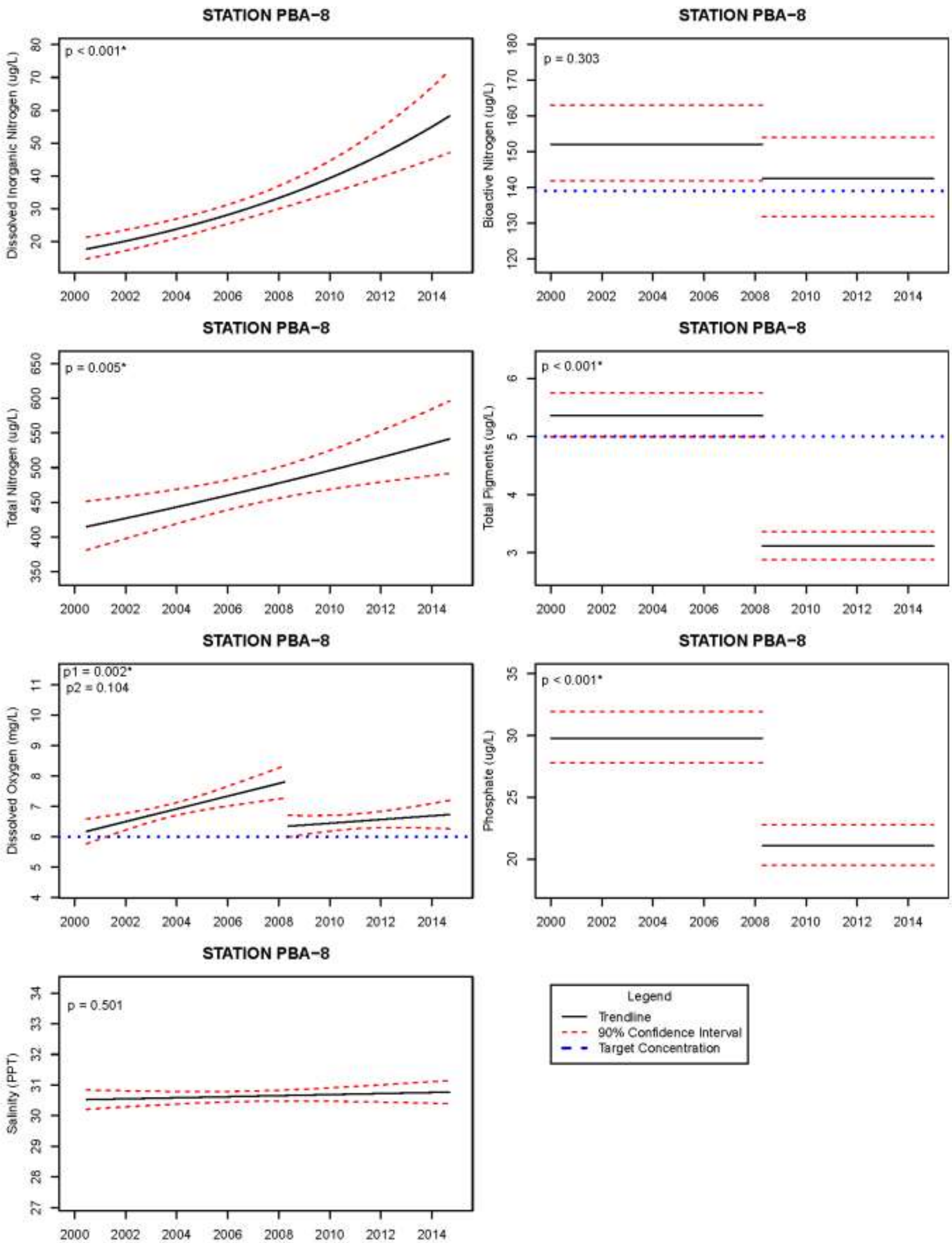

STATION PBA-5A
p = 0.843
Dissolved Oxygen (mg/L)

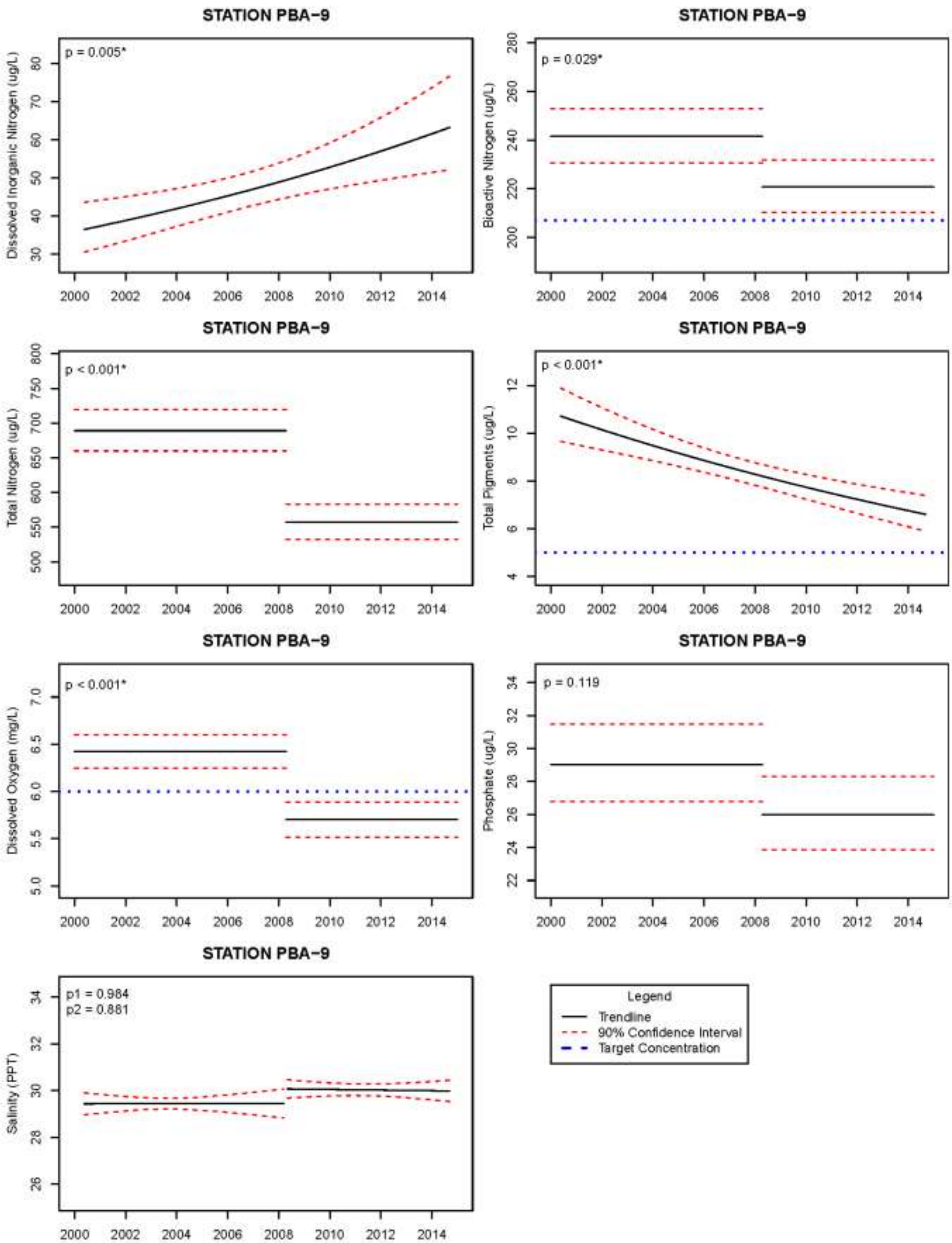

STATION PBA-5A
p = 0.568
Phosphate (ug/L)

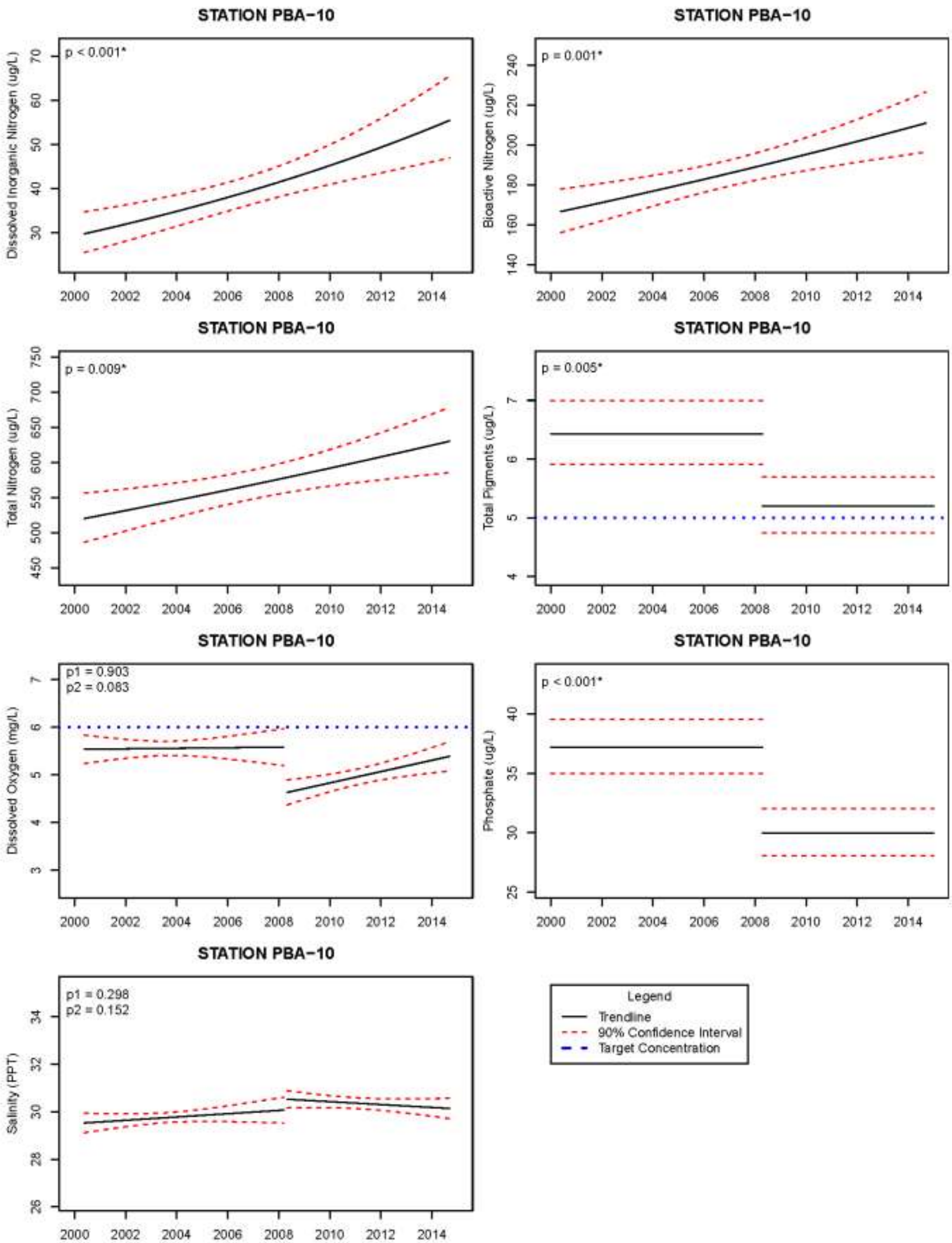

STATION PBA-5A
p1 = 0.003*
p2 < 0.001*
Salinity (PPT)

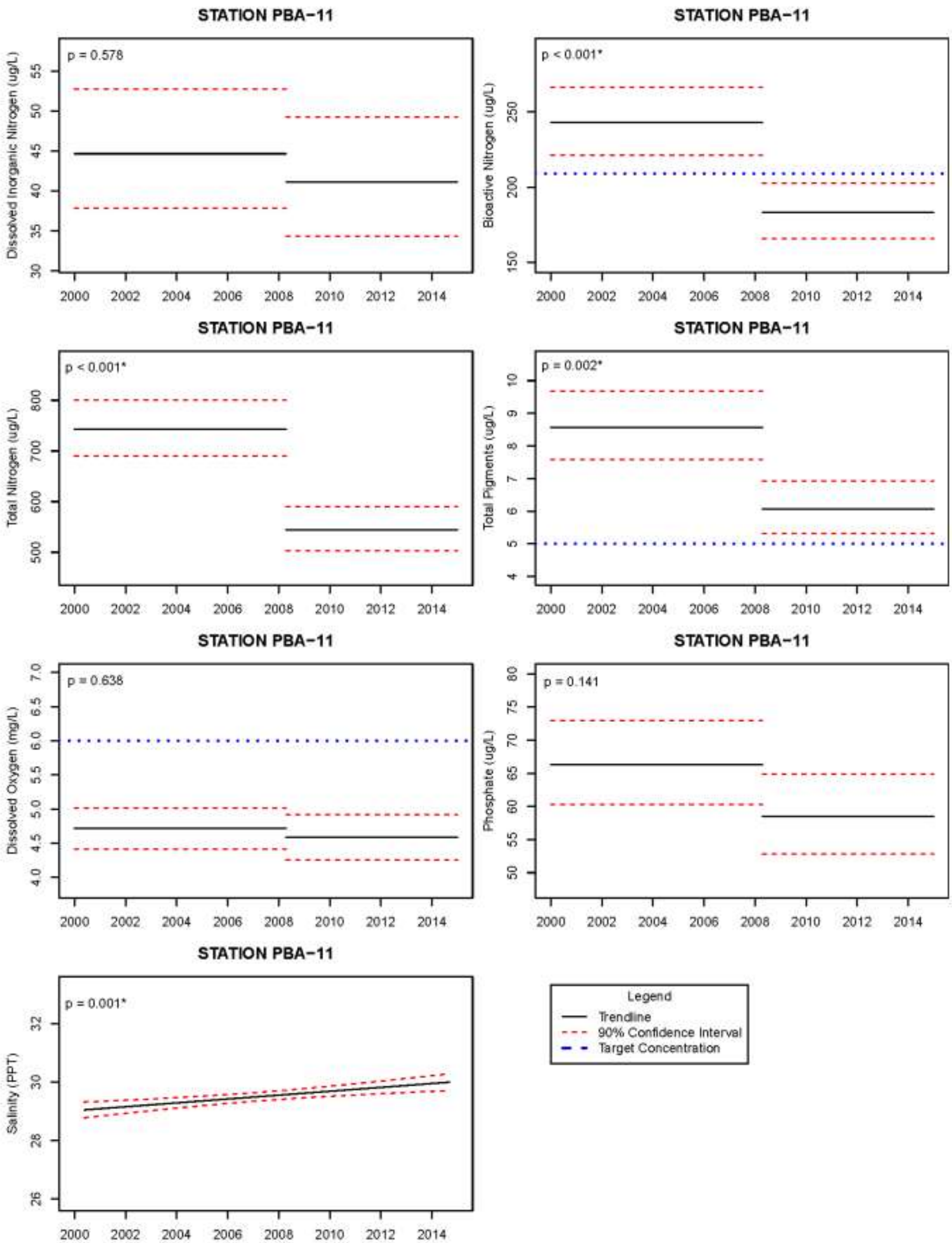

Legend
Trendline
90% Confidence Interval
Target Concentration

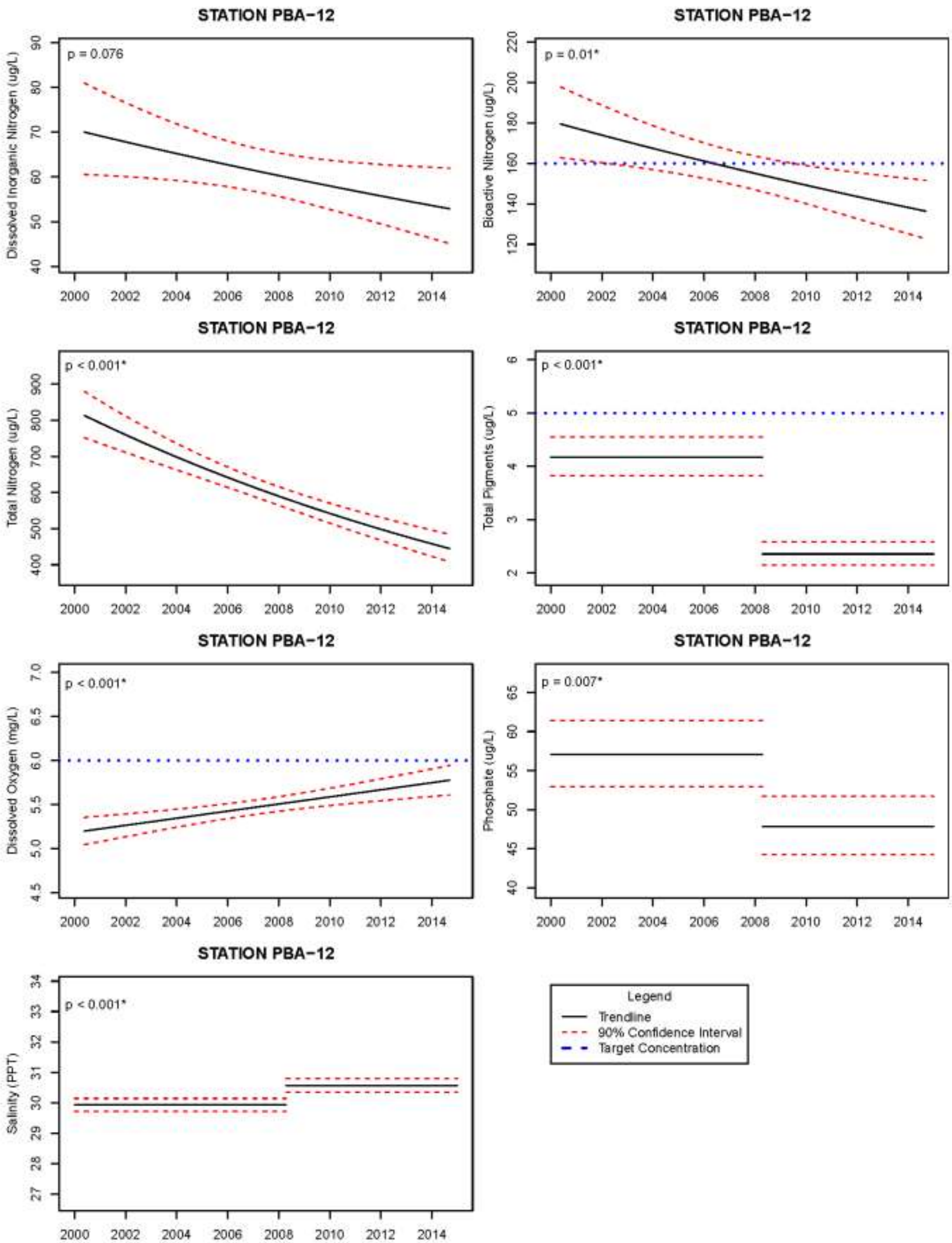

STATION PBA−6
p = 0.553
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−6
p = 0.067
Bioactive Nitrogen (ug/L)
STATION PBA−6
p < 0.001*
Total Nitrogen (ug/L)
STATION PBA−6
p < 0.001*
Total Pigments (ug/L)
STATION PBA−6
p < 0.001*
Dissolved Oxygen (mg/L)
STATION PBA−6
p < 0.001*
Phosphate (ug/L)
STATION PBA−6
p = 0.009*
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

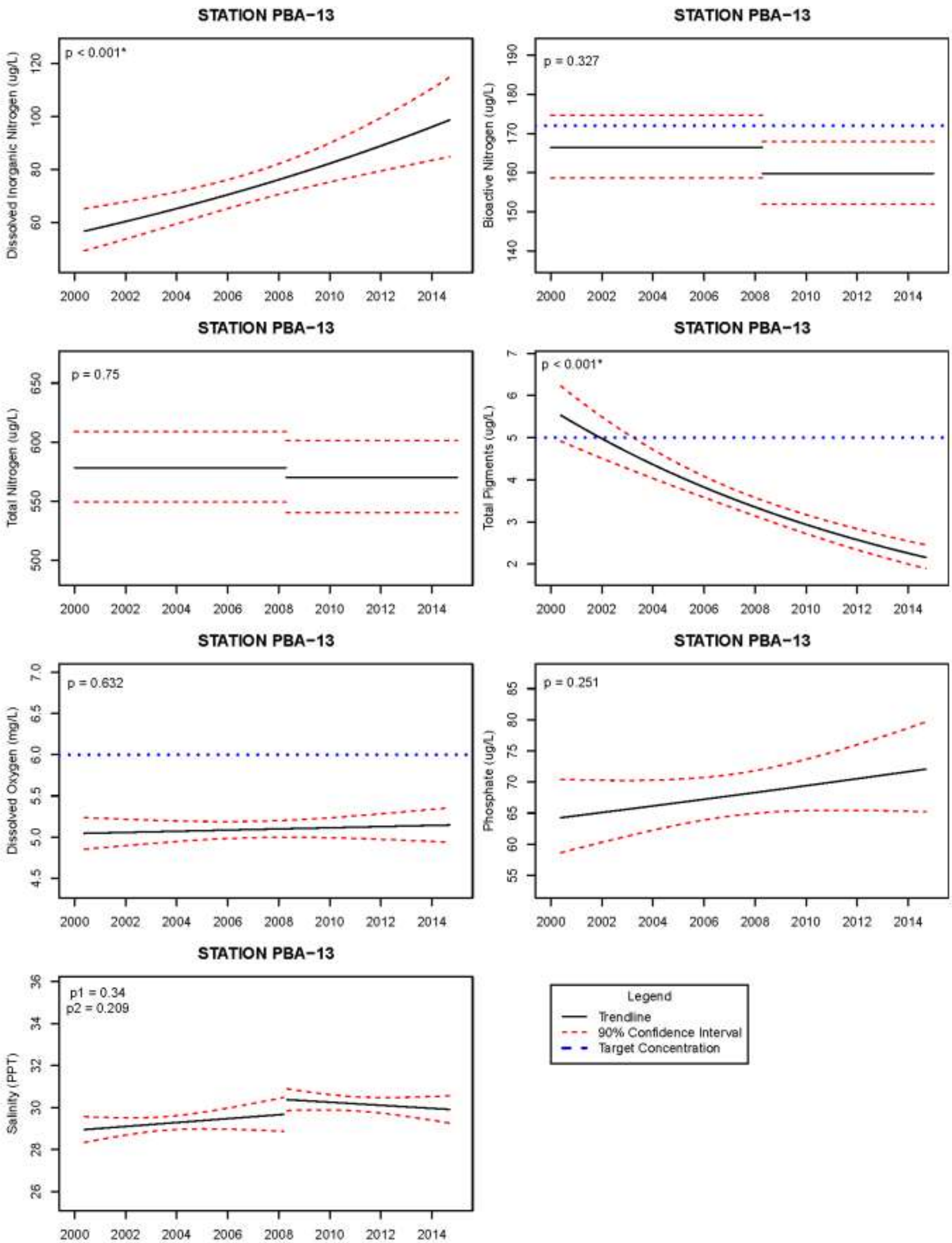

STATION PBA−8
p < 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−8
p = 0.303
Bioactive Nitrogen (ug/L)
STATION PBA−8
p = 0.005*
Total Nitrogen (ug/L)
STATION PBA−8
p < 0.001*
Total Pigments (ug/L)
STATION PBA−8
p1 = 0.002*
p2 = 0.104
Dissolved Oxygen (mg/L)
STATION PBA−8
p < 0.001*
Phosphate (ug/L)
STATION PBA−8
p = 0.501
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

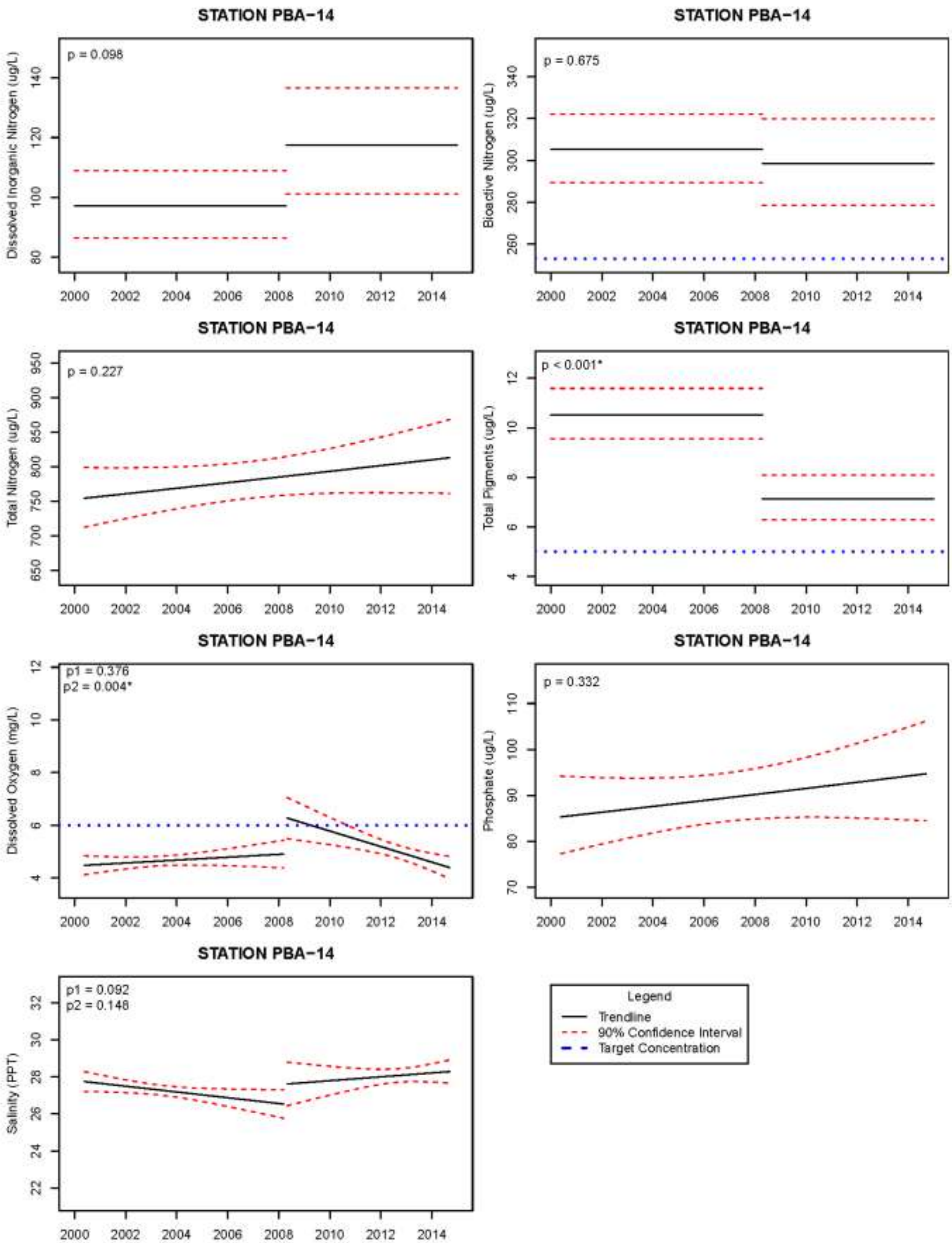

STATION PBA−9
Dissolved Inorganic Nitrogen (ug/L)
p = 0.005*
STATION PBA−9
Bioactive Nitrogen (ug/L)
p = 0.029*
STATION PBA−9
Total Nitrogen (ug/L)
p < 0.001*
STATION PBA−9
Total Pigments (ug/L)
p < 0.001*
STATION PBA−9
Dissolved Oxygen (mg/L)
p < 0.001*
STATION PBA−9
Phosphate (ug/L)
p = 0.119
STATION PBA−9
Salinity (PPT)
p1 = 0.984
p2 = 0.881
Legend
Trendline
90% Confidence Interval
Target Concentration

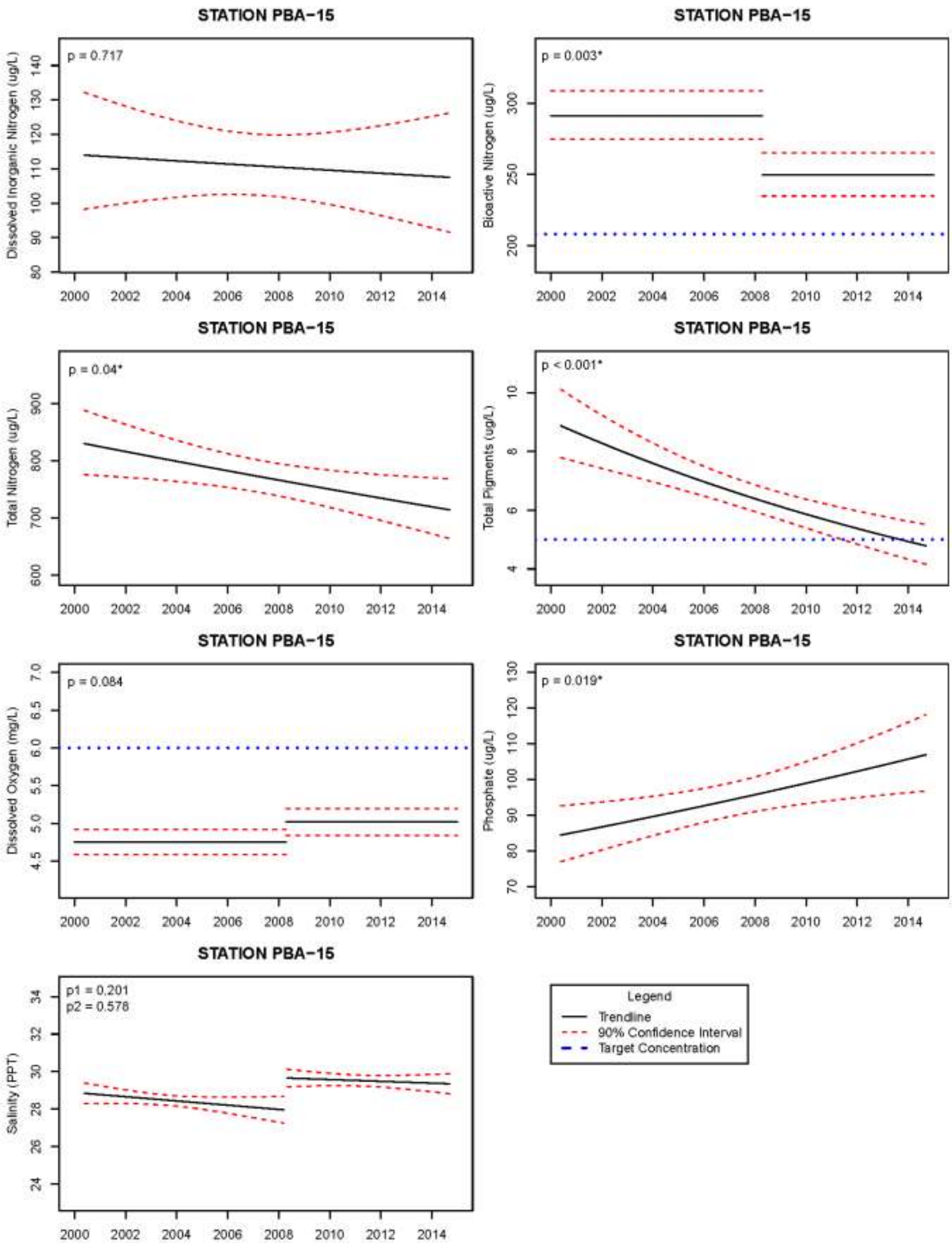

STATION PBA−10
p < 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−10
p = 0.001*
Bioactive Nitrogen (ug/L)
STATION PBA−10
p = 0.009*
Total Nitrogen (ug/L)
STATION PBA−10
p = 0.005*
Total Pigments (ug/L)
STATION PBA−10
p1 = 0.903
p2 = 0.083
Dissolved Oxygen (mg/L)
STATION PBA−10
p < 0.001*
Phosphate (ug/L)
STATION PBA−10
p1 = 0.298
p2 = 0.152
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

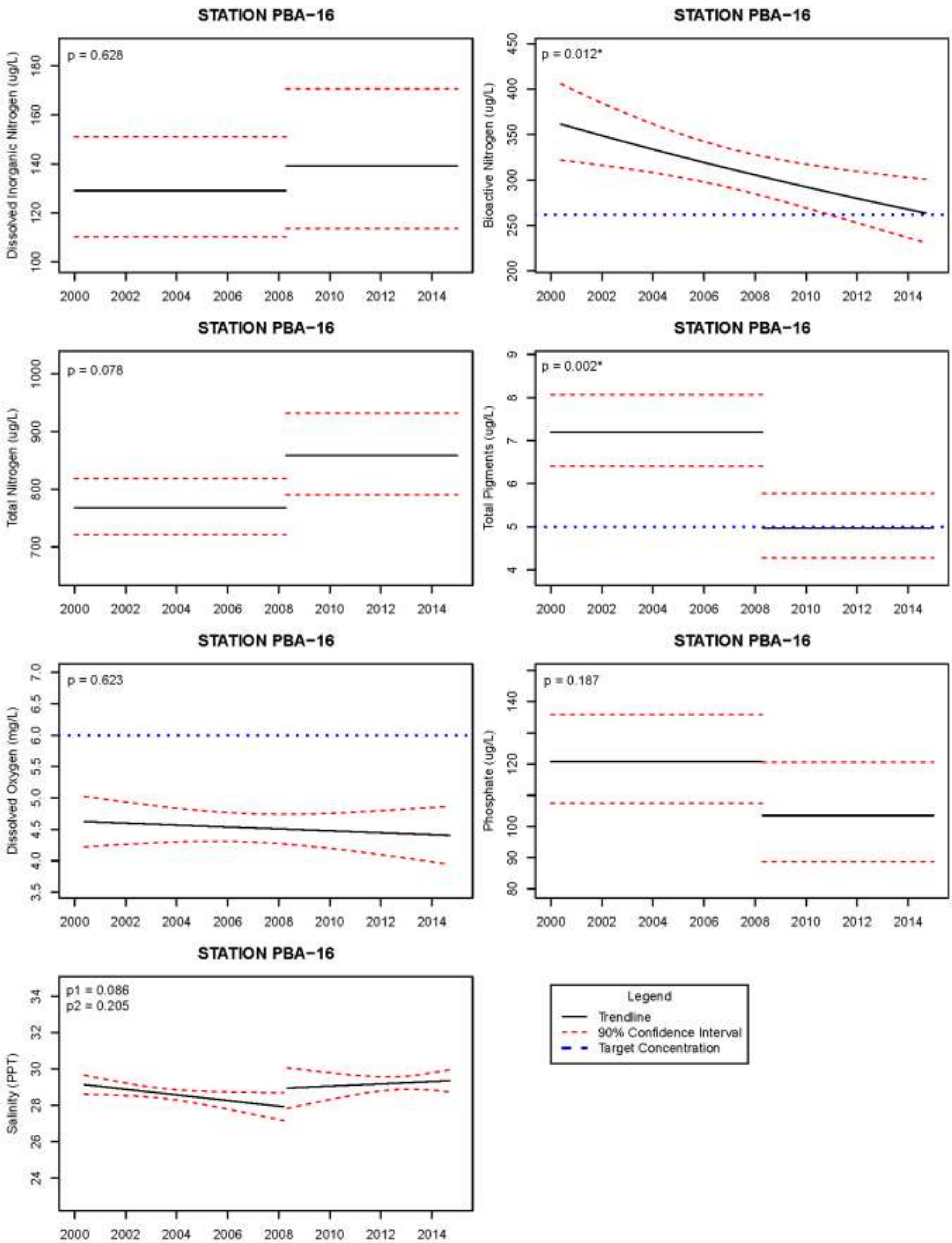

STATION PBA−11
p = 0.578
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−11
p < 0.001*
Bioactive Nitrogen (ug/L)
STATION PBA−11
p < 0.001*
Total Nitrogen (ug/L)
STATION PBA−11
p = 0.002*
Total Pigments (ug/L)
STATION PBA−11
p = 0.638
Dissolved Oxygen (mg/L)
STATION PBA−11
p = 0.141
Phosphate (ug/L)
STATION PBA−11
p = 0.001*
Salinity (PPT)
2000 2002 2004 2006 2008 2010 2012 2014
Legend
Trendline
90% Confidence Interval
Target Concentration

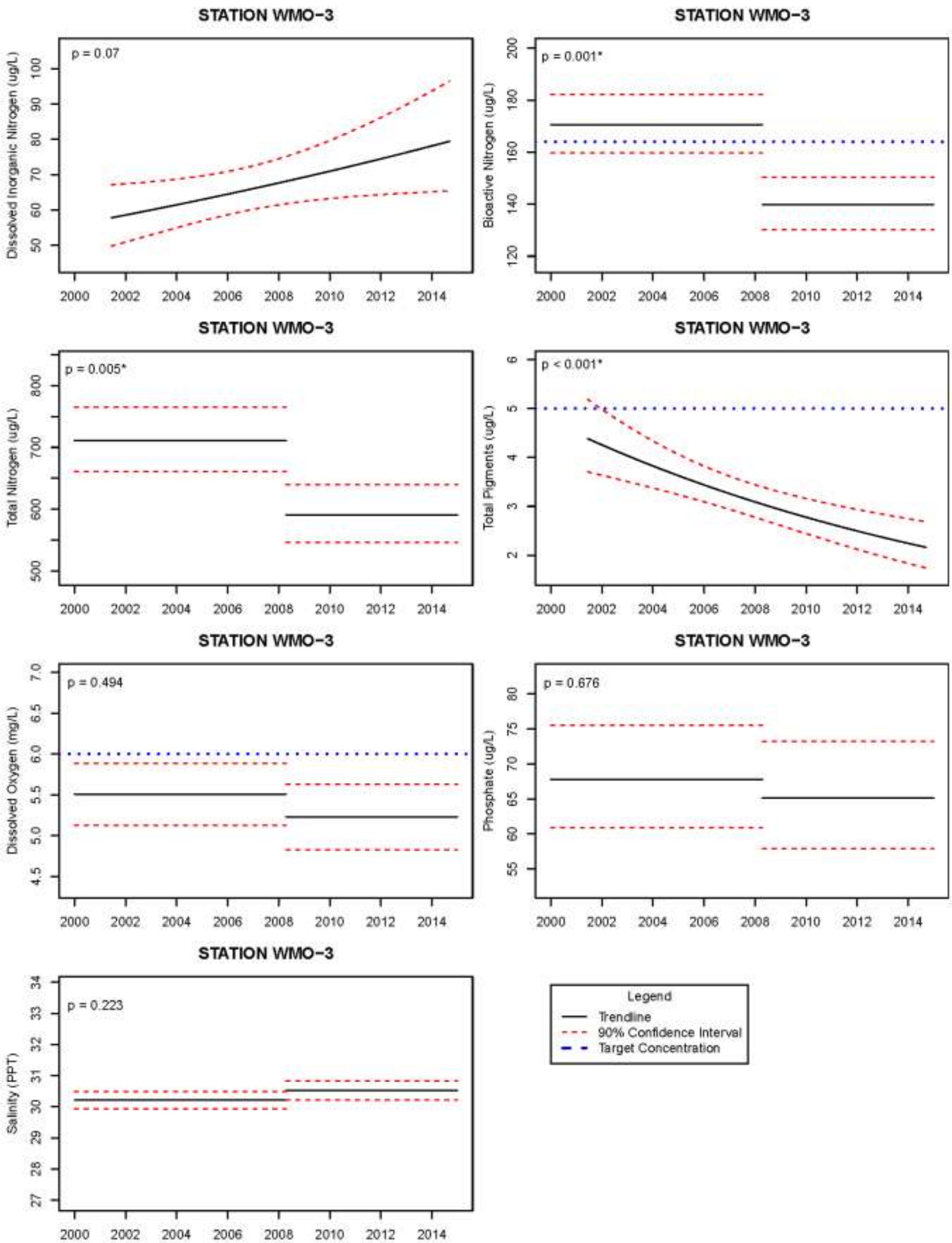

STATION PBA−12
p = 0.076
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−12
p = 0.01*
Bioactive Nitrogen (ug/L)
STATION PBA−12
p < 0.001*
Total Nitrogen (ug/L)
STATION PBA−12
p < 0.001*
Total Pigments (ug/L)
STATION PBA−12
p < 0.001*
Dissolved Oxygen (mg/L)
STATION PBA−12
p = 0.007*
Phosphate (ug/L)
STATION PBA−12
p < 0.001*
Salinity (PPT)
2000 2002 2004 2006 2008 2010 2012 2014
Legend
Trendline
90% Confidence Interval
Target Concentration

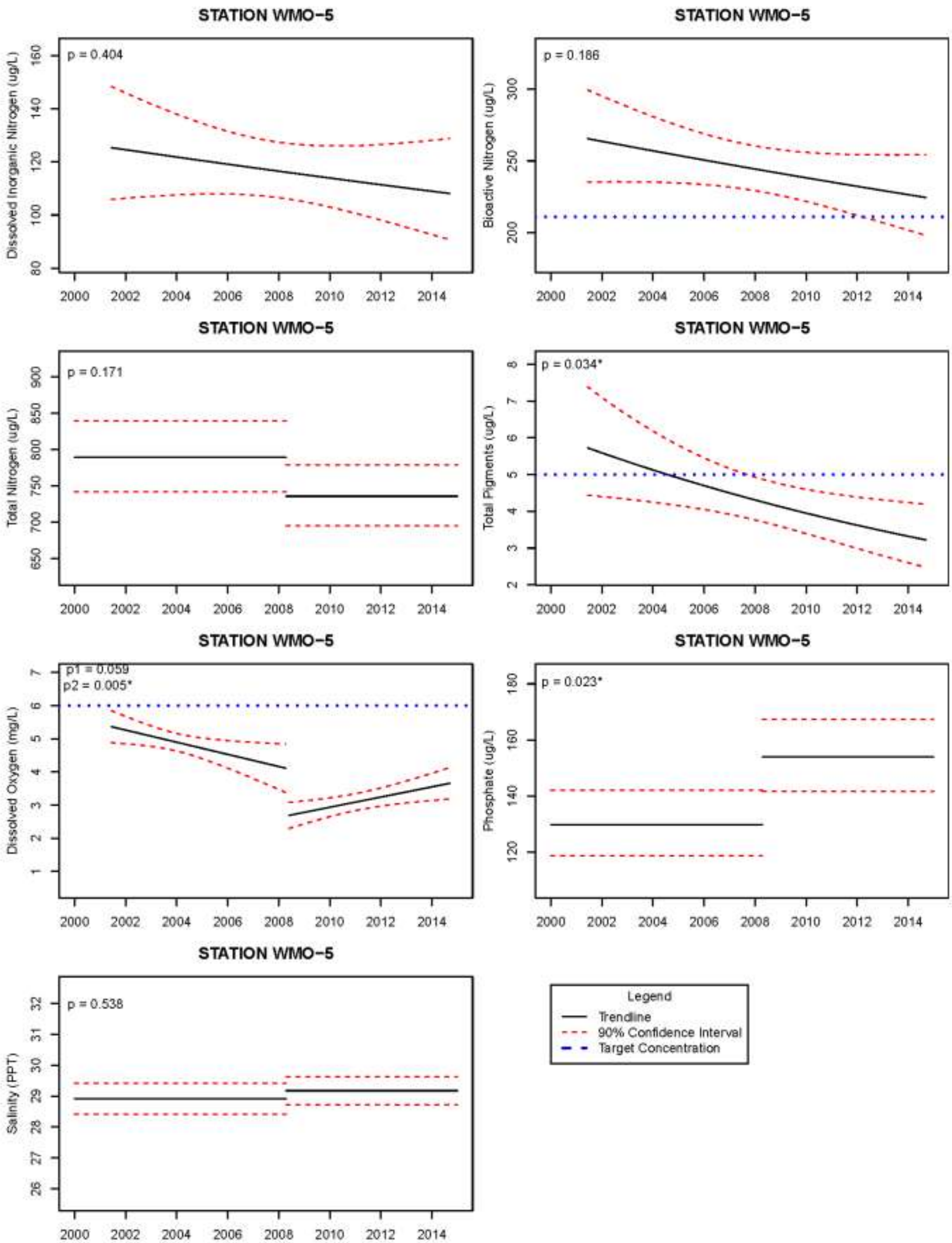

STATION PBA-13
p < 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA-13
p = 0.327
Bioactive Nitrogen (ug/L)
STATION PBA-13
p = 0.75
Total Nitrogen (ug/L)
STATION PBA-13
p < 0.001*
Total Pigments (ug/L)
STATION PBA-13
p = 0.632
Dissolved Oxygen (mg/L)
STATION PBA-13
p = 0.251
Phosphate (ug/L)
STATION PBA-13
p1 = 0.34
p2 = 0.209
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration


STATION PBA−14
p = 0.098
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−14
p = 0.675
Bioactive Nitrogen (ug/L)
STATION PBA−14
p = 0.227
Total Nitrogen (ug/L)
STATION PBA−14
p < 0.001*
Total Pigments (ug/L)
STATION PBA−14
p1 = 0.376
p2 = 0.004*
Dissolved Oxygen (mg/L)
STATION PBA−14
p = 0.332
Phosphate (ug/L)
STATION PBA−14
p1 = 0.092
p2 = 0.148
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

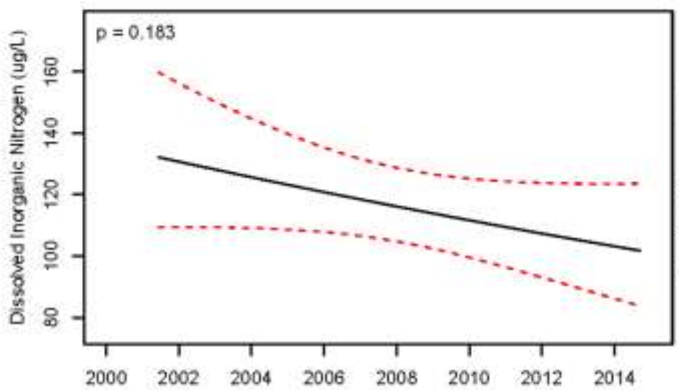

STATION PBA−15
p = 0.717
Dissolved Inorganic Nitrogen (ug/L)
STATION PBA−15
p = 0.003*
Bioactive Nitrogen (ug/L)
STATION PBA−15
p = 0.04*
Total Nitrogen (ug/L)
STATION PBA−15
p < 0.001*
Total Pigments (ug/L)
STATION PBA−15
p = 0.084
Dissolved Oxygen (mg/L)
STATION PBA−15
p = 0.019*
Phosphate (ug/L)
STATION PBA−15
p1 = 0.201
p2 = 0.578
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration


STATION PBA−16
Dissolved Inorganic Nitrogen (ug/L)
p = 0.628
STATION PBA−16
Bioactive Nitrogen (ug/L)
p = 0.012*
STATION PBA−16
Total Nitrogen (ug/L)
p = 0.078
STATION PBA−16
Total Pigments (ug/L)
p = 0.002*
STATION PBA−16
Dissolved Oxygen (mg/L)
p = 0.623
STATION PBA−16
Phosphate (ug/L)
p = 0.187
STATION PBA−16
Salinity (PPT)
p1 = 0.086
p2 = 0.205
Legend
Trendline
90% Confidence Interval
Target Concentration

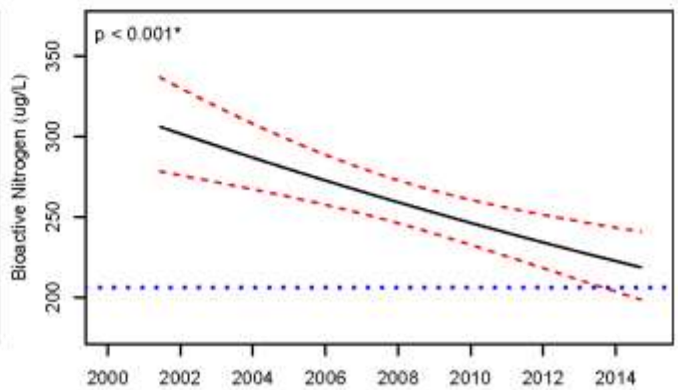

STATION WMO-3
p = 0.07
Dissolved Inorganic Nitrogen (ug/L)
STATION WMO-3
p = 0.001*
Bioactive Nitrogen (ug/L)
STATION WMO-3
p = 0.005*
Total Nitrogen (ug/L)
STATION WMO-3
p < 0.001*
Total Pigments (ug/L)
STATION WMO-3
p = 0.494
Dissolved Oxygen (mg/L)
STATION WMO-3
p = 0.676
Phosphate (ug/L)
STATION WMO-3
p = 0.223
Salinity (PPT)
2000 2002 2004 2006 2008 2010 2012 2014
Legend
Trendline
90% Confidence Interval
Target Concentration


STATION WMO-5
p = 0.404
Dissolved Inorganic Nitrogen (ug/L)
STATION WMO-5
p = 0.186
Bioactive Nitrogen (ug/L)
STATION WMO-5
p = 0.171
Total Nitrogen (ug/L)
STATION WMO-5
p = 0.034*
Total Pigments (ug/L)
STATION WMO-5
p1 = 0.059
p2 = 0.005*
Dissolved Oxygen (mg/L)
STATION WMO-5
p = 0.023*
Phosphate (ug/L)
STATION WMO-5
p = 0.538
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration

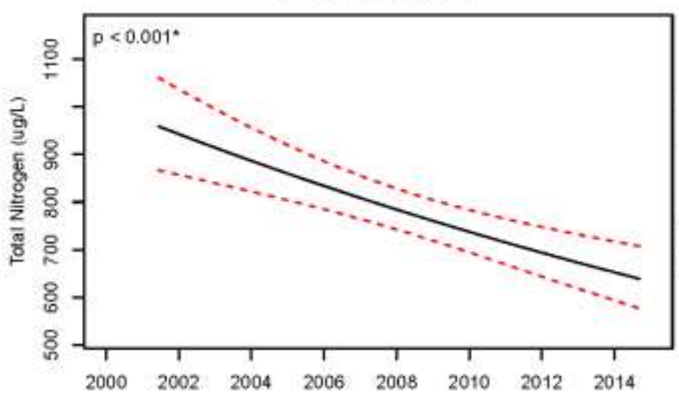
STATION WMO−6



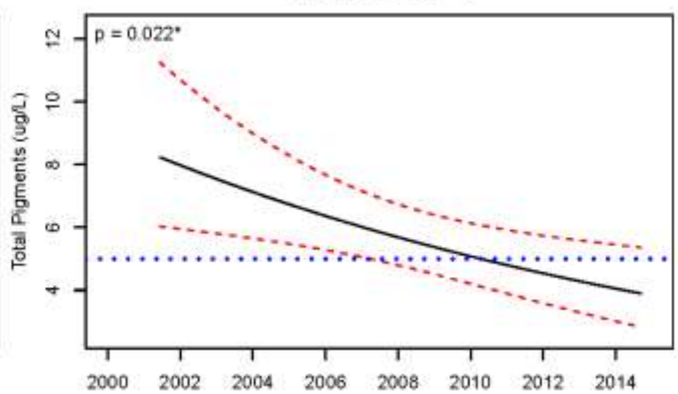
STATION WMO−6



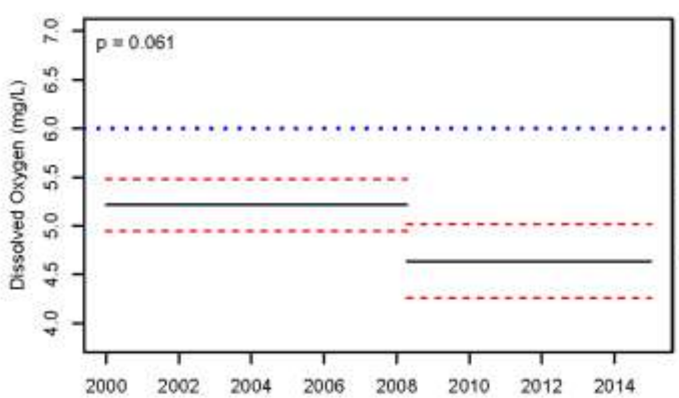
STATION WMO−6



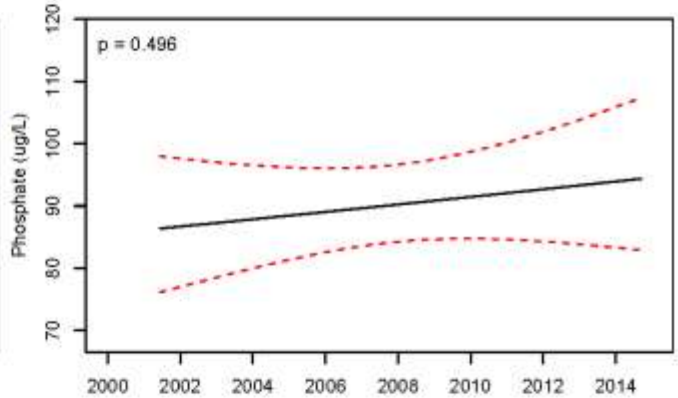
STATION WMO−6



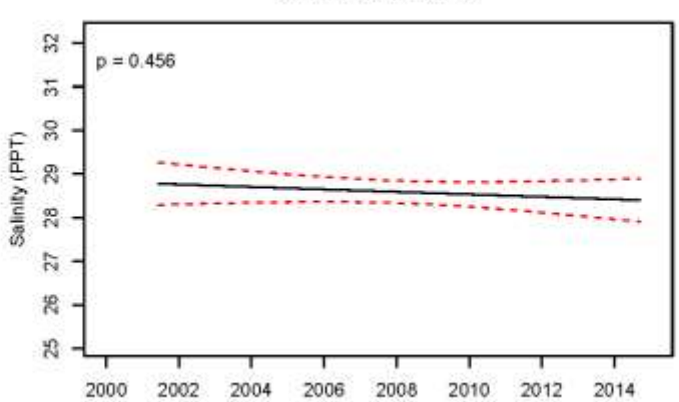
STATION WMO−6

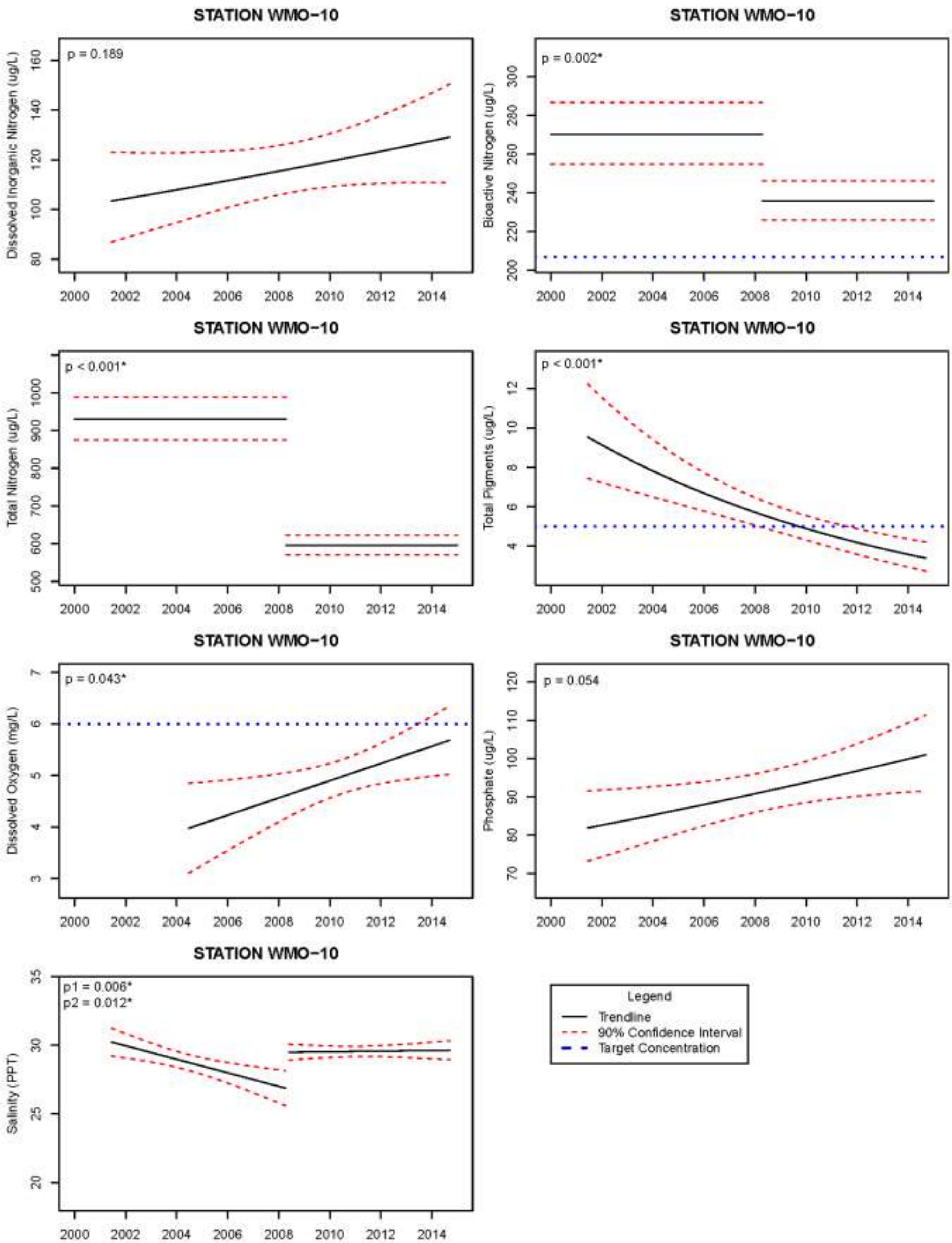


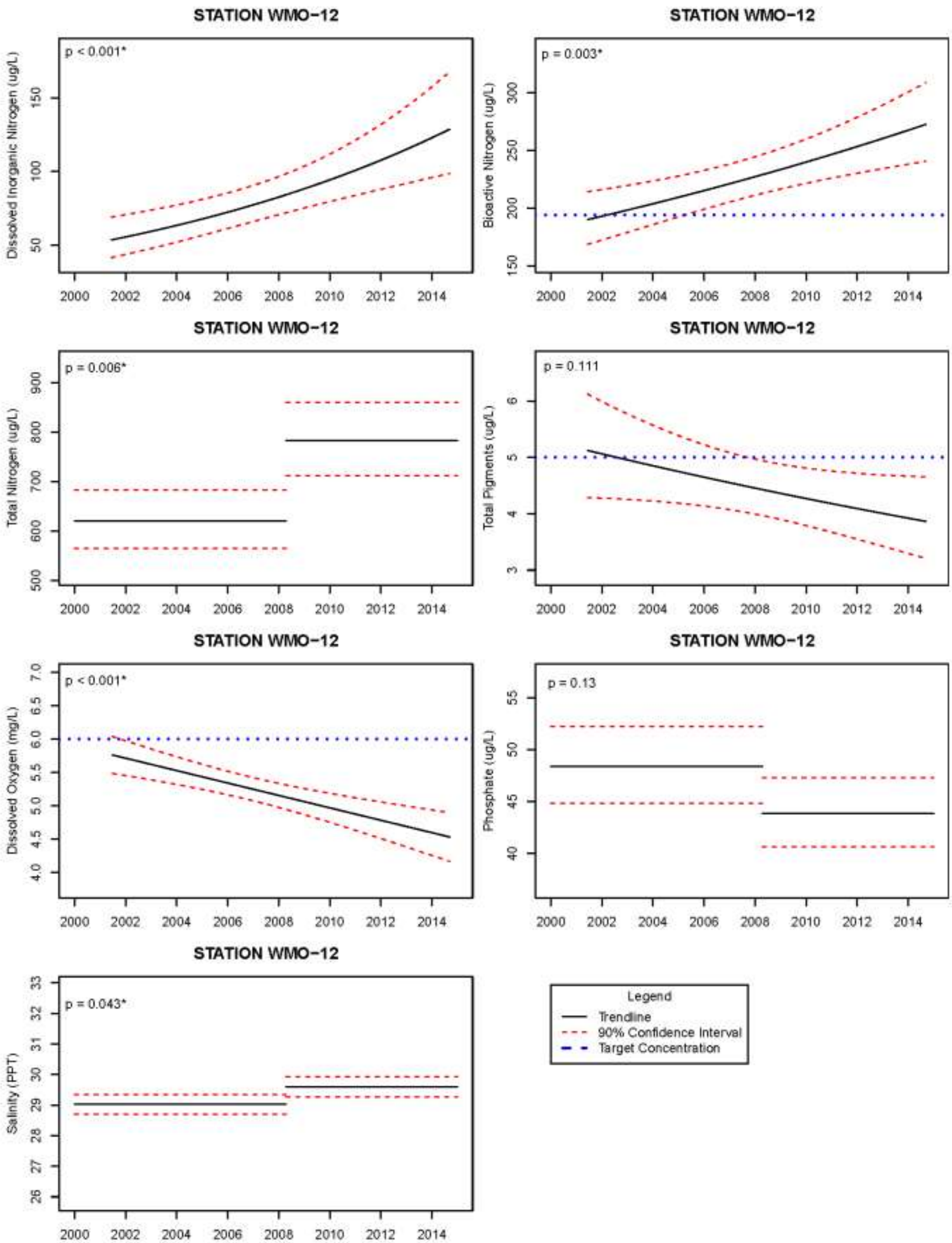
STATION WMO−6



STATION WMO−6




STATION WMO−10
p = 0.189
Dissolved Inorganic Nitrogen (ug/L)
STATION WMO−10
p = 0.002*
Bioactive Nitrogen (ug/L)
STATION WMO−10
p < 0.001*
Total Nitrogen (ug/L)
STATION WMO−10
p < 0.001*
Total Pigments (ug/L)
STATION WMO−10
p = 0.043*
Dissolved Oxygen (mg/L)
STATION WMO−10
p = 0.054
Phosphate (ug/L)
STATION WMO−10
p1 = 0.006*
p2 = 0.012*
Salinity (PPT)
Legend
Trendline
90% Confidence Interval
Target Concentration


STATION WMO−12
p < 0.001*
Dissolved Inorganic Nitrogen (ug/L)
STATION WMO−12
p = 0.003*
Bioactive Nitrogen (ug/L)
STATION WMO−12
p = 0.006*
Total Nitrogen (ug/L)
STATION WMO−12
p = 0.111
Total Pigments (ug/L)
STATION WMO−12
p < 0.001*
Dissolved Oxygen (mg/L)
STATION WMO−12
p = 0.13
Phosphate (ug/L)
STATION WMO−12
p = 0.043*
Salinity (PPT)
2000 2002 2004 2006 2008 2010 2012 2014
Legend
Trendline
90% Confidence Interval
Target Concentration