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Conceptual Plan for Nutrient Criteria Development in Maine Coastal Waters

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Conceptual Plan for Nutrient Criteria Development in Maine Coastal Waters

EPA REGION 1, MAINE DEPARTMENT OF
ENVIRONMENTAL PROTECTION, AND
EPA OCEAN AND COASTAL PROTECTION DIVISION

CONCEPTUAL PLAN FOR NUTRIENT CRITERIA DEVELOPMENT IN MAINE COASTAL WATERS

Prepared for:

EPA Region 1
Suite 1100 (CWQ)
One Congress Street
Boston, MA 02114-2023

And

Maine Department of Environmental Protection
17 State House Station
Augusta, ME 04333

And

Oceans and Coastal Protection Division
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., NW
Washington, D.C. 20460

Prepared by:

Battelle
153 B Park Row
Brunswick ME 04011

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1.0 INTRODUCTION

The Clean Water Act (CWA) directs the U.S. Environmental Protection Agency (EPA) to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Under the CWA, the EPA has established a Water Quality Standards Program to help achieve this objective, and EPA Region 1 has worked closely with the New England states over the past decade to develop and incorporate nutrient criteria into state water quality standards. While good progress has been made by states like Maine towards establishing freshwater criteria, little progress has been made in establishing nutrient criteria for marine waters.

EPA published a National Nutrient Strategy (EPA 1998), which describes the approach for adopting nutrient criteria to meet the goals of the Clean Water Action Plan. The establishment of nutrient criteria is critical to the process of managing our water resources. Nutrients are essential for aquatic ecosystems, but they are also a major factor in the environmental degradation of our rivers, streams, lakes, ponds, estuaries and coastal waters. Geographically, there are large variations in the natural physical, chemical, and biological characteristics of water resources (and adjacent lands) that influence how a particular waterbody responds to changes in nutrient loads. In order to take these variations into account, nutrient criteria must be established on appropriate spatial scales and not merely dictated on a national scale. Therefore, the major focus of the National Nutrient Strategy has been the development of technical guidance documents for specific waterbody types (i.e., lakes/reservoirs, rivers/streams, estuarine/coastal waters). Temporal scales may also be considered as nutrient dynamics can change seasonally.

A technical guidance manual for developing nutrient criteria in estuarine and coastal marine waters was published in 2001 (EPA 2001). The guidance manual provides an in depth review of nutrient issues facing US coastal waters including eutrophication, red tides, hypoxia, and loss of seagrass and other benthic habitats. The guidance focuses on causal (nitrogen and phosphorous) and response (chlorophyll, dissolved oxygen, and water clarity) variables, but highlights the importance of N as the limiting nutrient in most coastal marine waters. The document also specifies a variety of approaches that could be used to develop criteria and noted that other approaches may also be appropriate given the dynamic nature of estuarine and other near shore marine waters. Overall, the guidance acknowledges that nutrient criteria and the associated nutrient management plan must be scientifically defensible, economically feasible, and practical and acceptable to the communities involved. These three factors served as the guiding principals for the data examination, examples, discussion, and recommendations contained in this report.

Battelle was contracted to assist EPA Region 1 in working with the Maine Department of Environmental Protection (ME DEP) and other stakeholders to plan the nutrient criteria development process for marine waters in Maine. This report focuses on existing coastal data for the State of Maine collected by EPA and the Friends of Casco Bay (FOCB) to describe current ambient conditions. These data have been incorporated into the report to provide context for a plan to develop nutrient criteria for Maine coastal waters. This report details the steps and methods used to acquire FOCB and EPA data, develop an MS Access database, and conduct preliminary data analyses. The results of these analyses describe current levels of nutrients and other key water quality parameters in Maine coastal waters and are presented as an example of how nutrient criteria may be developed using a pragmatic approach. It should be noted that the data collection effort was neither exhaustive nor comprehensive and was focused on three datasets with limited temporal and spatial resolution. However, it is one of the largest statewide nutrient datasets available for Maine coastal waters. The overall objective for this report is to establish a plan for moving forward with nutrient criteria development in Maine coastal waters.

1.1 Development Process

Maine, like many states, has been focused on the development of nutrient criteria in freshwater systems (lakes/reservoirs and rivers/streams). These systems represent clearly defined water bodies that have been monitored by ME DEP over the past few decades. The development of nutrient criteria for Maine's estuaries and coastal waters has taken a back seat until recently. This has also been the case on the national level as only a few states have developed estuarine nutrient criteria for N, P or response parameters (HI, MD, DE, VA, CT, and NY). The Maryland, Delaware and Virginia criteria were developed as part of the Chesapeake Bay criteria effort (EPA 2003) and the Connecticut and New York criteria are only for dissolved oxygen in Long Island Sound. The difficulty in developing estuarine and coastal criteria was understood by EPA and evident in the order in which EPA published the technical guidance manuals for nutrient criteria development. The lakes/reservoirs and rivers/streams manuals were published in April and July 2000, respectively (EPA 2000a and 2000b), while the estuary/coastal manual was published a year and a half later (EPA 2001).

In Maine, the process of developing estuarine and coastal water nutrient criteria was pushed forward in 2007 with passage of LD 1297[1] by the 123rd Maine State Legislature. Work Assignment 4-53 was supported by EPA Region 1 to assist ME DEP in their efforts to comply with LD 1297 and this report serves as an initial step in the development of a conceptual plan for establishing estuarine and coastal nutrient criteria in Maine.

From the start, the timeframe for nutrient criteria development has been seen as a multi-year process (Figure 1). This report skips over the initial planning phase and the efforts covered in this report fall in the data assessment phase. However, there are clearly understood goals underlying the effort to establish the criteria (e.g. maintain water quality to sustain fisheries, human activities, ecological health, etc.) and the variables to examine (at least initially) are limited to the data in hand or the data that will be collected for ongoing programs. Thus, the major step that has been passed over is classification of waterbodies.

There are a wide range of waterbody types along the Maine coast – from highly river influenced systems such as Penobscot Bay and Merrymeeting Bay to semi-enclosed, long residence time embayments like Quahog Bay and the New Meadows River. At this time, the lack of readily available physical and hydrographic data to classify these systems, as well as the limited amount of nutrient data available, makes both classification of water bodies and development of waterbody type specific criteria essentially impossible. Thus, we have used readily available data on total nitrogen (TN), dissolved inorganic nitrogen forms, chlorophyll, and DO to attempt to examine potential approaches to developing criteria for these waters. The efforts documented in this report focus on the data gathering and assessment phase and provide examples on how to proceed with the next phase of actually developing criteria. Note, however, that we may need to revisit some of the planning phase (i.e. classification) that this pragmatic approach skips when it comes time to apply criteria statewide.

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[1] LD1297 – *Resolve, Regarding Measures To Ensure the Continued Health and Commercial Viability of Maine's Seacoast by Establishing Nutrient Criteria for Coastal Waters* complete text available at http://janus.state.me.us/legis/ros/lom/LOM123rd/RESOLVE49.asp

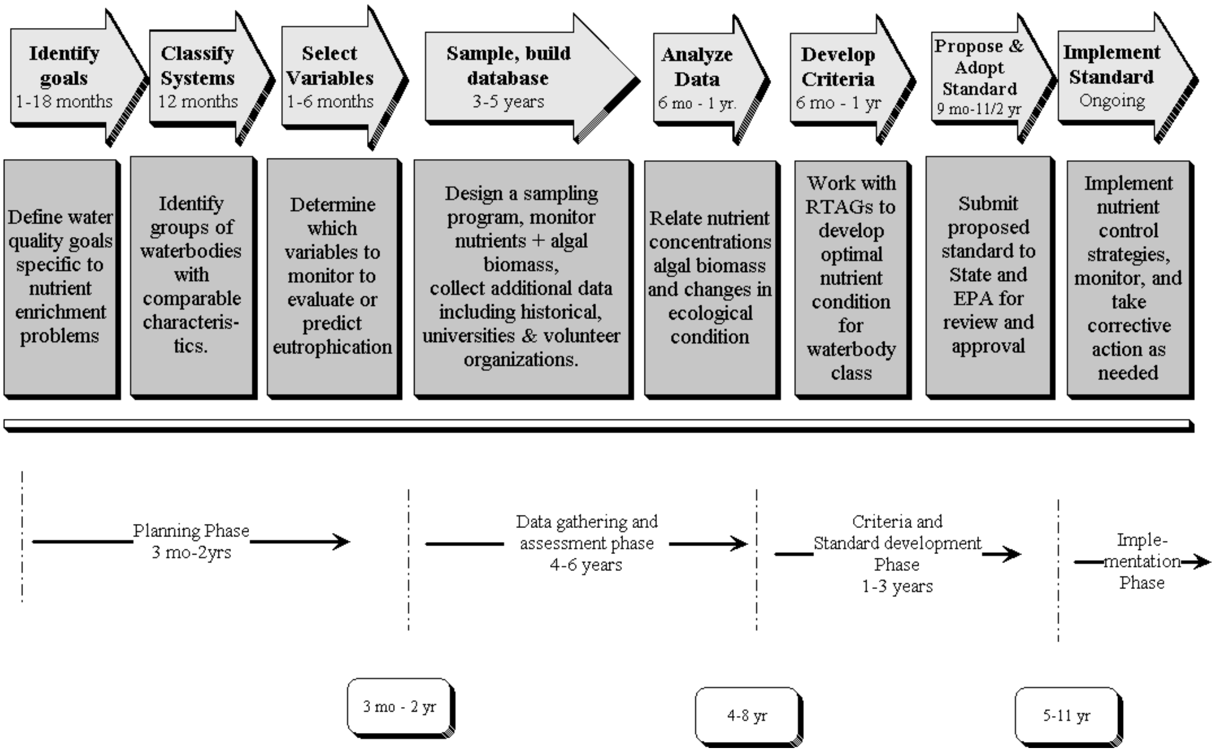

Figure 1. Nutrient criteria development process timeline (reproduced from EPA xxxx).

1.2 Approaches

There are a number of approaches that can be taken to develop nutrient criteria. The relative value and attributes of each are summarized below.

Reference Condition Approach – This approach relies on the use of nutrient data collected in areas that are determined to be relatively pristine and minimally impacted (i.e. Class SA waters). Nutrient concentration thresholds are selected from the distribution of the collected nutrient data (e.g. 90th percentile).

Advantages:

- High confidence that waters attaining the nutrient criteria are good quality with all uses protected.
- Relatively simple means to calculate threshold.
- Simple to implement.

Disadvantages:

- Lack of reference sites where data can be collected or historical reference quality data.
- Subjective selection of threshold value. Some “reference” waters may be above the nutrient threshold, therefore, in violation of the criteria (even if unperturbed and high quality).
- Does not account well for other factors that can affect nutrient function.

Data Distribution Approach – This approach utilizes all nutrient data collected from waters of all designated classes and conditions. As with the reference condition approach, thresholds are selected from the distribution of the data (e.g. usually a lower percentile because some large fraction of the data is assumed to be from waters with altered or impaired quality). A reasonably low percentile needs to be selected so there is reasonable expectation that most waters will attain. Selection of threshold(s) should include examination of expected attainable conditions based on implementation of best attainable treatment and best management practices for all discharging facilities. This approach sets a goal of bringing all waters to some nutrient concentration target that should put most waters in attainment. The burden of implementation is on the sources (point and nonpoint) to meet technology standards.

Advantages:

- Data available (expect additional data will be needed).
- Multiple thresholds may be selected representing different conditions based on classification (SA, SB, SC)
- Relatively simple means to calculate threshold. Most waters could attain criteria and maintain designated uses.
- Simple to implement.

Disadvantages:

- Requires data that includes the range of conditions good to poor that are expected to occur.
- Subjective selection of nutrient concentration threshold value, may not be ecologically defensible.
- Does not account well for other factors that affect nutrient function.

Predictive Model Approach – This approach selects criteria thresholds based on use of predictive models (e.g. regressions) that correlate nutrient concentrations with other environmental effects.

Advantages:

- Can account for other factors that can influence nutrient function in the environment.
- Multiple thresholds may be selected representing different conditions based on the State’s current classification system (SA, SB, SC)
- Commonly used for other criteria development.
- Simple to implement.

Disadvantages:

- Requires development of one or more models that correlate nutrient levels to various environmental effects. Models need to be calibrated for Gulf of Maine.
- Limited availability of data for model construction (nutrient, other independent variables, and dependent response variables) across range of conditions good to poor that are expected to occur.
- Difficult to control amount of error (variance) in the model(s).

Effects-based Approach – This approach establishes nutrient criteria as “screening” values (they are not enforced until some other impaired “response” is demonstrated). Appropriate response criteria need to be established (e.g. oxygen, chlorophyll, cell counts, marine life, etc.). The screening thresholds for nutrient concentrations are developed by one of the above approaches.

Advantages:

- High confidence that designated uses are attained (direct measurement of designated use). Attainment is based on response criteria (actual detection of negative effects in the ecosystem).
- Takes into account other variables that affect nutrient function.
- Multiple thresholds may be selected representing different conditions based on classification (SA, SB, SC)
- Opportunity for site-specific criteria.

Disadvantages:

- Lack of data on suitable response criteria (preferably already existing in statute or rule, e.g. oxygen). Limited set currently available for marine waters.
- Need to develop relationship of nutrients to response criteria.

- Several response criteria are required to assess water quality condition and designated uses that could be affected by nutrients.
- Two data types required to make an assessment (nutrient and response criteria).
- Increased monitoring cost.
- Implementation is complex. Results not always clear if nutrients are low and response criteria are violated or, conversely, the measured nutrients are high and there is no violation of response criteria.

Under this work assignment, Battelle was tasked with examining three sets of nutrient data. Given the limitations associated with this dataset and keeping in mind that nutrient criteria should be scientifically defensible, economically feasible, and practical and acceptable to the communities involved, we used the data to illustrate a pragmatic approach that is a hybrid of the Reference Condition/Data Distribution approaches. The ultimate decision on how to proceed with estuarine and coastal nutrient criteria in Maine is most likely to be a management policy decision. The increase in confidence gained by the modeling or effects based approaches comes with increased costs associated with the levels of complexity and associated efforts each entail. Thus for this report, we have used the available data and our best professional judgment to describe current conditions and provide an example of what this pragmatic approach might lead to and what additional data or other efforts it may require.

2.0 DATA ACQUISITION AND MANIPULATION

2.1 Data Sources and Sampling Locations

Three sources of data were specified for this work assignment: Friends of Casco Bay, EPA National Coastal Assessment (NCA) Program, and EPA Coastal Marine Program data. The data for FOCB were obtained directly from the organization. The EPA NCA data were downloaded from the NCA Northeast Region data pages[2]. The Casco Bay Estuary Partnership (CBEP) provided the EPA Coastal Marine Program data. Information on each of these datasets is provided in the following paragraphs.

The FOCB monitoring program has been ongoing since 1993. The program is carried out with the aid of volunteers who sample at more than 80 shore-based stations and assist FOCB staff at 11 profile stations located throughout Casco Bay. The parameters measured include standard oceanographic parameters of temperature, salinity, pH, Secchi depth, dissolved oxygen, plus ancillary air and water measurements. The program was expanded to include measurements for dissolved inorganic nutrients in 2001 and chlorophyll and total kjeldahl nitrogen (TKN) in 2007 as a subset of stations (Figures 2 and A-5). The FOCB stations were sampled for nutrient parameters on a monthly basis over the summer. Battelle had a database for the 1993-2004 FOCB data from an earlier project. Additional MS Excel files were provided by FOCB for 2005-2007 data.

The EPA NCA program data were available for 2001-2004. The data included a range of standard oceanographic parameters and nutrients though not all parameters were available for each of the years nor was the same set of data available for each state for each of the years. In general, dissolved inorganic nutrients, dissolved oxygen and chlorophyll data were available for MA in 2000 and 2001, NH in 2001, 2002 and 2003, and in ME for all five years. Total nitrogen and total phosphorous were only available for MA and NH in 2003 and in ME for 2003 and 2004. EPA NCA station locations are redistributed each year and are presented in Figure 2 and by individual states in Figures A-2 to A-4. The NCA stations were sampled only once per year during the summer. All of the NCA data were directly downloaded from the internet as MS Excel files.

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[2] http://www.epa.gov/emap/nca/html/regions/northeast.html

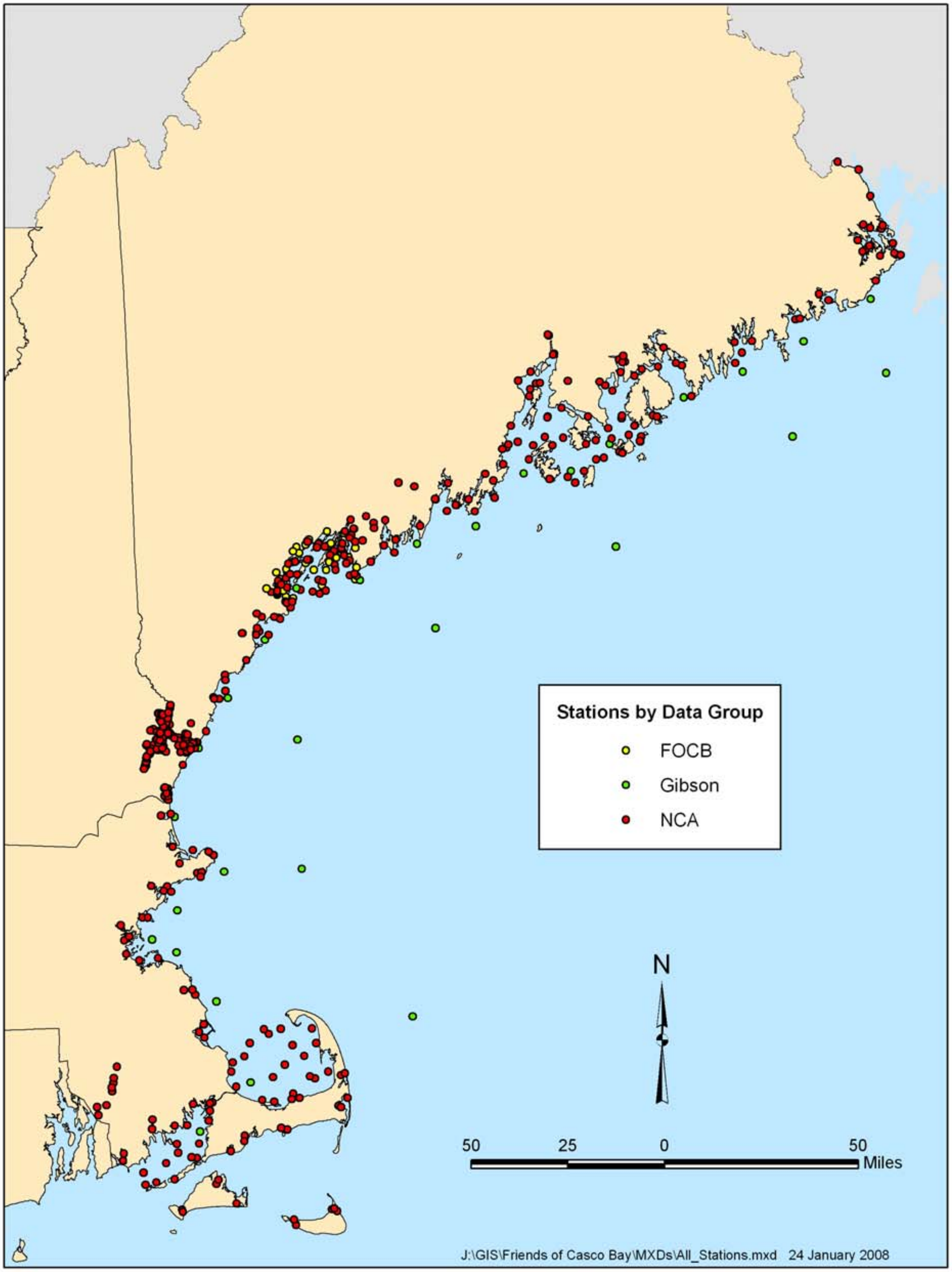

Figure 2. Locations of all stations sampled by the three programs included in this report. Not all parameters were sampled at each station and stations may have been sampled single or multiple times. Individual program stations are also presented in Appendix A with station IDs.

The EPA Coastal Marine program data were collected in 2004 and 2005 at twenty nine stations extending from the Canadian border to south of Cape Cod (Figures 2 and A-1). Data were collected for *in situ* parameters, chlorophyll *a*, TN, and TP. Both of these surveys were conducted during the month of June. Note that this dataset is often referred to as the "Gibson" data herein (George Gibson led the effort and the name took on a life of its own during database development and analyses). The Gibson data were provided by CBEP in a single MS Excel file.

2.2 Database development

The FOCB MS Access database that Battelle had developed for a previous project served as the basis for the new Maine Nutrient Criteria database. The various excel files were imported into the database. Three separate tables were set up to contain the NCA station location, nutrient and *in situ* data. For FOCB data, the same process occurred except the nutrients and *in situ* data were in one table along with all of the location information. The Gibson data had to be significantly reformatted before it was brought into Access; 2004 data was formatted into one excel sheet, 2005 data was in a separate sheet, and the location information (coordinates and some *in situ* data) into a separate sheet.

Once all of the data was imported, the units were updated to be consistent (µM for all nutrients, mg/l for dissolved oxygen and PSU for salinity). The nutrients were then imported into a crosstab table (parameters as column headers). If duplicates/replicates were in the original nutrient tables, then they were averaged prior to being imported. Additional columns were added to the Crosstab nutrient table to accommodate *in situ* data. Location information was also appended at the same time.

Access queries were then run to populate the *in situ* columns. The queries were based upon joins between station name, collection date and water column depth (i.e. surface, mid or bottom). Numerous records were not updated for the NCA data files because of inconsistencies in the data. Occasionally, nutrient records did not have corresponding *in situ* data, while at other times there was *in situ* data, but no nutrient data. In some of the original *in situ* data files the same data was reported for surface and bottom layers. These records had to be assigned to the appropriate nutrient records manually and then a "find duplicates query" was run to ensure that no duplicates were in the database. The final step was to query the table containing all of the *in situ*, nutrient, and location data for just the summer months- June, July, August and September. This query built a table called Just Summer Data.

Our initial plans called for an examination of the data for potential outliers and typical range of values checks of all data. However, since the planned analyses were relegated to summary statistics (including percentiles) and box and whisker plots, there was no need to conduct this examination as outliers would be noted during analysis. In fact, Battelle was specifically requested to make sure that the datasets were complete and not arbitrarily filtered for outlier values. That said, there are a number of values that are surprisingly high and well outside of expected (or even unexpected) ranges (specifically some of the dissolved inorganic nitrogen values in the FOCB dataset). In the future, it is recommended that the database be thoroughly examined prior to loading of additional data and conducting final analyses for criteria development.

2.3 Data Selection

The technical guidance manual specifies a set of causal and response variables appropriate for criteria development. The causal enrichment variables are total nitrogen (TN) and total phosphorous (TP) and the response variables cited are chlorophyll *a*, water clarity/turbidity, and dissolved oxygen (DO). We chose to focus on TN, but also included TP, chlorophyll *a*, DO, and dissolved inorganic nitrogen (DIN) species ammonium (NH_4) and nitrate+nitrite (NO_3+NO_2) for some of the data summaries. Total nitrogen was measured for the NCA and Gibson programs, but for FOCB TKN was measured and we calculated TN from TKN and NO_3+NO_2. This is one of the caveats in the TN analyses presented. The other is that TN data from multiple years have been pooled together for the summary statistics and box plots.

Several other a priori decisions were made in the selection of data for analysis. First, only summer data were examined and the season was defined as date collected from June through September. The reasons for this are two fold. The summer season is the time when most of the negative responses to nutrient enrichment would be expected to be most noticeable and problematic (e.g. hypoxic DO conditions) and the NCA and Gibson data were collected only once per year and sampling occurred from June to September. We also decided to focus on surface data since this depth was sampled at each station and it provided a single set of data for comparisons. The only exception was for DO where bottom data were used.

2.4 Data Analyses

The data analyses entailed developing summary statistics and graphical presentations of the surface, summer data from all stations. The data were also broken down into a series of spatial and program based groupings for comparison. The first level of grouping was at the State level with all MA NCA and Gibson data (stations R1-20 to R1-29), NH NCA data, and ME inshore data. The ME inshore data included all NCA and FOCB data, but only the inshore Gibson stations (R1-2, R1-3, R1-4, R1-6, R1-7, R1-8, R1-9, R1-11, R1-12, R1-13, R1-15, R1-16, R1-17, and R1-19). The offshore Gibson stations (R1-1, R1-5, R1-10, R1-14 and R1-18) were not included in the overall ME group for the state to state comparisons. The second level of groupings broke the Maine data into four groups – NCA data, inshore and offshore Gibson data, and FOCB (also referred to as Casco Bay) data. Finally, the FOCB Casco Bay data were split into four groups ranging from inshore to offshore and across the bay – Portland Harbor/Coast, Western Bay, Eastern Bay, and Offshore. These Casco Bay groups are presented in Figure A-5 for reference. Summary statistics and box plots were run for the key parameters for each of these groupings of data.

The summary statistics were calculated in SAS and included overall mean, minimum and maximum values, standard deviation, and percentiles (10th, 25th, 75th, and 90th) for each parameter of interest (TN, TP, chlorophyll *a*, DO, and the dissolved inorganic nitrogen concentrations). Frequency plots were produced in MS Excel to describe the overall data distribution, and GIS maps were produced to depict the spatial distribution of these parameters. Box and whisker plots were produced in SAS using the GLM procedure which uses the method of least squares to fit general linear models. The GLM procedure also provides an indication of whether there are significant differences among the groups analyzed. When the data for the groups were found to be different, the Duncan's multiple range test was employed (SAS) to determine which station groups were significantly different from one another.

3.0 DATA RESULTS

3.1 Summary Statistics

The summary statistics for all summer, surface data are presented in Appendix B (Tables B-1 and B-2) for each of the data groupings. The mean values are summarized in Table 1 for comparison across areas. Mean TN concentrations are highest in Maine compared to the other states. The elevated levels are driven by higher TN concentrations (mean 37.1 µM) in the FOCB Casco Bay dataset in general, and specifically the elevated TN concentrations measured by FOCB in western Casco Bay (37.4 µM) and Portland Harbor/Coast (42.9 µM). As stated in Section 2, the FOCB TN data were not directly measured, but rather calculated from TKN and NO_3+NO_2. It is unclear at this time whether the TN comparison across states and across the Maine datasets is compromised by the difference in methods. However, comparisons across Casco Bay are internally consistent and clearly show higher mean TN concentrations in Portland Harbor/Coast and western Casco Bay compared to Offshore and Eastern Bay areas. The TN data are examined in more detail in Section 3.2.

The TP dataset is very limited (total count of 139 data points), but on average the ME concentrations were slightly lower than NH and MA (Table 1). There was little difference between the inshore and offshore Gibson TP data for Maine, but as seen for TN the Maine NCA data were lower than the inshore Gibson data. Total phosphorous data have not been collected for the FOCB program in Casco Bay. Chlorophyll *a* concentrations were also lower for ME than MA or NH. There was good agreement between the ME NCA, Gibson inshore, and FOCB datasets with mean concentrations of ~1.8 µg/L. The use of comparable fluorometric methods likely contributed to this consistency. Offshore chlorophyll *a* levels were lower than inshore levels in the Gibson dataset and concentrations were higher in the vicinity of Portland than in western Casco Bay. A quick look at the maximum concentrations observed across the states (Table B-1) shows that chlorophyll levels in NH and MA achieve maxima of >30 µg/L, while the highest ME reading was 10.6 µg/L and levels within Casco Bay peaked at ~5 µg/L).

Table 1. Mean concentrations of key parameters for specified levels and groupings of stations. Calculated for summer data (June-Sept) using surface data for all parameter except DO which used bottom water results. Complete set of summary statistics is provided in Appendix B.

Level	Grouping	TN (µM)	TP (µM)	Chl *a* (µg/L)	DO (mg/L)	DIN (µM)	NH_4 (µM)	NO_3+NO_2 (µM)
States	Maine (inshore)	26.0	0.72	1.79	8.44	8.04	4.24	3.61
	Massachusetts	18.2	0.85	2.90	7.64	8.93	3.61	5.06
	New Hampshire	22.5	1.11	4.56	7.70	12.26	6.90	4.47
Maine	ME NCA Stations	10.3	0.62	1.79	8.14	6.84	2.20	2.59
	ME Gibson inshore	23.1	0.96	1.88	9.83			
	ME Gibson offshore	24.0	0.89	1.07	8.36			
	Casco Bay	37.1		1.75	8.57	8.09	4.44	3.67
Casco Bay	Portland Harbor/Coast	42.9		2.00	9.00	9.04	4.87	4.21
	Western Bay	37.4		1.19	8.90	6.78	3.74	3.04
	Eastern Bay	19.3			8.19	6.23	3.89	2.34
	Offshore	29.2			8.67	14.01	6.34	7.81

Bottom water mean DO concentrations were all relatively high and not indicative of any wide spread DO problem. Maine levels were higher than those in MA or NH. In Casco Bay, the lowest mean value was for the Eastern Bay, which tends to have restricted flows in some of the embayments (Battelle 2005). The relatively high bottom water DO concentrations are not surprising as even in Boston Harbor and Massachusetts Bay, which some might suspect are more heavily enriched than most Maine waters, bottom water DO levels seldom reach levels below 6 mg/L (Libby *et al*. 2007). In regards to low DO, areas of concern have been noted for Maine (Kelly and Libby 1996, Kelly 1997) and within Casco Bay (Battelle 2005). An examination of the minimum bottom water concentrations (Table B-1) shows ME and NH reaching minima of ~4.3 mg/L and a minimum of <1 mg/L in MA. All of these minima are below the level that EPA has proposed as a standard (4.8 mg/L) for the waters from Cape Cod, MA to Cape Hatteras, NC (EPA 2000c) and could be detrimental to biota exposed to them for prolonged periods. Clearly such hypoxic levels as measured for the MA minimum are cause for concern.

The results of this data evaluation are similar to those found for Maine and Casco Bay during studies conducted by the Wells National Estuarine Research Reserve (NERR) and Maine Department of Environmental Protection (MEDEP) in 1995 and 1996 (Kelly and Libby 1996, Kelly 1997). Most importantly, each of these studies found that overall Maine and Casco Bay DO levels are generally high and not problematic, though they highlighted areas of concern that may be more susceptible to low DO in the future. The 1996 Wells NERR and MEDEP study also measured chlorophyll and various nitrogenous nutrients and the results indicated that conditions in Casco Bay were relatively good in comparison to eutrophic coastal waters. Chlorophyll concentrations in Casco Bay (as well as the rest of the locations along the coast of Maine) were consistently low (means < 2.5 µg/l) and dissolved inorganic nitrogen concentrations were not indicative of eutrophic conditions.

An examination of the dissolved inorganic nitrogen (DIN) data for the current set of data supports these earlier findings. On average, the ME mean DIN concentrations are lower than those reported for MA and NH and Portland Harbor/Coast are higher than western and eastern Casco Bay levels, but lower that those measured at the offshore stations (Table 1). Dissolved inorganic nutrients were not sampled as part of the Gibson dataset and thus the Offshore FOCB data are the best representation of what typical concentrations for unimpacted coastal waters might be for the summer period. As mentioned previously, the data have not been screened for outliers for this analysis and there were a number of very high NH_4 (>100 µM) and NO_3+NO_2 (500 µM) results that are likely suspect. A more detailed review of these data is necessary to clarify the distribution of elevated levels of these nutrients. The mean levels of these nutrients, however, are not problematic and, as mentioned above, the highest levels of DIN were measured at the presumably least impacted locations of outer Casco Bay.

3.2 Total Nitrogen Analyses

A more in depth analysis was conducted for TN results using statistical and graphical tools. As noted above, FOCB used a different method (TKN) than the other programs, but comparison of Gibson and NCA data is not necessarily a direct comparison either given that NCA data were collected in more localized areas in July-Sept 2003 (Kennebec to Penobscot) and August-September 2004 (Casco Bay to NH) and Gibson data regionally distributed in June of both 2004 and 2005. When interpreting the results, the spatial and temporal disconnects in these datasets must also be acknowledged. With the expectation that additional data will become available in the future, we proceeded with comparisons across the groupings to gain some insight into the regional distribution of TN levels.

As observed in the comparison of State means, Maine had the highest TN concentrations compared to the other states, the widest interquartile range (IQR; 25th to 75th quartiles), and was the only state with outliers >100 µM (Figure 3a). The SAS GLM procedure indicated that there were no significant differences among the three state groupings (P=0.32). The high outliers in the Maine data were all from the FOCB data (Figure 3b).

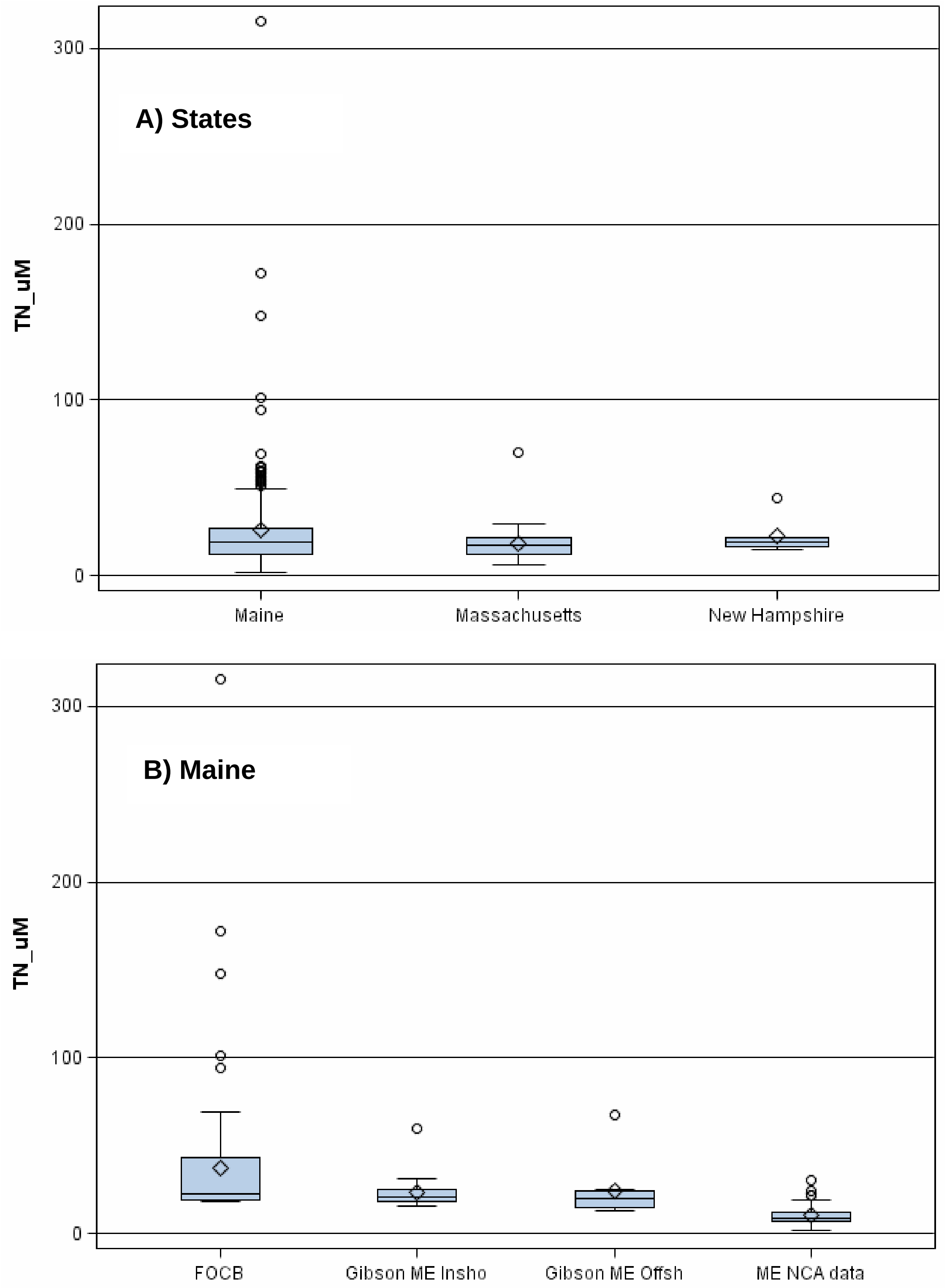

Figure 3. Box and whisker plots of summer, surface TN concentrations (µM) at the A) State and B) Maine level of groups. The groupings are described in Section 2.4. The various symbols represent values as follows: the box = 25th to 75th quartile range, the line in the box = median, the diamond = mean, open circles are outliers, and the whiskers extend to the furthest value below and above the quartiles that is within 1.5 times the interquartile range (IQR).

The influence of the outliers on the overall distribution of data and summary statistics is illustrated by a comparison of the high mean TN (37.1 µM) in the FOCB Casco Bay dataset with a median of 22.2 µM. The mean is skewed higher due to the outliers. The SAS GLM procedure indicated that there was a significant difference among the Maine data groups ($P<0.0001$). Duncan's multiple range test was run to determine which of the means were significantly different (Table 2). As suggested by the plots in Figure 3b, the FOCB and ME NCA data means (37 and 10 µM) were significantly different from each other. A comparison of the median values suggest less of a difference between the FOCB and Gibson datasets (22.2, 21.1 and 20.4, respectively) than numerically indicated by the means (Table 2). There was very little difference between the inshore and offshore Gibson TN data. The median value for the ME NCA data was 9.2 µM. The comparison of median values suggests that the TN values calculated for FOCB may be more appropriate for comparison to the Gibson TN data than was suggested by the examination of the means and range.

Table 2. Results of Duncan's multiple range test (SAS) comparing the data from the four Maine data groups. Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	Grouping
A		37.06	92	FOCB
A	B	24.00	10	Gibson ME Offshore
A	B	23.06	28	Gibson ME Inshore
	B	10.27	60	ME NCA data

The highest TN concentrations measured in Casco Bay were observed in Portland Harbor/Coast and western Casco Bay (>100 µM; Figure 4). A comparison of means showed a decreasing trend from Portland Harbor/Coast to Western Bay to Offshore with the lowest mean observed in Eastern Bay (Table 1). However, the means for the Offshore and Portland Harbor/Coast are skewed upward by a few high TN concentrations as shown by the median lines almost even with the 25th percentiles in the box plots (Figure 4). When the median concentrations are examined the Western Bay stations are highest (31 µM), followed by Portland Harbor/Coast (20.8 µM) and then Eastern Bay and Offshore (both 18.7 µM). The comparisons of means, medians, and outliers for these Casco Bay groups indicates that there are intermittent incursions of high TN waters in both Offshore and Portland Harbor/Coastal waters and that TN levels are more consistently elevated in western Casco Bay than the other areas. Also it seems that TN concentrations in eastern Casco Bay are very consistent and quite low by comparison – though it should be noted that the number of samples is especially small for both Offshore (n=9) and Eastern Bay (n=12).

The TN data were also examined on a station by station approach showing the average surface values at each station and year sampled (Figure 5). Total nitrogen levels of 35-50 µM (~0.5-0.7 mg/L) are generally within the range of values that potentially start to elicit negative responses. A review of stressor-response models using TN and chlorophyll *a* shows elevated chlorophyll *a* levels occurring at these TN concentrations or higher (Dettmann and Kurtz 2006). Researchers in the Gulf of Mexico have proposed summertime TN standards of <35 µM for Pensacola Bay (Hagy *et al.* 2008). Pensacola Bay is clearly not comparable to Casco Bay, but is referenced here as one of the few TN criteria that has been proposed for marine waters.

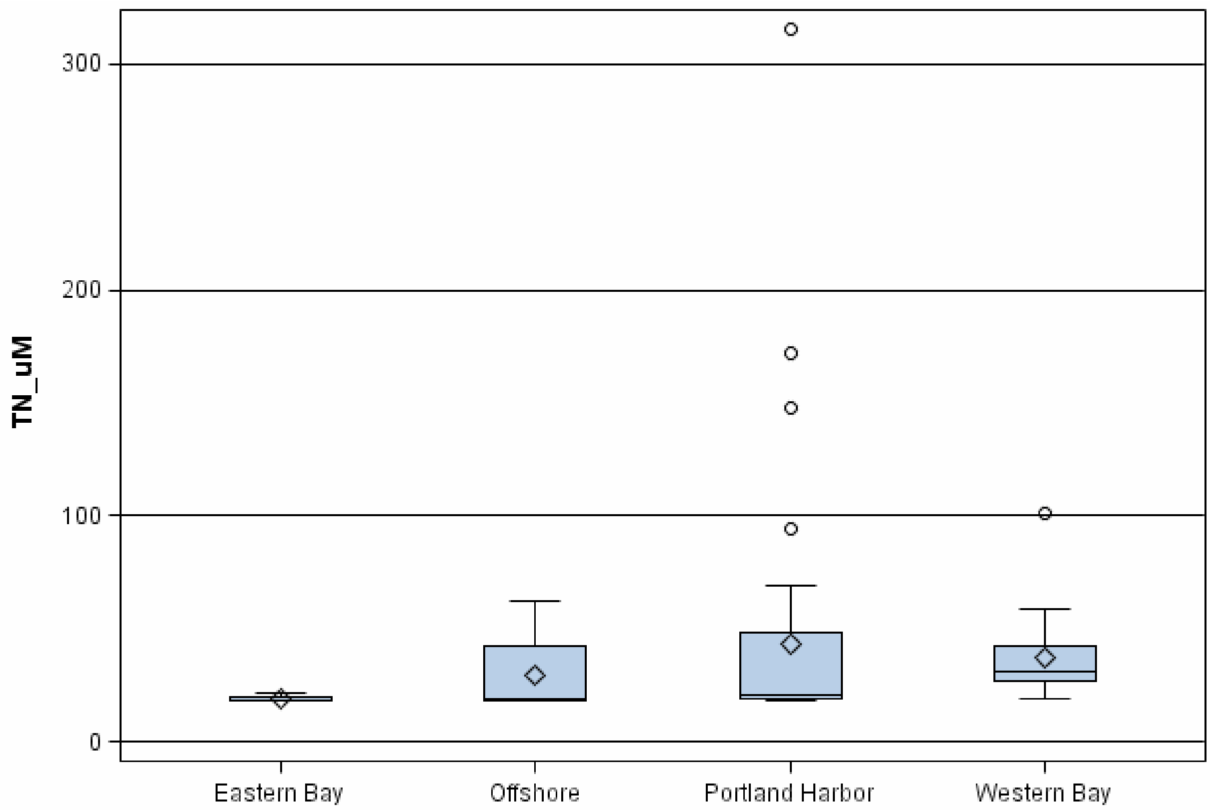

Figure 4. Box and whisker plots of summer, surface TN concentrations (µM) for the FOCB Casco Bay groups. The stations in the groupings are described in Section 2.4 and depicted in Figure A-5. The various symbols are described in Figure 3.

In 2003, levels in Maine surface waters were all <35 µM and most <20µM (Figure 5). The highest TN concentration was measured in Boston Harbor (70 µM) and a high TN concentration (57 µM) was measured in Great Bay, NH. The distribution of NCA stations in Maine in 2003 was focused on the Mid Coast region from the Kennebec River to the Penobscot River. In 2004, TN levels were generally low across the region with most NCA data values <20µM (collected July-September) and Gibson data were slightly higher on average with most stations having TN levels in the 20-25 µM range.

Only Gibson data were available for 2005. The levels and distributions of TN were similar to 2004 from MA to Penobscot Bay, but there were very high concentrations measured in eastern Maine waters (Figure 5). Total nitrogen concentrations at these two inshore and offshore stations were 60 and 67 µM, respectively and comparable to levels measured in Boston Harbor and Great Bay in 2003. For 2007, the only data available is from the FOCB program. These data represent averages of surface water TN measurements made on a weekly to monthly basis. The highest mean TN concentration (73 µM) was measured in Portland Harbor, but levels of 35-50 µM were also measured at stations in the vicinity of Portland, at the mouth of the Presumpscot River, and at the offshore station south of Small Point in eastern Casco Bay. This eastern station has been shown to be influenced by not only offshore oceanographic conditions, but also the Kennebec River plume. Overall, the mean summer, surface TN levels for Casco Bay in 2007 are comparable to those observed during the other three years.

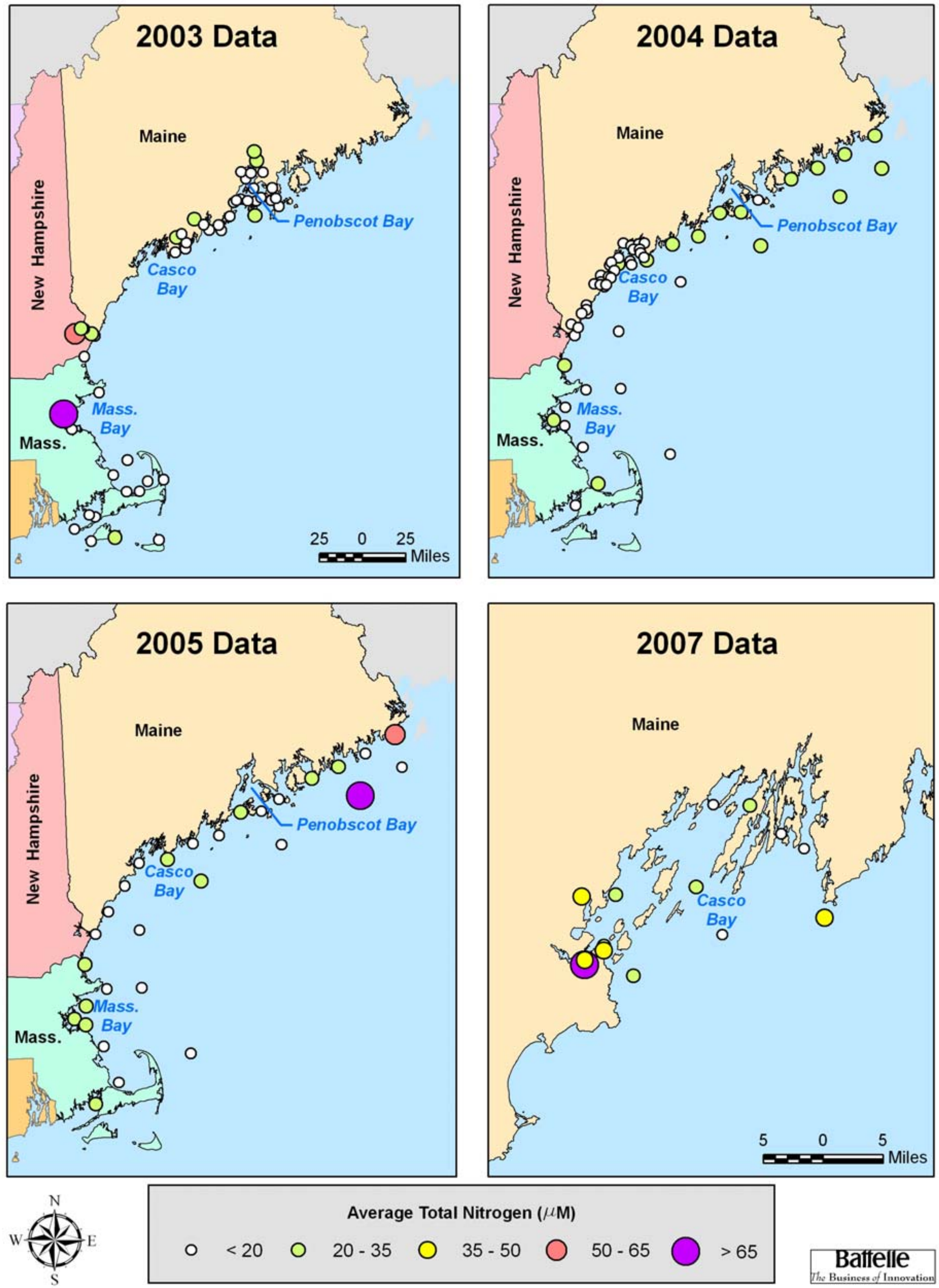

Figure 5. Spatial distribution of surface mean summer TN concentrations for each year measured. Note that the following datasets were available for each year plotted: 2003 only NCA data, 2004 NCA and Gibson data, 2005 only Gibson data, and 2007 only FOCB Casco Bay data. For reference, TN concentrations of 35-50 µM are approximately equal to 0.5-0.7 mg/L.

It is likely, however, that nutrient criteria will be implemented on an individual sampling basis much as most other water quality criteria, rather than a summer average. The data distribution approach discussed in Section 1 could examine the frequency distribution of summer, surface TN concentrations. In Figure 6, these data are presented for all of the ME and MA&NH datasets and the percentiles (10th, 25th, 75th and 90th) are presented in Table B-1 for comparison. In Maine, the 90th percentile for surface TN values during the summer period is 48.6 µM. The values are lower for both MA and NH (25.7 and 44.2 µM, respectively) as Figure 6 suggests with only a few values higher than 30 µM. For this comparison, it must be noted again that the MA and NH surveys represent only single surveys per year, while the ME data includes the weekly to monthly FOCB data for Casco Bay. The 35 and 50 µM values are highlighted in Figure 6 to show the limited number of measurements above these levels and this is further supported by the calculated 90th percentiles.

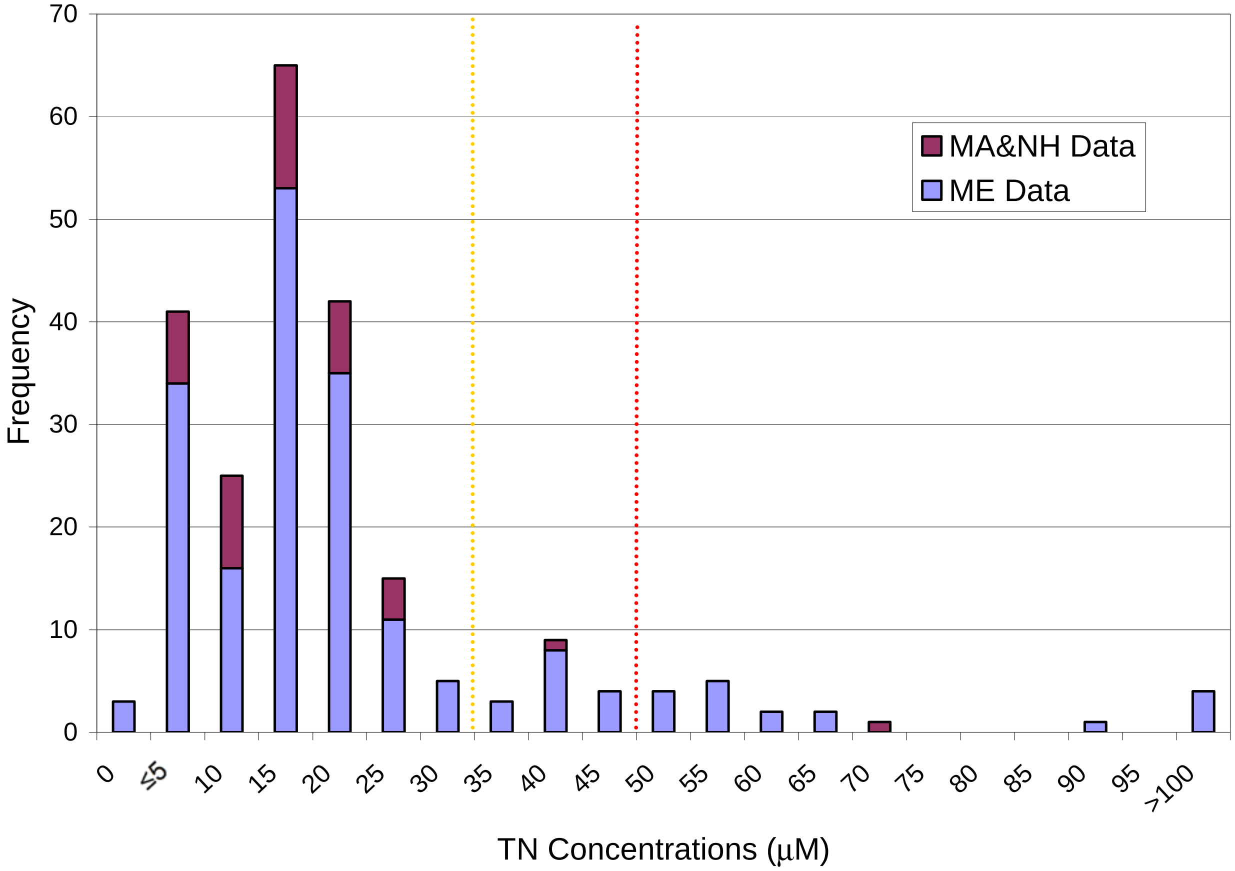

Figure 6. Frequency distribution of summer, surface TN values for Maine, Massachusetts and New Hampshire. The yellow and red lines represent values within the 35-50 µM (~0.5-0.7 mg/L) range of TN concentrations.

4.0 DISCUSSION AND RECOMMENDATIONS

This report is a preliminary step towards the development of nutrient criteria in Maine's coastal waters. EPA started the process in 1998 with the National Nutrient Strategy for adopting nutrient criteria to meet the goals of the CWA and continued by providing guidance on the development process in 2001 (EPA 2001). From the beginning, it has been acknowledged that the development of nutrient criteria for coastal waters will be a long process due to the complexities associated with nutrient dynamics in estuarine and coastal waters. Maine has taken a major step forward in the process with passage of LD 1297 in 2007. Only a handful of States have established nutrient criteria for coastal waters and most of them have been able to do this because of the availability of extensive datasets (Chesapeake Bay States) or because poor water quality conditions have spurred public outcry for action (Long Island Sound States). This report may constitute a small step forward, but it is envisioned that it will keep Maine at the forefront of the estuarine and coastal nutrient criteria development process.

4.1 Approaches used in other Regions

A summary of the various approaches for establishing nutrient criteria was provided in Section 1.2 and a few examples of what is being done in other regions have been touched upon in the report and are briefly summarized here for reference and comparison to the proposed approach for Maine. In Chesapeake Bay, criteria have been developed for DO, water clarity, and chlorophyll *a* (EPA 2003). DO criteria have been assigned to five different regions of the bay defined by uses and depth and water clarity criteria have been assigned to four different salinity regimes. For chlorophyll *a*, a narrative standard was established for the entire bay. The fact that criteria were able to be established for so many different regions of Chesapeake Bay is a testament to the extraordinary amount of research that has been conducted in that area and the vast amount of data associated with those efforts.

In Long Island Sound (LIS), problems with seasonal hypoxia/anoxia in the western portion of the Sound led to establishment of the Long Island Sound Study in 1985. After 15 years of monitoring and related modeling and synthesis, a Total Maximum Daily Load (TMDL) for nitrogen loading to the Sound was approved by the EPA and the states of New York and Connecticut. This TMDL was established in order to meet DO water quality criteria in LIS and a multiyear effort has been phased in by the States to meet the TMDL of a 58.5% reduction in nitrogen loading by 2014[3]. As was the case with Chesapeake Bay, the LIS DO criteria was established after many years of monitoring and data evaluation.

More recent efforts to create nutrient criteria have been conducted by the EPA for pilot studies in Yaquina Estuary, OR and Pensacola Bay, FL (Brown *et al*. 2007, Hagy *et al*. 2008). In Yaquina Estuary, existing data were used to examine spatial and temporal trends and a "weight of evidence" approach was used to develop criteria. Criteria were derived for the 'dry season' (May-October) and, given the estuarine nature of the system (~50% tidal), it was divided into two zones for criteria development. Zone 1 is highly influenced by offshore coastal water and nutrient loading from the ocean. Zone 2, in the upper estuary, is influenced by riverine and point source nutrient inputs. Overall, water quality conditions in the estuary were good and support the existing seagrass habitat (one of the goals for establishing criteria). Following the EPA guidance (EPA 2001), criteria were proposed using median values from the existing dataset for DIN, phosphate, chlorophyll *a*, and water clarity (Brown *et al*. 2007). Oregon has an existing water quality standard for DO of 6.5 mg/L and although this was closer to the 25th percentile it was recommended to keep this standard for Yaquina Estuary because the only apparent DO problem was an intermittent incursion of hypoxic waters that enters the estuary from offshore coastal waters.

A weight of evidence approach was also used in Pensacola Bay (Hagy *et al*. 2008). The use of historical data to develop a reference condition was evaluated, but for this bay the historical condition was more

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[3] http://www.longislandsoundstudy.net/pubs/reports/tmdl.pdf

nutrient enriched than the current state. Nutrient loading to the system had decreased since 1980 and present water quality was considered protective of the desirable uses. Hypoxic conditions appear to be the result of natural processes and a propensity toward low DO in the system and loss of seagrass in the bay were related to pre-1980 degraded water quality. Their goal was to keep water quality at its current levels and not to have it degrade as the region continues to grow economically and in population. As in Oregon, criteria were proposed for Pensacola Bay based on the relative freshwater and seawater influences along the salinity gradients with separate criteria for oligohaline (<5 PSU), mesohaline (5-18 PSU), and polyhaline (>18 PSU). The summer median levels were proposed as criteria for chlorophyll *a*, Secchi depth, DIN, phosphate, TN (<35 µM), and TP (Hagy *et al*. 2008).

These two pilot studies did not attempt to use any embayment classification scheme as they were focused on single waterbodies. However, in both cases, the systems were divided based upon salinity regimes. The importance of freshwater inputs will need to be taken into account for any statewide criteria development in Maine, but due to the limited dataset this was not possible in this report. Classification of systems is one of the main steps in the planning phase for criteria development (Figure 1). This aspect of the process was beyond the scope of the current study, but will be necessary at some scale in the future. The diversity of waterbodies along the Maine coast precludes site by site classification; but, at a minimum, freshwater-dominated versus limited-freshwater inputs and high and low residence time need to be considered. A more extensive set of factors influencing susceptibility of waterbodies to eutrophication is presented in the EPA guidance manual (EPA 2001) as developed by the National Research Council (2000). This list of 12 factors ranges from physiographic setting to nutrient load to residence time/flushing to rates of denitrification. It is an ambitious list of measures for any monitoring program and not one that could be applied in Maine in totality in the near future. An evaluation of these measures should be made to consider whether come could be readily incorporated into a monitoring program

A different type of classification scheme has been presented in work by Dettmann and Kurtz (2006). They propose using stressor-response relationships to group waterbodies by how they respond to nitrogen loading as the stressor. They focus on two separate responses – extent of eelgrass habitat and phytoplankton biomass response (as measured by chlorophyll concentration). For our purposes, we'll take a closer look at the phytoplankton response findings. Ambient concentrations of chlorophyll and TN were directly compared and the relationships between these two parameters were compared across ten estuarine/coastal systems. There were clear year to year variations within and between systems, but when average summer (June-August) data were examined from each system, the ten systems separated out into two groupings – coastal embayments and riverine dominated systems. In the four coastal embayments examined (LIS, Boston Harbor, Tampa Bay, and Peconic Estuary), the slopes of the regressions for log transformed chlorophyll vs. TN concentrations were statistically the same, while the intercepts were statistically different. The differences in the intercepts were related to the level of total suspended solids (TSS) in the system. It was concluded that there is a consistent phytoplankton response related to ambient TN concentrations, but that other factors (water clarity in this case) may reduce the response (lower light availability at higher TSS leads to lower production). The riverine influenced systems had similar relationships, but it was more complex given the wide range in TSS levels. Regardless, this classification approach provides two types of systems to examine and provides a possible mechanism for linking ambient TN levels to the response variable chlorophyll. Even with this stressor-response relationship, a decision on what level of stressor is protective of waterbody uses still needs to be determined.

Additional classification schemes are available and should be examined for applicability and ease of use for Maine coastal waters. The Coastal and Marine Ecological Classification Standard (CMECS) was developed in conjunction with NOAA and it classifies habitats and ecological roles from head of tides in estuaries, to the coast, and out into the oceans of North America (Madden *et al.* 2005). The EPA has promoted the use of coastal Level III ecoregions as a mechanism for classifying systems and is heavily involved in the evaluation and development of additional classification approaches (Kurtz *et al*. 2006). Another obvious option is for the State to develop criteria based on the current classification scheme (SA, SB, SC) that focuses on attainable uses. Nonetheless, a thorough evaluation of the classification schemes should be undertaken as part of the next phase of nutrient criteria development in Maine coastal waters.

4.2 Summary of Maine Approach

In this report, we propose and have provided an example of an approach similar to that taken in the Yaquina Estuary and Pensacola Bay pilot studies. We have examined the data currently available, compared TN levels across the region, state, and Casco Bay and the data have been presented in a manner by which median or percentile levels could be chosen as a potential criteria level. A similar approach could be used to examine the other parameters of interest (DIN, chlorophyll, and DO). Although we embarked on this approach by necessity given the limited dataset, an understanding that there are limited funds available, and a push by the state to move the process forward, it is similar to the weight of evidence approach taken in these two pilot studies. As in Yaquina and Pensacola, Maine has relatively good water quality along the coast with some localized problems. The pragmatic approach taken in this report should provide reasonable initial values that could be proposed and discussed by the various stakeholders prior to institution of the criteria.

The current study not only provides an example of how Maine might approach criteria development, but it also highlights a number of problems or issues that will have to be addressed during the process of nutrient criteria development. First, and foremost for this study, is the issue of data acquisition and database development. In this study, we used three clearly defined datasets. The first from a long term monitoring program in Casco Bay and the other two from short term EPA studies in the region. One would hope that such datasets could be readily integrated, but differences in format, units, methods, and years sampled all led to database problems or caveats in our interpretation of the results. As Maine proceeds with criteria development, clear database structure and management procedures need to be developed. This will be important no matter what approach ME DEP decides to pursue – whether it be data mining, additional monitoring, effects based or predictive modeling, or some combination of these. There will be more data acquired and it needs to be managed/stored in a clearly defined manner.

A project Battelle is currently undertaking with the EPA is the development of a Gulf Nutrients Data Management Platform (GNDMP) that is intended to identify and gather existing water quality data and compile it in a standardized platform that will be available via the web to a broad range of users. The GNDMP is intended to support work to protect habitat and address problems of nutrient enrichment in Gulf of Mexico estuaries and coastal systems, primarily by providing manageable data for use in the analysis of status and trends. Currently, data exist in various institutions and formats and have been generated using various collection and analytical methods. All of which make it difficult to make broad assessments of the overall health of the Gulf waters. The GNDMP is taking advantage of existing data that have been collected by numerous government and academic organizations. The GNDMP will organize and standardize the data and provide an intuitive web based interface with which to discover, access, and use these data. A similar effort should be undertaken in Maine – not only the database development, but also data mining as there are clearly many datasets that have not been accessed for the current analysis (including the datasets cited for Wells NERR and ME DEP). As mentioned, there are inherent issues involved with integrating relatively disparate datasets, but data identification and acquisition is a more cost effective approach than instituting new, large scale monitoring efforts.

The findings in this report suggest that water quality in the coastal waters of Maine is relatively good, which is consistent with the findings of recent national water quality assessments (i.e. EPA 2007 and Bricker *et al*. 2007). The analysis has also identified a few areas of concern as have also been suggested in the national assessments and numerous state and locally based reports (e.g. Kelly and Libby 1996, Kelly 1997, Battelle 2005). The TN values presented in Figure 5 show elevated levels in Portland Harbor as one might expect, but also in offshore waters south of Machias in Downeast Maine at a station that was presumably selected as a potential reference site. This highlights the difficultly of ascribing criteria in such a complex environment for parameters that can be quite variable. However, the distribution of TN data in Figure 6 suggest that a criteria value of 35-50 µM (0.5-0.7 mg/L) might be appropriate given the limited number of exceedances of these levels. In Yaquina Estuary and Pensacola Bay, they proposed using the median values of parameters for criteria, but for the Maine waters this would be too restrictive and not acknowledge the natural productivity of our coastal waters. For example, the median value for inshore Maine data was only 19 µM, which is far too low for a standard as ambient levels of DIN often exceed 10 µM in Maine coastal waters. The 90th percentile for the Maine TN data is just under 50 µM. The use of the 90th percentile to establish criteria could appear to be too lenient; but, based on the data in hand, it may be protective of proscribed uses.

There are obvious limitations associated with the TN example presented in this report. Not the least of which is the limited amount of data used. Nevertheless, the approach has merit and led to a proposed TN level that appears to be scientifically reasonable, economically feasible, and conceivably acceptable to stakeholders. It is envisioned that a similar approach could be taken with a more comprehensive set of data to develop nutrient criteria for TN and other parameters for Maine estuarine and coastal waters. One advantage to this approach is that it could get reasonable criteria in place on a timescale of a few years rather than 5-10 years (see Figure 1). An additional advantage is that the data collected as part of federal, state, local, or industry sponsored monitoring programs instituted to assure compliance with the criteria would be available to validate and potentially modify the criteria as necessary. These data would also support further analysis using predictive or other types of models and effects based approaches once they are more refined and robust. Ultimately, the State must make a management policy decision as to what approach to use. In the current economic climate, the modified data distribution approach presented in this report is a pragmatic and viable option.

4.3 Recommendations

A series of recommendations are included below. These are based on a combination of the data analyses presented here, experience on other nutrient criteria related projects, discussions with stakeholders and managers, review of relevant literature and reports, and best professional judgment. The recommendations are broken out into various categories and are made with the understanding of the current economic climate and fiscal feasibility of undertaking these activities. Although it would be scientifically interesting to pursue predictive modeling and effects based approaches, they are not included in the recommendations at this time because they are not deemed economically feasible.

Nutrient Criteria Development

- Identify and acquire available nutrient related data from other sources – federal, state or local monitoring efforts, scientific research efforts, etc. This should include data that could be used to classify waterbodies in the future if that approach becomes more feasible.
- Explore methods of classification of systems as an option for development of more fine tuned criteria (e.g. freshwater dominated vs. offshore dominated systems).
- Develop a comprehensive database for this data with established data management procedures.
- Apply the data distribution approach to the other parameters to evaluate potential criteria.
- Examine the applicability of stressor-response models as they become more robust and accepted in the literature (e.g. Dettmann and Kurtz 2006)
- Evaluate federal mechanisms for funding nutrient criteria development activities – from field work to data mining to public outreach.
- Continue to collect data for this effort on a local and statewide basis as funds allow as described in the next two categories.

Casco Bay Monitoring and Pilot Study

- Continue nutrient study in 2008 and subsequent years as necessary to establish criteria and monitor effectiveness once in place.
- Switch to analysis of TN rather than TKN to minimize potential impact of laboratory methods when comparing to TN data.
- Collect additional chlorophyll *a* samples – increase number of samples collected concomitantly with TN samples.
- Expand number of sampling sites to better characterize the apparent gradient in TN and other parameters – high in and near Portland Harbor and rivers (Presumpscot and Royal) and decreasing to eastern Casco Bay.

Statewide Monitoring

- Develop a plan that fits the approach recommended by ME DEP. If the recommended approach is similar to the approach taken in this report, then sampling that is a modification of the NCA and Gibson surveys would be appropriate – spatially distributed as with the Gibson surveys, but more stations. A more in-depth evaluation of suitable station locations needs to be undertaken prior to initiating a statewide monitoring program.
- Sample for standard suite of oceanographic parameters including parameters necessary for criteria development.

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APPENDIX A - STATION MAPS

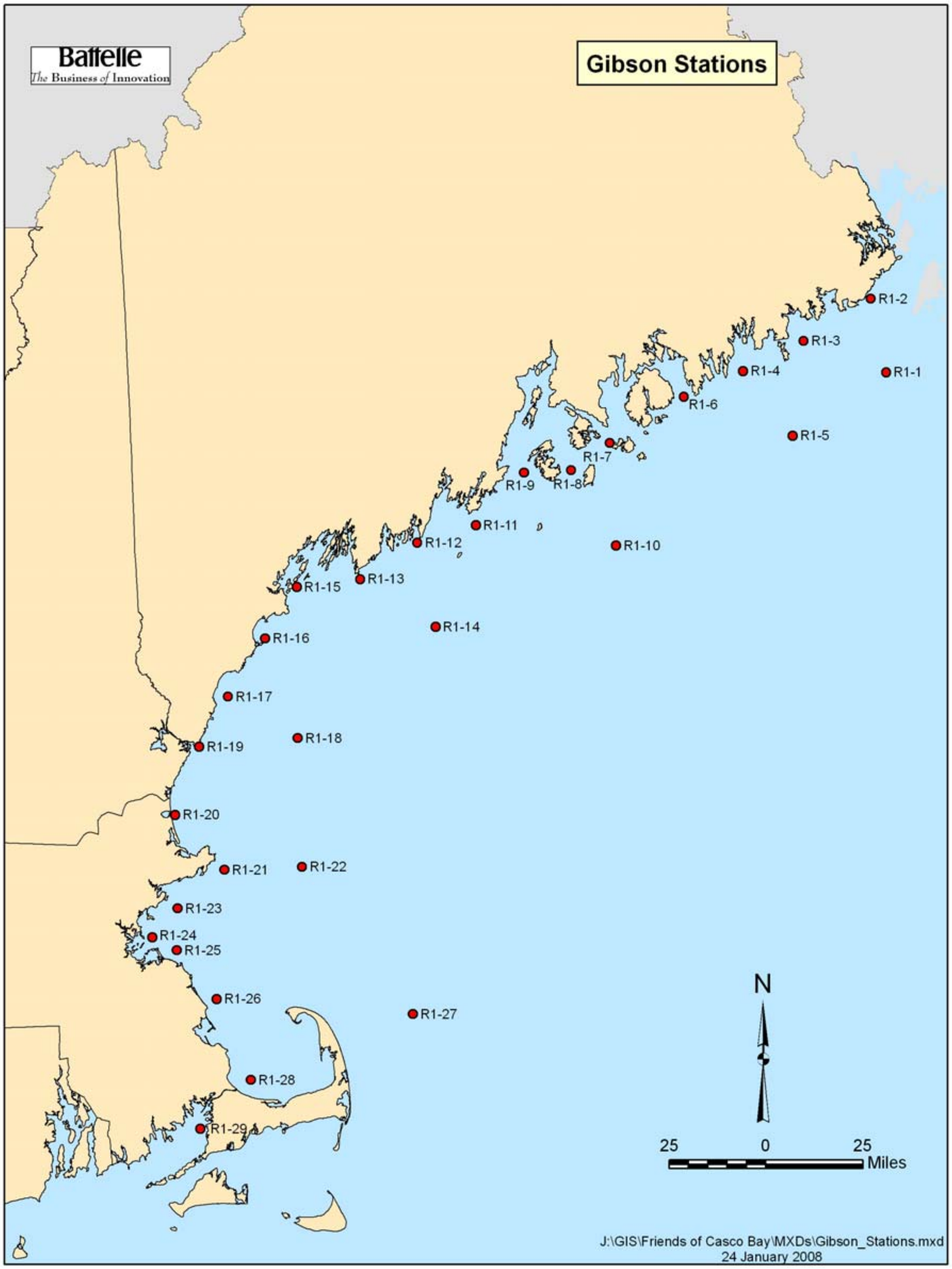

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Figure A- 1. EPA Coastal Marine Nutrient Survey stations. These stations have been termed "Gibson" stations in this report.

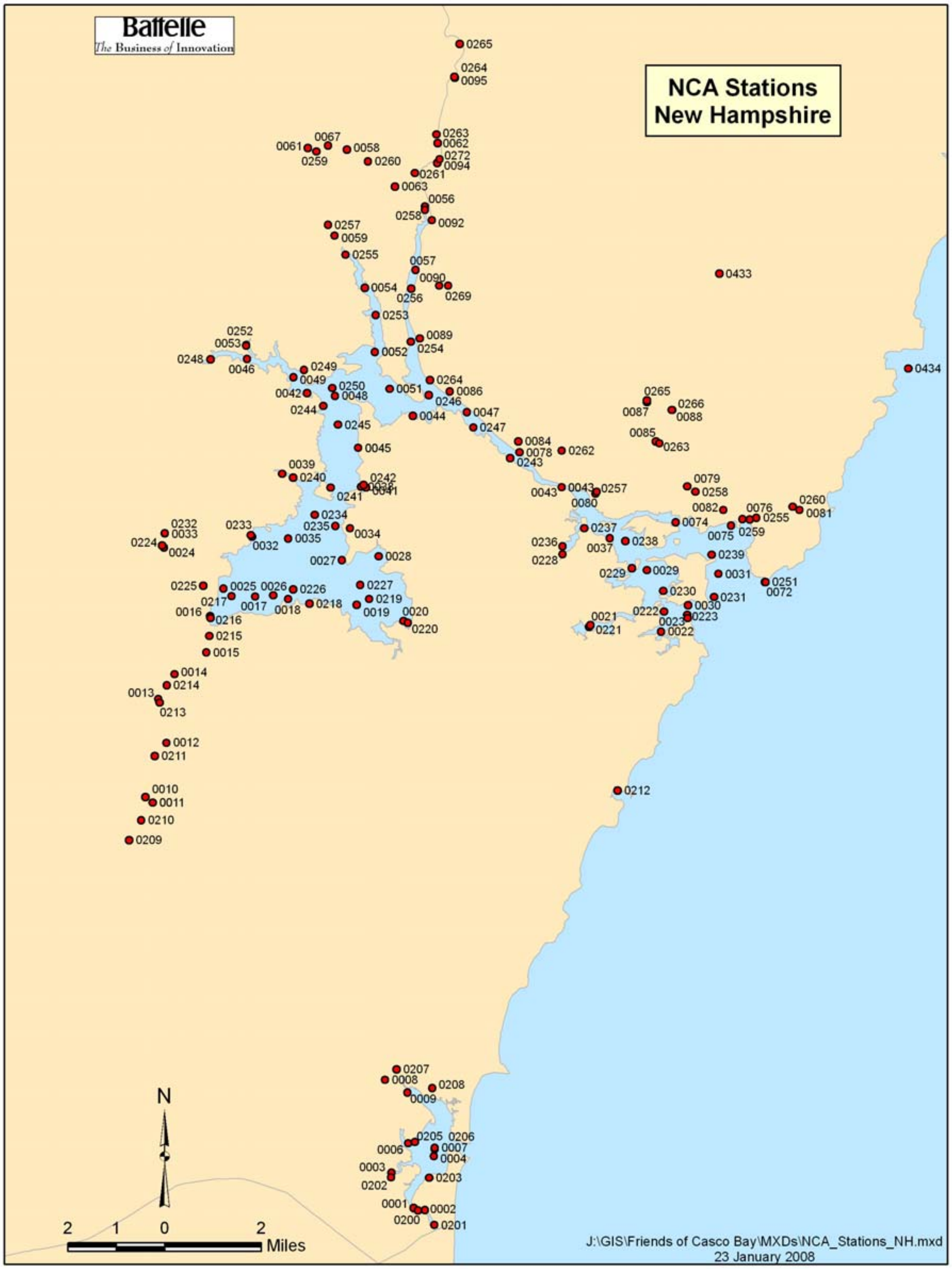

Figure A- 2. New Hampshire National Coastal Assessment stations. First two digits in station ID represent the year sampled.

Figure A- 3. Massachusetts National Coastal Assessment stations. First two digits in station ID represent the year sampled.

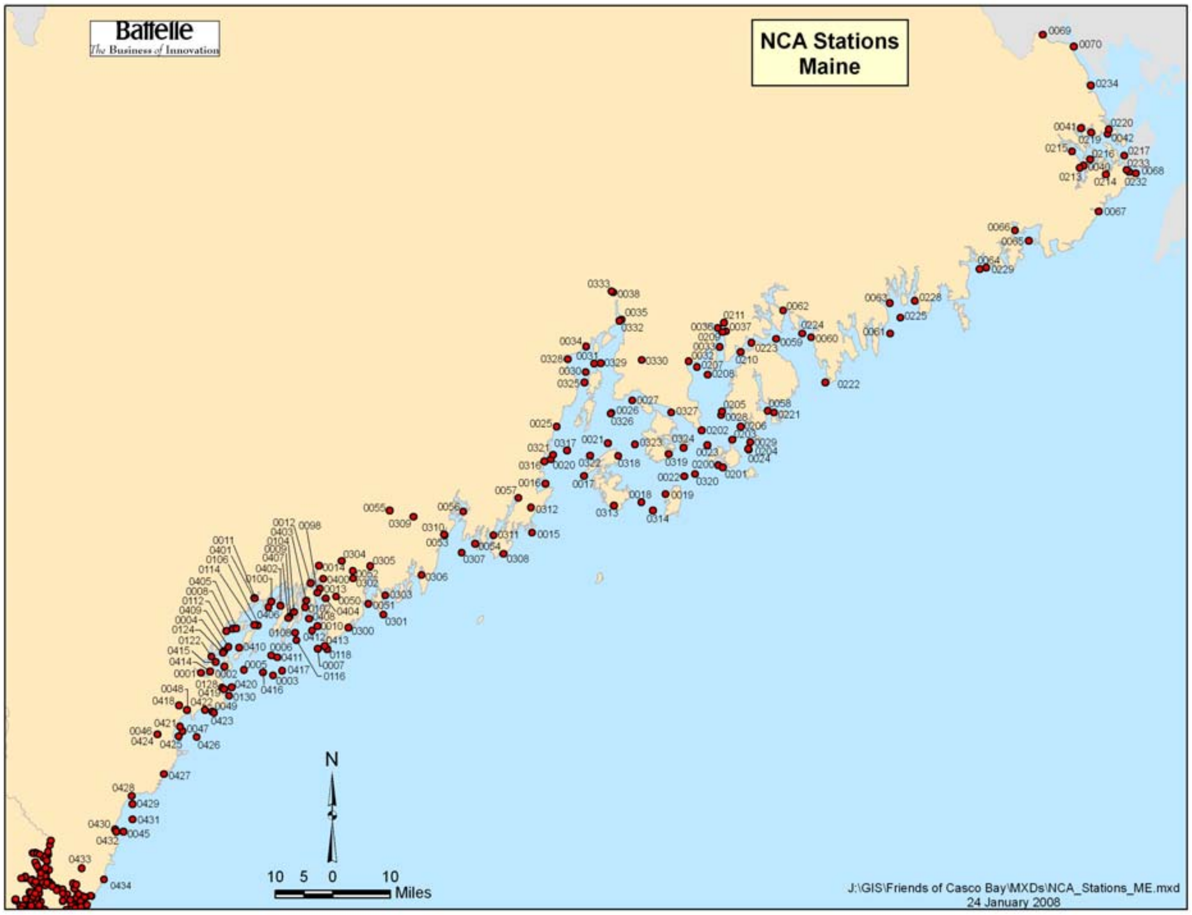

Figure A- 4. Maine National Coastal Assessment stations. First two digits in station ID represent the year sampled.

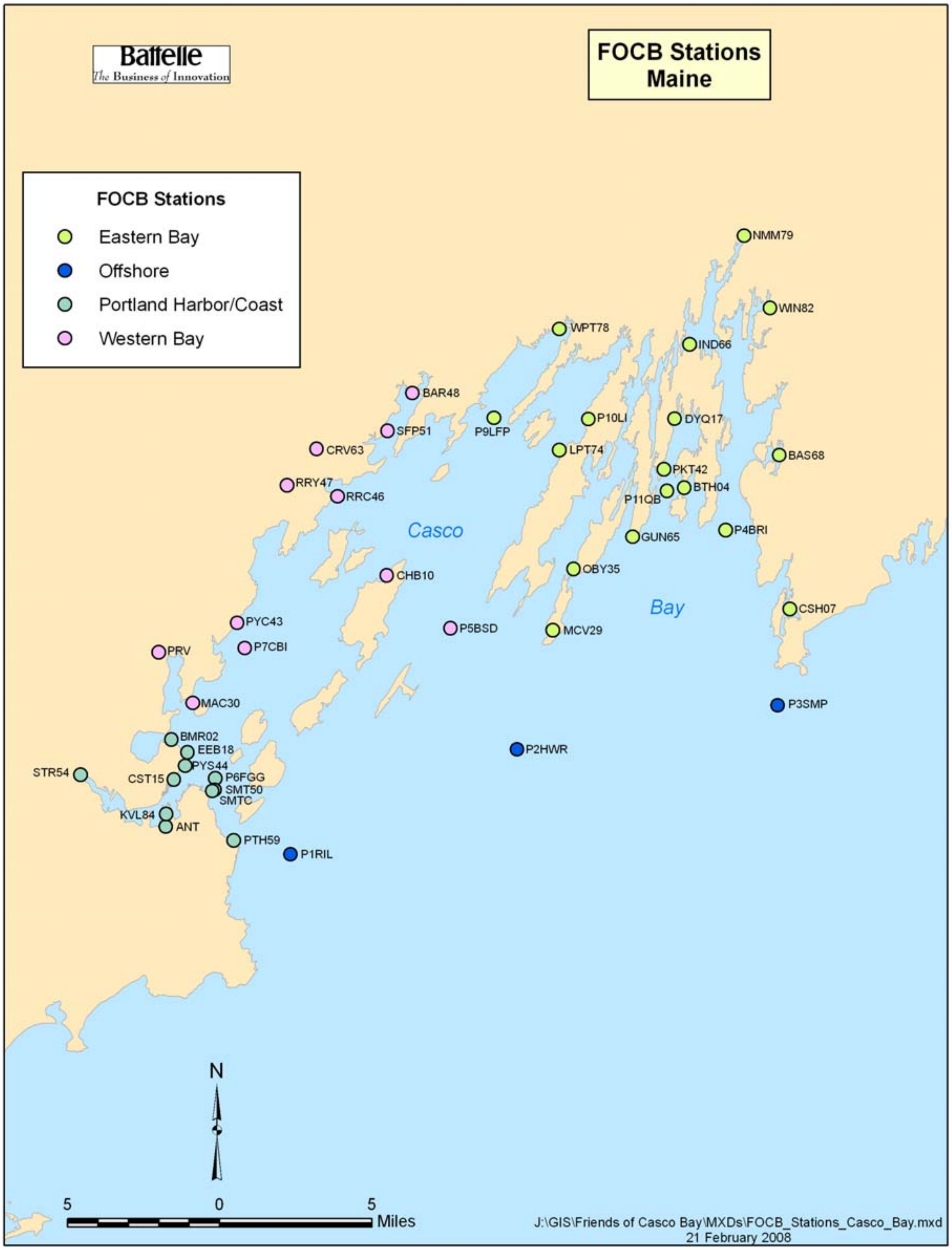

Figure A- 5. Friends of Casco Bay stations.

APPENDIX B - SUMMARY DATA TABLES

Table B- 1. Summary statistics for summer (June-September), surface water total nitrogen, total phosphorous, and chlorophyll *a* data and bottom water dissolved oxygen data for each of the water body groupings defined in the report.

Grouping	Parameter	Units	n	Mean	Min	Max	SD	10th	25th	75th	90th
Maine	TN	µM	180	25.96	1.50	315.41	30.54	7.14	11.82	26.69	48.55
Massachusetts	TN	µM	35	18.15	6.07	70.29	11.00	7.50	12.21	21.79	25.71
New Hampshire	TN	µM	6	22.51	14.71	44.21	11.00	14.71	16.36	22.00	44.21
ME NCA Stations	TN	µM	60	10.27	1.50	30.36	5.36	5.71	6.64	11.82	17.86
ME Gibson inshore	TN	µM	28	23.06	15.71	60.00	8.49	16.43	17.86	25.00	30.00
ME Gibson offshore	TN	µM	10	24.00	12.86	67.14	15.74	13.57	15.00	24.29	46.07
Casco Bay	TN	µM	92	37.06	17.91	315.41	38.80	18.41	19.04	42.88	58.92
Portland Harbor	TN	µM	47	42.92	18.28	315.41	51.41	18.80	19.32	48.13	69.44
Western Bay	TN	µM	24	37.42	18.76	100.93	17.76	22.35	26.69	42.54	55.66
Eastern Bay	TN	µM	12	19.29	18.08	22.03	1.45	18.36	18.40	19.93	21.79
Offshore	TN	µM	9	29.20	17.91	62.54	16.54	17.91	18.26	42.87	62.54
Maine	TP	µM	88	0.72	0.19	1.41	0.24	0.39	0.55	0.90	1.03
Massachusetts	TP	µM	35	0.85	0.48	1.65	0.32	0.54	0.58	1.10	1.29
New Hampshire	TP	µM	6	1.11	0.74	1.87	0.40	0.74	0.90	1.13	1.87
ME NCA Stations	TP	µM	60	0.62	0.19	1.10	0.20	0.39	0.47	0.74	0.90
ME Gibson inshore	TP	µM	28	0.96	0.69	1.41	0.15	0.79	0.85	1.04	1.16
ME Gibson offshore	TP	µM	10	0.89	0.57	1.36	0.28	0.58	0.60	1.04	1.32
Maine	Chlorophyll a	µg/L	260	1.79	0.15	10.60	1.40	0.62	0.85	2.28	3.39
Massachusetts	Chlorophyll a	µg/L	93	2.90	0.14	52.30	6.00	0.49	0.89	2.85	5.01
New Hampshire	Chlorophyll a	µg/L	93	4.56	0.15	33.59	4.91	0.77	1.63	5.75	9.83
ME NCA Stations	Chlorophyll a	µg/L	184	1.79	0.15	10.60	1.52	0.53	0.82	2.20	3.42
ME Gibson inshore	Chlorophyll a	µg/L	28	1.88	0.37	3.71	0.97	0.69	1.03	2.78	3.36
ME Gibson offshore	Chlorophyll a	µg/L	10	1.07	0.41	2.74	0.65	0.54	0.68	1.23	2.01
Casco Bay	Chlorophyll a	µg/L	48	1.75	0.85	5.09	1.08	0.85	0.85	1.70	3.39
Portland Harbor	Chlorophyll a	µg/L	33	2.00	0.85	5.09	1.18	0.85	0.85	2.54	3.39
Western Bay	Chlorophyll a	µg/L	15	1.19	0.85	2.54	0.54	0.85	0.85	1.70	1.70
Maine	DO	mg/L	500	8.44	4.34	30.40	1.47	7.01	7.67	9.20	9.86
Massachusetts	DO	mg/L	88	7.64	0.95	14.80	2.04	5.73	6.25	8.58	9.79
New Hampshire	DO	mg/L	108	7.70	4.30	11.69	1.29	5.77	7.03	8.55	9.24
ME NCA Stations	DO	mg/L	188	8.14	4.34	10.76	0.99	6.81	7.53	8.71	9.40
ME Gibson inshore	DO	mg/L	14	9.83	9.10	10.38	0.33	9.42	9.62	10.04	10.08
ME Gibson offshore	DO	mg/L	5	8.36	7.10	9.17	0.82	7.10	8.16	8.96	9.17
Casco Bay	DO	mg/L	298	8.57	5.10	30.40	1.69	7.10	7.70	9.30	9.99
Portland Harbor	DO	mg/L	37	9.00	7.40	10.40	0.78	7.90	8.50	9.40	10.20
Western Bay	DO	mg/L	60	8.90	6.90	30.40	2.98	7.40	7.80	9.10	9.95
Eastern Bay	DO	mg/L	117	8.19	5.10	10.70	1.23	6.50	7.40	9.10	9.80
Offshore	DO	mg/L	84	8.67	6.20	10.94	1.07	7.50	7.90	9.60	10.20

Table B- 2. Summary statistics for summer (June-September), surface water dissolved inorganic nitrogen, ammonium and nitrate+nitrite data for each of the water body groupings defined in the report.

Grouping	Parameter	Units	n	Mean	Min	Max	SD	10th	25th	75th	90th
Maine	DIN	µM	1337	8.04	0.00	620.00	31.06	0.39	1.28	7.63	14.45
Massachusetts	DIN	µM	52	8.93	0.72	69.29	14.34	1.50	2.33	7.64	13.93
New Hampshire	DIN	µM	82	12.26	1.36	165.43	19.40	2.29	3.50	15.07	22.57
ME NCA Stations	DIN	µM	54	6.84	1.18	22.07	4.86	2.57	3.43	8.38	12.28
Casco Bay	DIN	µM	1283	8.09	0.00	620.00	31.69	0.37	1.22	7.55	14.60
Portland Harbor	DIN	µM	510	9.04	0.00	620.00	28.76	1.44	2.87	8.59	18.27
Western Bay	DIN	µM	281	6.78	0.00	130.21	10.14	0.40	1.10	9.71	15.56
Eastern Bay	DIN	µM	390	6.23	0.00	620.00	32.45	0.16	0.80	4.84	9.92
Offshore	DIN	µM	102	14.01	0.00	620.00	64.62	0.05	0.28	5.99	16.16
Maine	NH4	µM	1404	4.24	0.00	127.33	9.69	0.14	0.80	4.50	8.14
Massachusetts	NH4	µM	75	3.61	0.07	15.21	3.30	0.64	1.71	3.79	7.93
New Hampshire	NH4	µM	95	6.90	0.43	162.86	16.84	0.93	2.07	8.21	12.14
ME NCA Stations	NH4	µM	124	2.20	0.07	16.00	2.71	0.14	0.36	2.93	5.79
Casco Bay	NH4	µM	1280	4.44	0.00	127.33	10.09	0.13	0.86	4.62	8.36
Portland Harbor	NH4	µM	508	4.87	0.00	120.00	7.51	0.81	1.62	5.45	10.34
Western Bay	NH4	µM	281	3.74	0.00	127.33	8.64	0.16	0.87	4.53	7.42
Eastern Bay	NH4	µM	390	3.89	0.00	120.00	9.59	0.01	0.52	4.10	7.56
Offshore	NH4	µM	101	6.34	0.00	120.00	21.02	0.00	0.06	3.19	8.14
Maine	NO2+NO3	µM	1353	3.61	0.00	500.00	23.90	0.09	0.12	2.47	6.92
Massachusetts	NO2+NO3	µM	55	5.06	0.12	56.29	12.03	0.33	0.51	2.17	9.50
New Hampshire	NO2+NO3	µM	85	4.47	0.36	33.50	6.29	0.64	1.14	5.33	13.21
ME NCA Stations	NO2+NO3	µM	73	2.59	0.15	13.71	2.65	0.44	0.71	3.43	5.54
Casco Bay	NO2+NO3	µM	1280	3.67	0.00	500.00	24.56	0.09	0.12	2.39	7.03
Portland Harbor	NO2+NO3	µM	508	4.21	0.00	500.00	22.72	0.25	0.77	3.07	7.45
Western Bay	NO2+NO3	µM	281	3.04	0.00	19.15	4.56	0.09	0.12	4.11	10.16
Eastern Bay	NO2+NO3	µM	390	2.34	0.00	500.00	25.42	0.05	0.09	0.84	2.11
Offshore	NO2+NO3	µM	101	7.81	0.00	500.00	50.00	0.00	0.09	2.10	7.64