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Friends of Casco Bay Twelve-Year Water Quality Data Analysis: 1993 – 2004 Report

Battelle

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Casco Bay Estuary
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Executive Summary

Friends of Casco Bay (FOCB), with support from the Casco Bay Estuary Project, has successfully conducted the Citizens Water Quality Monitoring program for twelve years and counting. The program is carried out with the aid of hundreds of volunteers who sample at approximately 80 shore-based stations and assist FOCB staff at 11 profile stations located throughout Casco Bay. They measure the standard oceanographic parameters of temperature, salinity, pH, Secchi depth, dissolved oxygen, plus ancillary air and water measurements. In the last 4 years, the program was expanded to include measurements for chlorophyll (as measured by *in situ* fluorescence) and dissolved inorganic nutrient concentrations.

Summary statistics for all Casco Bay surface data are presented in Table 1. The minimum and maximum values for each of the parameters provide a good representation of the variability among sites, across the bay, and over time. The shallowest water depth was measured in Anthoine Creek and the deepest depth was consistently measured at Halfway Rock. The coolest temperatures were measured at the sites that are sampled year-round, while the warmest single water temperature was found at the Cousins River site in front of the Muddy Rudder Restaurant during the summer of 1995. During the summer, the warmest waters were consistently observed at the Presumpscot River site, but for swimming Wolf Neck State Park offered some of the most inviting waters with an August mean temperature of 20°C (68°F). For a refreshing swim try Willard Beach, which had one of the lower August mean temperatures at 16.5°C (62°F). The lowest pH and salinity values were obtained at sites at the mouths of both the Royal and Presumpscot Rivers. The lowest DO concentrations and percent saturation measurements were made at Peabbles Cove where low DO levels are associated with the decomposition of seaweed that naturally accumulates in that location due to ocean currents and are not related to any anthropogenic influences. Sites in Portland Harbor consistently had some of the lowest DO levels and these low levels are likely associated with point or non-point source nutrient inputs and associated eutrophication effects. Whereas sites in Quahog Bay and New Meadows River had low DO levels that are likely due to restricted circulation in these embayments. Secchi depth, a measure of water clarity, was at a minimum at a number of shallow, inshore sites while the clearest water was found at Halfway Rock.

Table 1. Summary Statistics for All Estuarine Surface Data (1993-2004)

	Water Depth (m)	Temp (°C)	Salinity (ppt)	DO (mg/l)	DO (% saturation)	pH	Secchi Depth* (m)
Mean	7.25	12.95	29.02	9.20	103.5	7.94	2.98
SD	7.68	5.36	4.48	1.48	12.1	0.19	1.42
Minimum	0.1	-3.0	0.0	2.6	33.9	6.0	0.2
Maximum	55.0	30.0	34	14.9	177.5	8.7	15.3
Count	7022	8408	8322	8214	8126	7966	3808

*Secchi depth summary statistics calculated from 40 selected sites.

Chlorophyll and dissolved inorganic nutrient measurements were added to the FOCB monitoring program in 2001. *In situ* fluorescence is a measure of chlorophyll concentrations and an indirect estimate of phytoplankton biomass. It offers additional information on water quality conditions and factors that may be influencing DO concentrations. Although there were significant decreases in fluorescence from inshore to offshore profiled stations, temporal trends account for most of the variability with the highest fluorescence values measured during the winter/spring phytoplankton blooms in 2003 and 2004 (Table 2). Dissolved inorganic nutrients are crucial ingredients in the biogeochemical functioning of an estuarine system. However, high inputs of anthropogenic nutrient could drive the system towards eutrophication with elevated biomass, organic material, and eventually lower bottom water dissolved oxygen levels or even hypoxic conditions. The mean nutrient concentrations in Table 2 are typical of northeastern coastal waters, but the maxima suggest anthropogenic and riverine inputs. Although high nutrient concentrations were measured at various times at each station, the sites off the dock at Southern Maine Community College and near Fort Gorges were consistently higher in relation to the other stations. Profile station P3SMP, located offshore south of Phippsburg, is elevated in silicate due to the influence of the Kennebec River at this station. By adding these critical parameters to the monitoring program, FOCB has not only expanded the utility of the program, but provided a basis from which to more accurately attribute likely causes in the problem areas. This information will allow environmental managers to make more informed planning decisions.

Table 2. Summary Statistics for All Chlorophyll and Nutrient Data (1993-2004)

	Chlorophyll (μg/L)	NO_3+NO_2 (μM)	NH_4 (μM)	SiO_4 (μM)	PO_4 (μM)
Mean	5.9	2.57	2.60	6.97	0.95
SD	6.8	3.15	3.29	4.89	0.56
Minimum	0.0	0.0	0.0	0.0	0.0
Maximum	116	16.65	23.98	30.32	3.23
Count	2646	1307	1302	1337	1338

Evaluations of the twelve years of water quality data (1993 to 2004) indicate that overall water quality in Casco Bay is generally good. Dissolved oxygen (DO) is usually well above State standards and not close to levels that would impair biological processes (Figure 1). However, there are areas of potential concern with respect to DO levels (Figure 2). Nevertheless, low DO events tend to be exceptions rather than the rule in Casco Bay waters.

The monitoring data have been used to develop the Casco Bay Health Index (Figure 3). The index provides a reliable, uncomplicated indicator of the Bay's overall quality. The index is calculated based on DO percent saturation and the clarity of the water. Both of these parameters are strong indicators of water quality and the impacts of eutrophication. For each monitoring site, the summer means of these two parameters are scored based on their relative position between conservatively set low and high thresholds (65 to 95% and 0.5 to 3.5 m). The mean of these two values is the final index score. By summarizing these environmental indicators into one score, sites can be ranked, areas of concern identified, and trends in water quality may become more apparent over time.

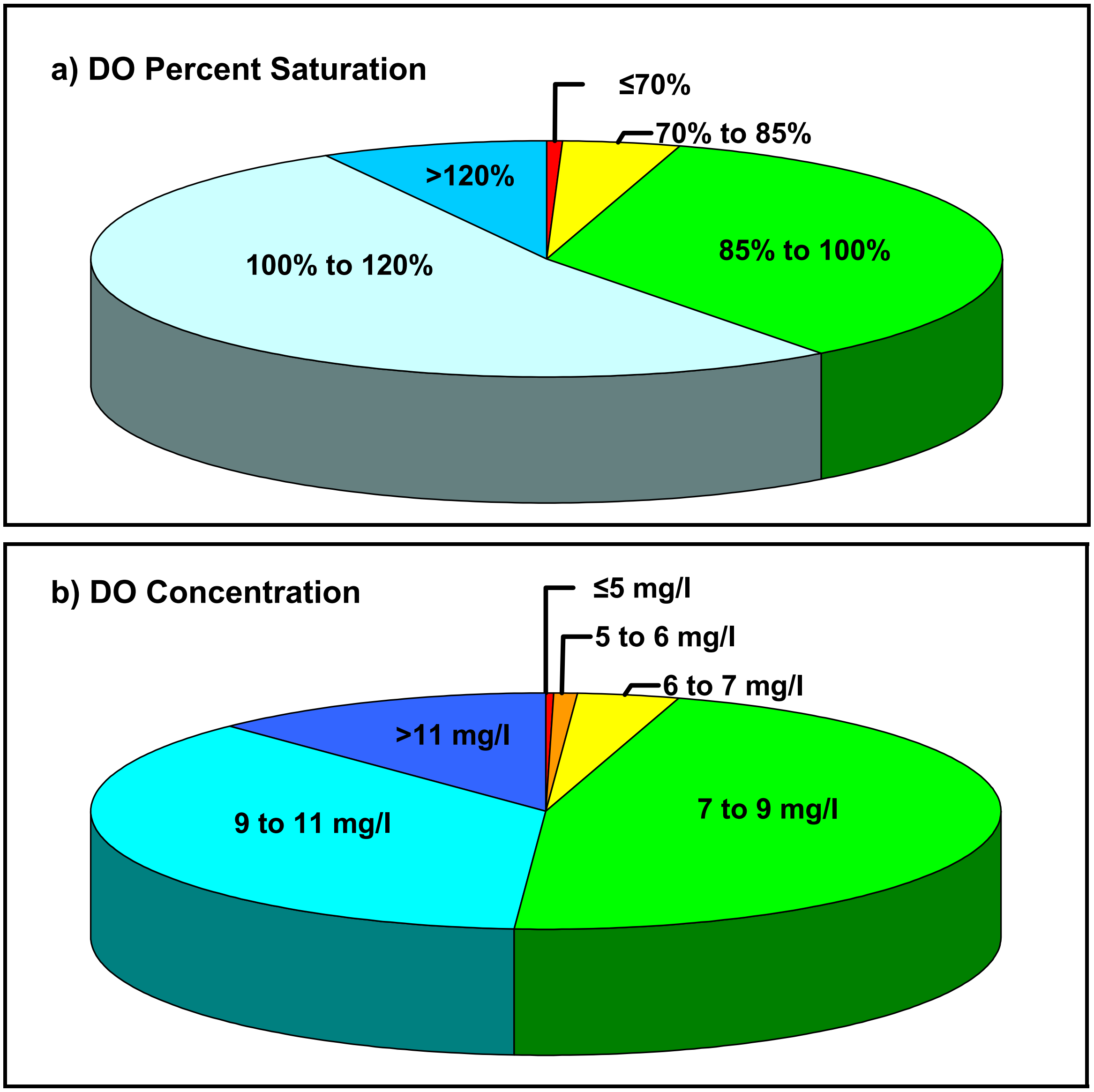

Figure 1. Pie Charts of a) DO percent saturation and b) DO concentration for all surface water data from 1993-2004. Overall, only 0.6% of the measurements were <70% and the majority of these readings were found in Portland Harbor, upper New Meadows River, and Peabbles Cove. Percent saturation readings of <85% were measured at 74 different sites, which suggests that this level is well within the natural variability for these waters.

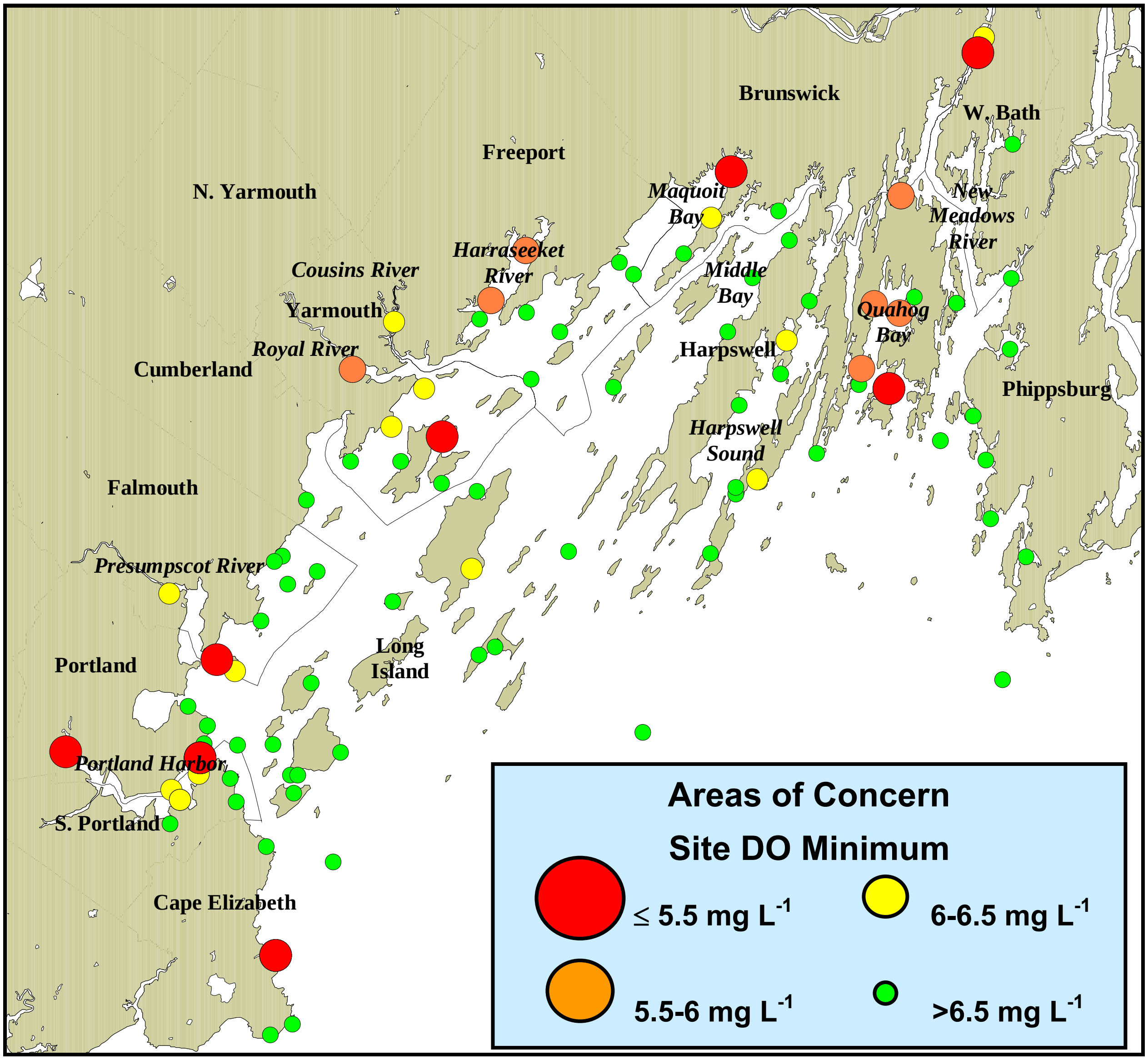

Figure 2. Areas of concern in Casco Bay based on minimum DO concentrations observed over the entire 1993-2004 period. Dissolved oxygen concentration in coastal waters is a dynamic property that varies spatially and temporally depending on physical, seasonal, biotic, and anthropogenic influences. The areas of concern in this figure are found in locations with potentially high nutrient loading either directly from point sources (Portland Harbor) or indirectly from riverine and other non-point sources (Royal River, Presumpscot River, and Harraseeket River) and also in waters where restricted circulation may exacerbate DO conditions (New Meadows River and Quahog Bay).

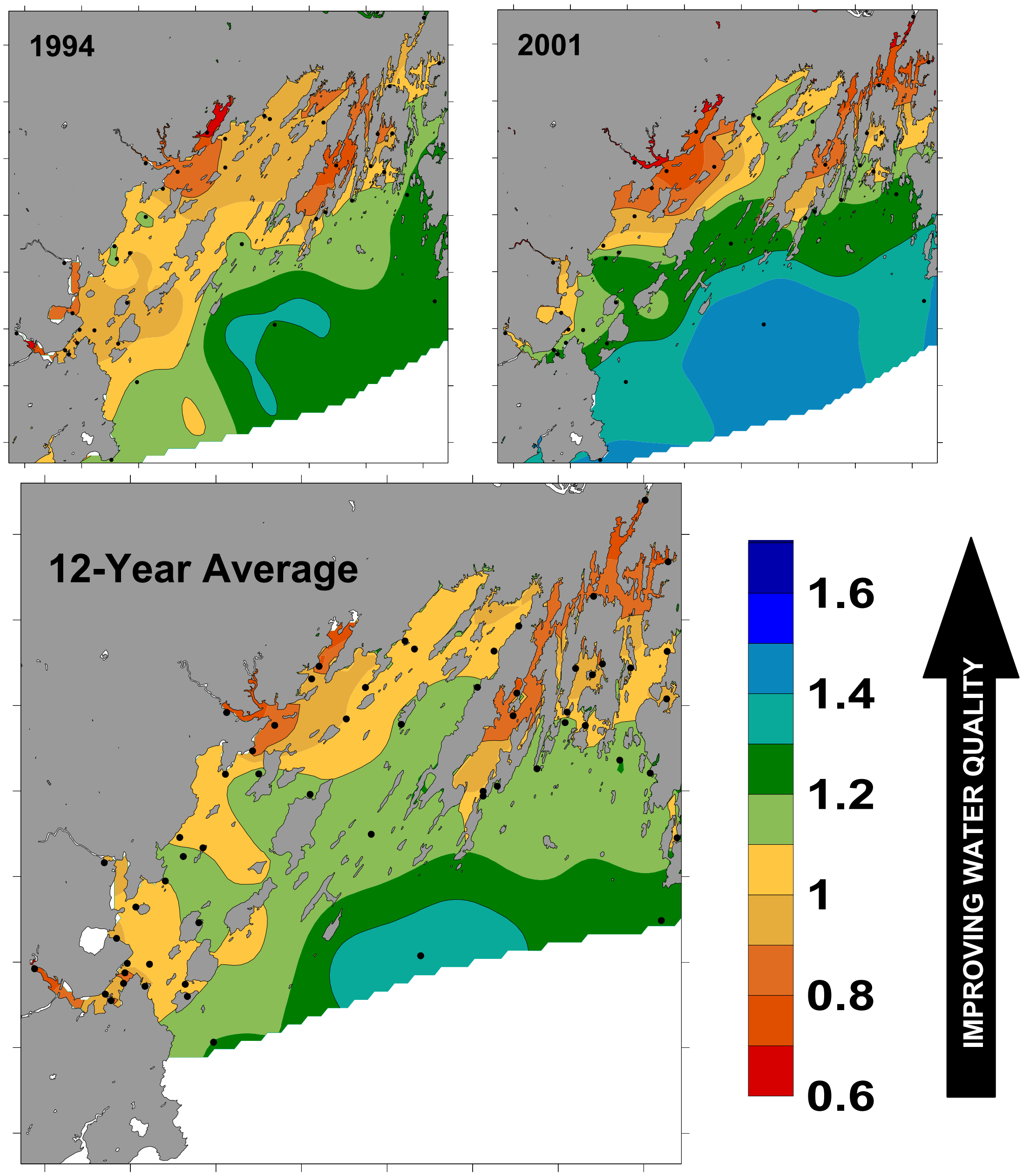

Figure 3. Casco Bay Health Index distributions. Data from 59 surface sites with sufficient Secchi depth data. On average, the lowest scores are found in Portland Harbor, in the vicinity of the Presumpscot and Royal Rivers, and in the restricted embayments in Northeastern Casco Bay. There is a clear inshore to offshore increase in the index with the highest scores consistently calculated for the site near Halfway Rock. This is due to both higher DO levels and greater water clarity the further removed from anthropogenic and riverine inputs. Year-to-year variability is evident in the distribution of the index as indicated by the plots for 1994 and 2001. In 1994, low DO concentrations were observed at numerous sites along the northeastern coastline and offshore scores also tended to be lower than observed in 2001 or the 120year average. In 2001, water quality was better throughout much of Casco Bay, though low scores were still seen at a few of the areas of concern. Note that most of the sites score ≥1 indicating that even when using relatively conservative low and high thresholds water quality appears to be good throughout most of Casco Bay.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1.0 Introduction

Since 1989, the Friends of Casco Bay (FOCB) has been dedicated to improving and protecting the environmental health of Casco Bay. As an EPA designated "Estuary of National Significance", the mission to preserve and protect the Bay has become one of local and national importance. With support from the Casco Bay Estuary Partnership (CBEP), Gulf of Maine Ocean Observing System (GoMOOS), University of Maine School of Marine Sciences (UM), FOCB members, and a variety of other public and private donors, Friends of Casco Bay has successfully conducted the Citizens Water Quality Monitoring (CWQM) program for more than twelve years. The program is carried out with the aid of hundreds 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 the standard oceanographic parameters of temperature, salinity, pH, Secchi depth, dissolved oxygen, plus ancillary air and water measurements. In the last four years, the program was expanded to include measurements for chlorophyll (as measured by *in situ* fluorescence) and dissolved inorganic nutrient concentrations. All parameters are measured in strict accordance with FOCB's Quality Assurance Project Plan (QAPP) approved by EPA Region 1 (FOCB 2001). The FOCB QAPP indicates that the CWQM program data will be used to aid environmental managers in:

- Establishing baseline water quality conditions;
- Determining long-term water quality trends;
- Documenting effects of water quality improvement programs;
- Screening for sources of pollution by identifying existing problems; and
- Making decisions on shoreline planning and zoning.

In 2001, an evaluation of the first six years of water quality data (1993 to 1998) indicated that although overall water quality in Casco Bay was generally good, there were areas of potential concern with respect to dissolved oxygen (DO) levels (Battelle 2001). These areas were found in locations with potentially heavy nutrient loading either directly from point sources (Portland Harbor) or indirectly from riverine and other non-point sources (Royal River, Presumpscot River, and Harraseeket River) and also in waters where restricted circulation may exacerbate DO conditions (New Meadows River and Quahog Bay). The six-year review also highlighted the consistency of seasonal and annual cycles across the bay and across the region.

Based on the findings and recommendations in the six-year report, chlorophyll and dissolved inorganic nutrient measurements were added to the FOCB monitoring program in 2001. By adding these critical parameters to the monitoring program, FOCB has not only expanded the utility of the program, but provided a basis from which to more accurately attribute likely causes contributing to low DO levels in the problem areas. This information will allow environmental managers to make more informed planning decisions.

The 2001 report addressed a number of the uses of the data, specifically:

- identifying potential problem areas;
- examining trends in water quality over six years; and
- providing a basis from which environmental managers could make shoreline planning decisions.

Although baseline water quality conditions were not explicitly identified or defined, the six-year dataset could have served to describe baseline conditions in the event that managers had implemented major water quality improvements at that time.

One of the main objectives for the current evaluation of the 12 years of data is to corroborate the findings of the earlier report with regards to spatial and temporal trends in water quality conditions and identify areas of concern within Casco Bay. In addition, the 12-year dataset will provide a basis for additional comparisons to regional datasets (i.e. Massachusetts Water Resources Authority - MWRA, Gulf of Maine Ocean Observing System - GoMOOS) and the evaluation of long-term trends in the data. These trends will be evaluated with an eye towards establishing a set of baseline conditions from which to compare future data and to use as a yardstick for future water quality improvements or impairments (both local and regional in scope). To that end, a Casco Bay Health Index has been developed to track particular trends.

As with the six-year report, this report emphasizes DO as a key indicator and integrator of water quality in coastal waters. As a basic necessity for aquatic life, DO levels directly affect ecosystem health. Diaz and Rosenberg (1995) state that there is no other environmental variable of such ecological importance to coastal marine ecosystems that has changed so drastically in such a short period of time as dissolved oxygen. These authors argue that while hypoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing and the cause seems most likely to be accelerated by human activities (Nixon, 1995; Bricker et al., 1999).

The amount of DO contained in marine waters at saturation is a function of physical, chemical, and biological conditions. Cold waters hold more DO than warm waters at a given salinity. Seawater at equilibrium at a given temperature contains substantially less DO than freshwater. Thus, DO concentrations naturally follow a seasonal pattern of winter maxima and summer minima that is directly related to temperature, but influenced by biological processes. Biological production and utilization of DO in coastal waters has a well-known theoretical relationship to nutrient supplies. Increased nutrient supplies often lead to increased photosynthetic production of organic matter by phytoplankton or other algae. This increase in production often results in super-saturated DO levels in the upper water column, while a dominance of heterotrophic activity, especially microbial respiration, can lead to greatly under-saturated conditions. Highly productive waters may experience super-saturated conditions during the day and under-saturated conditions at night, around sunrise as respiration has been occurring for maximal duration. Another factor that affects DO concentration in estuarine and coastal waters is mixing, or lack thereof. Deeper waters where vertical density differences exist, especially sub-pycnocline waters, may become hypoxic during the summer when DO solubility is lowest and ample supplies of labile organic carbon are available (due to sinking of senescent phytoplankton) to support microbial respiration and benthic respiration in the bottom waters. Dissolved oxygen utilization in deeper stratified waters may outpace DO replenishment by transport of atmospheric DO, mixing, and any potential net gains of DO from photosynthesis. Dissolved oxygen concentration in coastal waters is a dynamic property that varies spatially and temporally depending on physical, seasonal, biotic, and anthropogenic influences.

Additional parameters examined in this report include Secchi depth, chlorophyll, and dissolved inorganic nutrients. Secchi depth is a measure of water clarity or turbidity. Higher values indicate clearer water, and lower values indicate high turbidity. Turbid waters typically appear cloudy, have high concentrations of total suspended solids, and allow less light to penetrate through the water. Low Secchi depth values can be due to a myriad of factors, but most often it is attributed to excessive algal growth or freshwater, riverine inputs. In Casco Bay, both of these factors play a major role in water clarity, but episodic events such as land run-off, shore-line erosion, resuspension of bottom sediments (especially at shallow stations), or dredging operations may also impact Secchi depth measurements.

Chlorophyll and dissolved inorganic nutrients were added to the suite of measurements in 2001. *In situ* fluorescence is a measure of chlorophyll concentrations and an indirect estimate of phytoplankton biomass. In general, chlorophyll concentrations are correlated to phytoplankton biomass though there are biological (phytoplankton species, growth rate) and environmental conditions (high or low light, nutrient availability, etc.) that affect the relative level of chlorophyll to carbon biomass. Regardless, *in situ* fluorescence measurements provide insight into the relative phytoplankton biomass and offer additional information on water quality conditions and factors that may be influencing DO concentrations. The dissolved inorganic nutrients measured by FOCB include nitrate plus nitrite (NO_3+NO_2), ammonium (NH_4), silicate (SiO_4), and phosphate (PO_4). These nutrients are crucial ingredients in the biogeochemical functioning of an estuarine system; however, too much of a good thing, in this case anthropogenic nutrient inputs, can drive the system toward eutrophication with elevated biomass, organic material, and eventually lower bottom water dissolved oxygen levels or even hypoxic conditions.

The first step taken in this data evaluation was to revisit the set of issues addressed in the six-year report. Based on the results from the six-year evaluation, the current dataset was assessed to confirm similar temporal and spatial variations in parameters, specifically DO, at sites and basins across the bay. The new measurements, chlorophyll and dissolved inorganic nutrient concentrations, were then considered to help evaluate potential causes for those differences.

The extended duration of the monitoring program to twelve years allows for the evaluation of:

- long-term trends in the data both internally and against external data sources in the region;
- interannual variability on both a seasonal and annual basis; and
- the feasibility of establishing a set of baseline conditions based on a subset of the 12 year dataset.

These topics are addressed by the data analysis presented in this report. The report also examines the application of the Casco Bay Health Index at both the volunteer monitoring sites (plus surface profile site data) and the profile sites. These indices seek to convey information about the system in a format that is informative and easily understood by the public. The indices focus on levels of dissolved oxygen and Secchi depth, and fluorescence and nutrients at the profile sites. As with the previous report, this examination of the FOCB data also provides an overall characterization of water quality in Casco Bay and highlights areas of concern.

2.0 Methods

2.1 FOCB Sampling and Analytical Procedures

The FOCB water quality data consist of data collected from 1993 to 2004 at approximately 80 shore-based stations by citizen volunteers and 11 profile stations sampled by FOCB staff (Figure 1). At the shore-based CWQM stations, data were collected within the upper six inches of water. The profile stations were sampled within the upper six inches of water for surface samples, at 1 meter, and then at 2-meter intervals throughout the entire water column. Surface and profile stations were sampled twice per month in 1993-1995 and once per month in 1996-2004. The majority of the surface sites were sampled from April to October. The profile sites and a select few surface sites were sampled year round. A variety of air, water, and site data were recorded for each site-sampling event on a datasheet (Appendix A).

All regular sampling in the CWQM program involved ambient measurements collected and processed in the field. All measurements were made on-site, with the possible exception of DO, which could be fixed on-site, then titrated within eight hours after collection. A few of the surface sites were sampled from volunteers' boats, but most were sampled from bridges, piers, bulkheads, floats, jetties, and docks where there is at least ten feet of water at low tide. This minimum water depth requirement allowed for a Secchi disk reading to be taken at almost any tide stage. Unfortunately, requiring a strict minimum depth was not feasible. Because of the limited number of ideal spots and because consistency is related to convenience, a number of stations are sampled by wading-in from shore. All CWQM surface sites were visited by FOCB staff or volunteer regional coordinators to measure latitude and longitude using a GPS unit, to take a reference photo, and to establish a point at the station from which sampling could be done both safely and consistently. All surface water samples were collected by 5-gallon bucket. The sampling period was designated as a Saturday plus or minus two days (i.e. Thursday through Monday). The recommended time frame was 9:00 AM to 3:00 PM and was not tide dependent (tide stage was recorded).

In addition to the surface sites sampled by citizen monitors, eleven stations have been sampled over the program from the Baykeeper boat by FOCB staff often accompanied by volunteers. These eleven stations are only accessible by boat. At these stations, *in situ* water column profile data are collected for DO, temperature, salinity, pH and Secchi depth. Beginning in 2000 and 2001, pH and fluorescence were added to the list of *in situ* parameters measured at the profile stations. FOCB also began to collect samples for analysis of dissolved inorganic nutrient concentrations at UM. These samples are collected from surface, above and below a thermocline when present, and bottom depths and then filtered, fixed with chloroform, and frozen for analysis at Dr. David Townsend's laboratory at the University of Maine (UM). The profile sites and a small subset of the surface water sites are sampled year round (Figure 2).

Different, yet comparable, methods were used for analysis and measurement of parameters at the shore-based and profile stations. All of the analytical methods are detailed in the FOCB Quality Assurance Project Plan (QAPP) (FOCB 2001). The pH was measured by a colorimetric method using a pH octet comparator. A gravimetric procedure using a hydrometer was used to measure salinity. For both pH and salinity, the non-electrometric methods are more appropriate for the CWQM program. A Secchi disk was used to measure water clarity at both the surface and profile stations. These methods have been approved for use by citizen programs in other EPA regions, i.e. Region 3, Chesapeake Bay Citizen Monitoring Program and Region 6, Galveston Bay Foundation TEST Program. EPA-approved methods were used to measure DO and water temperature. Dissolved oxygen is measured using the azide-modified Winkler Titration method and temperature is measured using an alcohol-filled thermometer. At the profile stations, water temperature, salinity, DO, pH, fluorescence and depth were measured electrometrically using in situ sensors following procedures detailed in the QAPP (FOCB 2001). The dissolved nutrient samples were analyzed on an autoanalyzer following the methods outlined in Whitledge et al. (1986).

All data are reviewed by the Program Coordinator to ensure they meet program data quality objectives (Appendix B). The data quality objectives and validation procedures for this program have been designed to identify and correct problems in data collection and reporting. Should the results of data validation measures or quality assurance reviews indicate that the integrity of data are questionable and data quality objectives are not being met, the data set (or that portion which is deficient) are flagged as unacceptable for inclusion in the CWQM Data File. None of the suspect data were included in the data analysis presented.

After review, the data are entered into MURPHY, a relational database computer program developed by FOCB. Another series of data checks and calculations is undertaken within the database. Raw data are then used to calculate corrected pH, corrected salinity, DO % saturation, and density. The data are further evaluated graphically by mean, minimum, and maximum values for each parameter with site and time series plots of data every three months to ensure comparability between stations and across time.

2.2 Database Development

The data evaluation focuses on the key water quality parameters collected – temperature, salinity, pH, Secchi depth, dissolved oxygen (concentrations and % saturation), chlorophyll, and dissolved inorganic nutrients with major emphasis on dissolved oxygen. The data received from FOCB for 1999-2004 were loaded into an Access database containing historical data from 1993-1998, and working tables were developed for the profile data (FOCB_Profile_2005), all surface data (FOCB_report_2005), and the nutrient data (FOCB_nutrients_2005). FOCB_report_2005 included data from both the profile and shore-based stations. The profile data were received from FOCB as two separate files one that included the entire depth profile and another that included just the surface water data and ancillary profile site information. Data from the shore-based sites were delivered in one file that included all surface data and ancillary information. The nutrient data file also included data on coincident measurements of *in situ* parameters.

The *in situ* profiles were compiled into FOCB_Profile_2005, which contains data for 15,927 sampling depths collected from 1,462 profiles. The profile surface data and all data collected at the shore-based sites were compiled into FOCB_report_2005, which includes 8,544 site visits over the 12-year period. The nutrient data were not collected until 2001 and thus were added as a separate new table that contains 1,341 sampling records. A fourth table, FOCB_locations, was added to the database to provide location information for each of the sites. A series of queries was run to rectify discontinuities between the tables (i.e. check for replicated data, cross-referenced sites, etc.), and missing data were loaded to complete the database. The 91 locations that remained for the evaluation are presented in Table 1. Upon completion of database population and prior to data analyses and interpretation, the database was audited for completeness. The final Access data tables were audited by comparison with the data files submitted by FOCB and no errors or omissions were found.

There have been a number of changes over the 12 years of the monitoring project. The number of sampling sites has increased from 30 shore-based stations and 8 profile stations in 1993 to the 80 shore-based and 11 profile stations listed in Table 1 in 2004. Following the review of the first six years of data (Battelle 2001), site data were grouped into water bodies. The water body names and associated sites are listed in Table 1 and presented in Figure 1.

During 1993-1996, samples were collected every two weeks from April through October. From 1997-2004, sampling was conducted only once per month. In addition, intense sampling was conducted during special studies at the New Meadows Marina site (NMM79) in June-July 1997, July 1998, and June 2001 to monitor water quality over shorter time scales. To account for differences in sampling frequency and to remove any potential biases toward sites that were sampled more frequently, a database table (FOCB_report_estuarine_monthly_means) was populated with the monthly averages for each site, and these data were used for many of the graphical and statistical analyses. Data in this table were used to calculate the seasonal averages for each site, which were saved as a separate database table (FOCB_report_estuarine_seasonal_means). For this report, the seasons have been defined as January-March (winter), April-June (spring), July-September (summer), and October-December (fall).

In addition to potential data biases due to sampling locations and frequency, water depth at a station can cause significant biases on Secchi depth data. There are a number of stations where water depth and Secchi depth are equal (bottom still visible - BSV). Although the Secchi depth may be shallow at these stations, it does not necessarily mean water clarity is poor. To avoid biasing the Secchi data, a filtering procedure was developed to include only sites that had a sufficient number of Secchi depth samples; sites with >30 sampling events in FOCB_report_estuarine and with >50% of site samplings containing Secchi depth data, where the Secchi depth and water depth were not null. The resulting list of sites was then screened to remove sites that did not include a sufficient number of samples (≥80% of total samples collected) with a Secchi-depth to water-depth ratio of < 80%. This screening was conservative in an attempt to minimize bias from the Secchi depth measurements in the calculation of the Casco Bay Health Index (CBHI). This final filter resulted in a smaller set of "Secchi" stations than were used in the six-year report (40 vs. 50 sites), but still allowed for representative sampling across the bay.

Review of the fluorescence and nutrient data sets indicated that there were some suspiciously high values. Upon closer inspection, many of the high fluorescence values were measured at water depths of 0-1 meter. The YSI fluorometer used by FOCB, similar to many other models, can have interference from ambient light when deployed too close to the surface. Because of the high values and the potential for near surface data to be suspect, only fluorescence values from depths ≥ 1 m were used to calculate the average monthly mean values, which were then loaded into FOCB_report_estuarine_monthly_means and used for analyses.

There were also nutrient data that were deemed suspect based on combination of the magnitude of the values and comparison to coincident values for other nutrients or to nutrient values at other depths within a profile. Although these values were examined on a per sample basis, further review indicated that the majority of suspect samples fell into ranges of concentrations (individual values are presented in Appendix C for reference). The ranges used for filtering the data were >20 µM for NO_3+NO_2, >25 µM for NH_4, >30 µM for SiO_4, and >4 µM for PO_4 (34, 39, 4, and 3 values filtered, respectively out of 1,341 samples analyzed). These values occurred sporadically both spatially and temporally and there were no clear trends at to when or where they occurred. Although a more detailed examination of these outlier values may be warranted at some of the sites, it is beyond the scope of this report that is focused on larger baywide trends over a 12-year time period. To account for the high frequency sampling at the SMT50 site, the monthly means for each site and nutrient were calculated and loaded in nutrient_monthly_means.

Once the database tables were finalized, a suite of queries was developed to group data spatially, temporally, and by parameter. The data from these queries and the database tables mentioned above were used for the data analyses that are presented in the following section.

2.3 Data Analysis

Preliminary analysis entailed developing summary statistics and graphical presentations of the data from all stations. The summary statistics included overall mean, minimum and maximum values, and other univariate statistics for each parameter of interest (temperature, salinity, pH, Secchi depth, DO concentration and % saturation, chlorophyll, and the dissolved inorganic nutrient concentrations). Frequency plots were produced to describe the overall data distribution, and parameter vs. parameter scatter plots were used to evaluate potential linkages in the system. GIS maps and contour plots (Surfer) were also produced to depict the spatial distribution of seasonal and annual mean values of each of these parameters. Contour maps depicting Casco Bay Health Indices were also developed to highlight areas of concern.

Sites were grouped based on the findings of the six-year data review (Battelle 2001). That report highlighted inshore to offshore and other geographic trends in the data. It was determined that groupings based on geographic basins provide the best prospect for identifying areas of concern and understanding the potential causes of problematic conditions. Each of the water bodies was evaluated by the same set of statistical tools used for the complete data set. Relationships between parameters and water bodies were examined utilizing parametric (ANOVA) comparison of difference tests and associated planned comparison tests (Tukey's Studentized Range; Sokal and Rohlf, 1981). Log and natural log transformations of the data were evaluated, but did not provide any improvement of the variance associated with the raw data. Therefore, untransformed data were used for the planned comparison tests on DO, % saturation, temperature, salinity, and pH data by water body. Differences between groups were evaluated at the 95% significance level. Results of the parametric comparison tests are useful for ranking a comparative evaluation of the FOCB CWQM water bodies in Casco Bay.

To characterize temporal trends in the data, time series plots were produced to evaluate how parameters varied over the entire twelve-year period and seasonally (using monthly means). The time series plots were developed for a range of geographic scales – sites, water bodies, and baywide. At the profile stations, time series plots focused on variations in bottom and surface waters over time. The time series graphics are presented for selected sites and water bodies based on those selected for the six-year report. These sites were chosen because they are areas of concern, of public interest, or possible 'reference' locations.

Table 1. Site Locations for FOCB Water Quality Monitoring

Site Name	Site Number	Water Body Name	Water Body Code	Town	Water Class
Anthoine Creek	ANT01	Portland Harbor	PH	South Portland	SC
B&M Railroad Trestle	BMR02	Portland Coast	PC	Portland	SC
Bartol Island Causeway	BAR48	Harraseeket River	HR	Freeport	SB
Bear Island[1]	P4BRI	Eastern Coast	EC	Phippsburg	SB
Ben Island	BEN03	Quahog Bay	QB	Harpswell	SB
Bethel Point	BTH04	Quahog Bay	QB	Harpswell	SB
Birch Point (East of)	BIR05	New Meadows River	NMR	West Bath	SB
Boat Cove, Cliff Island	CLF71	Western Bay	WB	Portland	SB
Broad Cove, Cumberland	BCC06	Foresides	FS	Cumberland	SB
Broad Sound[1]	P5BSD	Eastern Bay	EB	Cumberland	SB
Cape Small Harbor[2]	CSH07	Eastern Coast	EC	Phippsburg	SB
Cat Cove, West Point	CAT69	Eastern Coast	EC	Phippsburg	SB
Channel Crossing	CHX09	Portland Harbor	PH	South Portland	SC
Chebeague Island, Johnson Cove	CIJ72	Western Bay	WB	Cumberland	SB
Chebeague Island	CHB10	Western Bay	WB	Cumberland	SB
Clapboard Island	CLP11	Western Bay	WB	Falmouth	SB
Clapboard Island[1]	P7CBI	Western Bay	WB	Falmouth	SB
Clark Cove	CLK12	Harpswell Sound	HS	Harpswell	SB
Cliff Island Public Landing	CLF13	Western Bay	WB	Portland	SB
CMP Dock	CMP61	Western Bay	WB	Yarmouth	SB
Cousins River, Muddy Rudder	CRV63	Royal River	RR	Yarmouth	SB
Cushing Island	CUS14	Western Bay	WB	Portland	SB
Custom House Wharf	CST15	Portland Harbor	PH	Portland	SC
Diamond Cove, Great Diamond Island	GRD21	Western Bay	WB	Portland	SB
Dyer Cove, Cape Elizabeth	DYR16	Cape Elizabeth	CE	Cape Elizabeth	SB
Dyers Cove, Quahog Bay	DYQ17	Quahog Bay	QB	Harpswell	SB
East End Beach	EEB18	Portland Coast	PC	Portland	SC
Ewin Narrows	EWN77	Harpswell Sound	HS	N. Harpswell	SB
Fort Gorges[1]	P6FGG	Portland Coast	PC	Portland	SC
Googins Ledge	GGL20	Eastern Bay	EB	Freeport	SB
Goslings	GOS19	Eastern Bay	EB	Harpswell	SB
Gun Point	GUN65	Quahog Bay	QB	Harpswell	SB
Halfway Rock[1]	P2HWR	Offshore	OFF	Harpswell	SA
High Head Yacht Club[2]	HHY22	Harpswell Sound	HS	Harpswell	SB
Indian Rest	IND66	New Meadows River	NMR	Harpswell	SB
International Ferry Terminal[2]	INT23	Portland Harbor	PH	Portland	SC
Jordan Point, Harpswell	JOR24	Middle Bay	MB	Harpswell	SB
Little Bustins Island[1]	P8LBI	Eastern Bay	EB	Freeport	SB
Little Chebeague	LCH25	Western Bay	WB	Portland	SB
Little Diamond Island	LTD60	Western Bay	WB	Portland	SB[3]
Little Flying Point	LFP26	Maquoit Bay	MQ	Freeport	SB
Little Flying Point[1]	P9LFP	Maquoit Bay	MQ	Freeport	SB
Little Iron Island[1]	P10LI	Middle Bay	MB	Harpswell	SB
Littlejohn Island	LJN27	Western Bay	WB	Yarmouth	SB
Long Island, New Meadows	LNM75	New Meadows River	NMR	Harpswell	SB
Lookout Point	LPT74	Middle Bay	MB	Harpswell	SB

Site Name	Site Number	Water Body Name	Water Body Code	Town	Water Class
Lowells Cove, Orrs Island	LWC28	Harpswell Sound	HS	Harpswell	SB
Mackerel Cove Bailey	MCV29	Harpswell Sound	HS	Harpswell	SB
Mackworth Causeway	MAC30	Foresides	FS	Falmouth	SC
Mackworth Stone Pier	MSP31	Foresides	FS	Falmouth	SB
Maquoit Bay, Haible	MQH32	Maquoit Bay	MQ	Brunswick	SB
Maquoit Bay, Wallace	MQW33	Maquoit Bay	MQ	Brunswick	SB
Marine East	MRE64	Portland Harbor	PH	South Portland	SC
Mill Cove, Harpswell[2]	MIL34	Harpswell Sound	HS	Harpswell	SB
New Meadows Causeway	NMC84	New Meadows River	NMR	Brunswick	SB
New Meadows Marina	NMM79	New Meadows River	NMR	Brunswick	SB
Orrs & Bailey Island Yacht Club	OBY35	Harpswell Sound	HS	Harpswell	SB
Peabbles Cove	PBL36	Cape Elizabeth	CE	Cape Elizabeth	SB
Peaks Island, Public Landing	PKP38	Western Bay	WB	Portland	SB[3]
Peaks Island, East	PKE37	Western Bay	WB	Portland	SB
Peaks Island, South	PKS39	Western Bay	WB	Portland	SB[3]
Pennellville, Middle Bay	PEN40	Middle Bay	MB	Brunswick	SB
Perry's Landing	PRY41	Quahog Bay	QB	Harpswell	SB
Phippsburg Town Pier	PTP76	Eastern Coast	EC	Phippsburg	SB
Pinkham Point, Quahog Bay	PKT42	Quahog Bay	QB	Harpswell	SB
Portland Headlight[2]	PTH59	Cape Elizabeth	CE	Cape Elizabeth	SB[3]
Portland Yacht Club	PYC43	Foresides	FS	Falmouth	SB
Portland Yacht Services	PYS44	Portland Harbor	PH	Portland	SC
Princes Point, Yarmouth	PPT45	Foresides	FS	Yarmouth	SB
Quahog Bay[1]	P11QB	Quahog Bay	QB	Harpswell	SB
Ram Island Ledge[1]	P1RIL	Offshore	OFF	Portland	SB
Royal River C5	RRC46	Royal River	RR	Yarmouth	SB
Royal Yankee Marina	RRY47	Royal River	RR	Yarmouth	SB
RT9 Presumpscot Bridge	PRV70	Presumpscot River	PR	Falmouth	SC
Seaborne, Yarmouth	SEA62	Foresides	FS	Yarmouth	SB
Seameadows	SEA73	Western Bay	WB	Yarmouth	SB
Sebasco Estates	SEB49	Eastern Coast	EC	Phippsburg	SB
Small Point[1]	P3SMP	Offshore	OFF	Phippsburg	SB
SMCC Pier	SMT50	Portland Coast	PC	South Portland	SC
South Freeport Town Landing	SFP51	Harraseeket River	HR	Freeport	SB
Stockbridge Point	STK52	Harraseeket River	HR	Freeport	SB
Stovers Point	STV53	Harpswell Sound	HS	Harpswell	SB
Stroudwater Bridge	STR54	Portland Harbor	PH	Portland	SC
The Basin	BAS68	New Meadows River	NMR	Phippsburg	SB
Two Lights, Cape Elizabeth	TWO55	Cape Elizabeth	CE	Cape Elizabeth	SB
Waites Landing	WAI56	Foresides	FS	Falmouth	SB
Whartons Point	WPT78	Maquoit Bay	MQ	Brunswick	SB
Willard Beach	WIL57	Portland Coast	PC	South Portland	SB[3]
Winter Point	WIN82	New Meadows River	NMR	West Bath	SB
Wolf Neck State Park	WLF58	Eastern Bay	EB	Freeport	SB
York Landing, Falmouth	YOL66	Foresides	FS	Falmouth	SB

[1]The 11 profile sites; sampled year-round.
[2]These five surface sites are also sampled year-round.
[3]These five sites were reclassified from SC to SB waters based on FOCB data.

3.0 Results and Discussion

The data fall into two general categories based on sampling protocols. The first includes all surface data (shore-based and profile stations). The second includes only profile station data (all depths). Although the two sets are evaluated separately to account for the effect of sampling depth, the results section is organized to present an overview of all of the data, spatial distribution and trends, temporal cycles and trends (including examination of baseline approaches), and finally an evaluation of Casco Bay Health Indices.

3.1 Overview

The summary statistics for all estuarine surface, profile, and nutrient data are presented in Tables 2, 3, and 4. The minimum and maximum values for each of the parameters provide a good representation of the variability between stations, across the bay, and over time.

The shallowest water depth was measured in Anthoine Creek and the deepest depth was consistently measured at Halfway Rock. The coolest temperatures were measured at the sites that are sampled year-round, while the warmest single water temperature was found at the Cousins River site in front of the Muddy Rudder Restaurant during the summer of 1995. During the summer, overall, the warmest waters were consistently observed at the Presumpscot River site, but for swimming Wolf Neck State Park offered some of the most inviting waters with an August mean temperature of 20°C (68°F). For a refreshing swim try Willard Beach, which had one of the lower August mean temperatures at 16.5°C (62°F). The lowest pH and salinity values were obtained at sites at the mouths of the Royal and Presumpscot Rivers. The lowest DO concentrations and percent saturation measurements were made at Peabbles Cove where low DO levels are associated with the decomposition of seaweed that naturally accumulates in that location due to ocean currents and are not related to anthropogenic influences (FOCB, 1996a). Sites near Custom House Wharf and in the upper New Meadows River also consistently had some of the lowest DO levels and these low levels are likely associated with point or non-point source nutrient inputs and associated eutrophication effects or restricted circulation. Secchi depth, a measure of water clarity, was at a minimum at a number of shallow, inshore sites while the clearest water was found at Halfway Rock.

Table 2. Summary Statistics for All Estuarine Surface Data

	Water Depth (m)	Temp (°C)	Salinity (ppt)	DO (mg/l)	DO (% saturation)	pH	Secchi Depth* (m)
Mean	7.25	12.95	29.02	9.20	103.5	7.94	2.98
SD	7.68	5.36	4.48	1.48	12.1	0.19	1.42
Range	54.9	33.0	34.0	12.3	143.6	2.7	15.1
Minimum	0.1	-3.0	0.0	2.6	33.9	6.0	0.2
Maximum	55.0	30.0	34.0	14.9	177.5	8.7	15.3
Count	7022	8408	8322	8214	8126	7966	3808

*Secchi depth summary statistics calculated from 40 selected sites.

At the profile stations, the range of *in situ* values was smaller and the means more typical of offshore marine waters (Table 3). The coldest temperatures were measured during January and February primarily in the surface waters at the inshore profile stations in Middle, Maquoit, and Quahog Bays (P9LFP, P10LI, and P11QB) and nearby station P8LBI. These same areas also exhibited most of the warmest temperatures during the summers as the offshore station temperatures are moderated during both winter and summer by mixing and influence of regional water masses. The lowest salinities were observed at profile stations most highly influenced by riverine inputs and surface run off – P6FGG off of Portland Harbor, P7CBI off of Falmouth and located between the Royal and Presumpscot Rivers, and P3SMP south of Phippsburg. The highest salinity was seen in the deep offshore waters near Halfway Rock (P2HWR), in the center of the bay (P5BSD), and south of Phippsburg (P3SMP). The surface waters at station P3SMP are often influenced by freshwater flow out of the Kennebec River, but this site also consistently displays values consistent with deep offshore waters from the Gulf of Maine.

Table 3. Summary Statistics for All Profile Data

	Temp (°C)	Salinity (ppt)	DO (mg/l)	DO (% saturation)	pH	Chlorophyll (μg/l)
Mean	9.91	30.40	9.55	101.7	8.01	5.9
SD	4.58	1.38	1.47	10.9	0.15	6.8
Range	24.9	26.7	9.8	85.8	1.1	116
Minimum	-1.6	6.2	4.9	57.7	7.4	0.0
Maximum	23.3	32.9	14.7	143.5	8.5	116
Count	15,926	15,842	15,639	15,553	3668	2646

The high and low pH values do not exhibit any clear spatial trends, but rather seasonal ones with the highest pH values occurring in the winter/spring and lowest in the late summer and fall. Although there may be an influence by freshwater during the freshet, it was overshadowed by the effect of biological production and respiration. Biological production utilizes dissolved carbon dioxide (CO_2) from seawater, while respiration releases CO_2 back into the water. These changes in CO_2 in turn lead to changes in the carbonate buffering system and pH in seawater. Decreases in dissolved CO_2 concentrations (production) push the chemical equilibrium towards higher pH as the buffering system removes H^+. In the winter/spring when phytoplankton production is high and low temperatures inhibit respiration, pH increases. In the fall when respiration increases, pH values tended to decrease (especially in the bottom waters).

The lowest DO levels (concentration and percent saturation) for the profile stations were consistently observed in the bottom water in Quahog Bay. All DO concentrations of <6 mg/l and nearly all of the percent saturation measurements of <70% were found at station P11QB. These low values were measured in late July through September at this inshore station. Low DO levels were also measured in the deep bottom waters at station P2HWR (6 to 6.5 mg/l and the only other values ≤70%). The low DO levels at this and other offshore stations tended to occur later in September and October. High DO concentrations and percent saturation values tended to be found in the surface waters across most of the stations. High DO concentrations occurred both in the winter when mixing tends to be vigorous and biological activity at a minimum and during the spring and fall periods when phytoplankton blooms occur and primary production is at a maximum. Percent saturation was also high during the spring and fall, but due to the low temperatures in the winter, the values tend to be moderate and only somewhat supersaturated.

Chlorophyll and dissolved inorganic nutrient measurements were added to the FOCB monitoring program in 2001 offering additional information on water quality conditions and factors that may be influencing DO concentrations. Although there were significant decreases in fluorescence from inshore to offshore profile stations, temporal trends account for most of the variability with the highest fluorescence values measured during the winter/spring phytoplankton blooms in 2003 and 2004 (Table 3). Dissolved inorganic nutrients are crucial ingredients in the biogeochemical functioning of an estuarine system. However, high anthropogenic nutrient inputs can drive a system towards eutrophication with elevated biomass, organic material, and eventually lower bottom water dissolved oxygen levels or even hypoxic conditions. The mean nutrient concentrations in Table 4 are typical of northeastern coastal waters, but the maxima suggest anthropogenic and riverine inputs (Libby *et al*. 2004). Although high nutrient concentrations were measured at various times at each station, the sites off the dock at Southern Maine Community College and near Fort Gorges were consistently higher in relation to the other stations. Profile station P3SMP, located offshore south of Phippsburg, is often elevated in silicate due to the influence of the Kennebec River at this station.

Table 4. Summary Statistics for All Nutrient Data 2001-2004

	NO_3+NO_2 (μM)	NH_4 (μM)	SiO_4 (μM)	PO_4 (μM)
Mean	2.57	2.60	6.97	0.95
SD	3.15	3.29	4.89	0.56
Minimum	0.0	0.0	0.0	0.0
Maximum	16.65	23.98	30.32	3.23
Count	1307	1302	1337	1338

The frequency distribution of all estuarine surface measurements of DO concentration (n = 8,214) is presented in Figure 3. The State of Maine has established water quality standards for DO percent saturation. The standard for class SA waters (highest quality) is dissolved oxygen "as naturally occurs" and is not directly quantified. In Casco Bay, only the offshore waters near Halfway Rock are classified as SA. The DO percent saturation standards for class SB and SC (lowest quality) waters are 85% and 70%, respectively. Class SC waters are primarily located in the vicinity of Portland Harbor. Only 0.3% of the measurements were <5 mg/l (and just 1% were <6 mg/l) and 0.6% were <70%. The majority of these readings were found in Portland Harbor, upper New Meadows River, and Peabbles Cove. Percent saturation readings of <85% were measured at 74 different sites throughout the bay. This, combined with the fact that DO percent saturations of well below 85% (minimum of 68%) have been measured at station P2HWR, suggests that there may be other factors contributing to low DO percent saturation and concentration. This standard is conservative and may not be appropriate as it is a level that is well within the natural variability for these waters. As a matter of record, FOCB data were instrumental in the State reclassification of waters off Peaks and Little Diamond Islands, Two Lights in Cape Elizabeth, and Willard Beach from class SC to SB.

3.2 Spatial Trends

The 6-year report (Battelle 2001) indicated that there were clear geographic trends in the data and the data were evaluated on both a site by site basis and by comparing groups of stations from particular waterbodies. The data have been examined following similar approaches in this report both statistically (stepwise comparisons) and graphically. The statistical analysis focused on comparisons across waterbodies and individual sites. Data that were collected at all sites were grouped by waterbody for analysis and nutrient and fluorescence data were analyzed by site. The mean site data were also used to graphically evaluate spatial trends in the data across the bay. The data were contoured using Surfer software and presented with GIS layers obtained from the Maine Office of Geographic Information Systems and NOAA.

Statistical tests were conducted to determine if differences in parameters between waterbodies were significant. ANOVA tests for each parameter indicated that there were significant differences across the 16 waterbodies ($P<0.001$). Tukey's Studentized Range comparison tests were run to test each waterbody against one another for each parameter during the summer (July-September) and the results are presented in Figures 4, 5, and 6. Although numerous comparisons were conducted, the results have been simplified for presentation by ranking the water bodies by mean values and then connecting groups of water bodies that were not significantly different from one another (in respect to the parameter considered) under the different comparisons. Due to the relatively small range of differences in the means, the results of the comparisons indicate a great deal of overlap among water bodies.

There were clear differences across the bay with regards to temperature (Figure 4). The coolest waters during the summer months were found in Cape Elizabeth (15.4°C), which were significantly cooler than waters in all the other waterbodies except the offshore sites. The waters at the Presumpscot River station were almost 7°C warmer than all Cape Elizabeth stations and significantly warmer than waters in all of the other waterbodies. The other waterbodies tended to group geographically. Cooler waters were found along the exposed coastlines of southern Casco Bay - Cape Elizabeth, Offshore, Portland Coast, and Western Bay – all of which had temperatures that were significantly lower than everywhere else except Eastern Coast sites. The Eastern Coast grouped with waters in Portland Harbor, Harpswell Sound, and Eastern Bay with summer mean temperatures of 17.2-17.6°C. The waters in the embayments to the east in Brunswick were about a degree or two warmer (18.2 to 19.8) and the difference was significant. The sites along the Foresides and Harraseeket River overlapped with both of these groups. The primary driver for summer surface temperatures was proximity to shallow embayments with limited mixing (warmer) and offshore, Gulf of Maine waters (cooler).

Both the salinity and pH comparisons were closely tied to sources of freshwater (Figure 5). The Presumpscot River sites had the lowest mean summer salinity (3.10 ppt). Salinity at the Royal River sites was more than 20 ppt higher, but still significantly lower than all other sites as was Portland Harbor. The nearby sites along the Portland Coast and Foresides areas, which also receive input via these rivers, although significantly higher than the previous three sites had mean salinities of <30 ppt. The only other waterbody with a mean summer salinity of <30 ppt was the Offshore area. This was due to the influence of the Kennebec River particularly at site P3SMP and reflects the surface sample only. The rest of the waterbodies had mean salinity of ≥30 ppt with no significant differences among them. The pH mean values exhibited similar rankings as seen with salinity, but there are a few deviations that are notable. The three water bodies most directly influenced by freshwater continued to have the lowest mean values with Presumpscot River being significantly lower than all other waterbodies and Portland Harbor significantly lower than all others except Royal River. There are three waterbodies that dropped in ranking (pH relative to salinity) – Harraseeket and New Meadows Rivers and Quahog Bay. This suggests that other factors may be contributing to the lower pH in these waters in comparison to some of the other high salinity/high pH waterbodies. It may be linked to elevated rates of respiration in the waters, as is also suggested by the low DO concentrations seen in each of these areas (Figure 6).

The lowest mean DO concentration was found in Harraseeket River (7.56 mg/l). This was a change from the findings in the 6-year report that had the lowest value in Portland Harbor. The harbor was still part of a group of five water bodies with mean DO concentrations of <8.0 mg/l (Harraseeket River, Portland Harbor, New Meadows River, Royal River, and Quahog Bay). These five waterbodies are not significantly different from one another, but are significantly lower than nine of the other waterbody means (Figure 6). The other two waterbodies that were not significantly different were Maquoit Bay and Presumpscot River, which had summer mean values of only slightly higher than 8 mg/l. There was considerable overlap for the waterbodies with mean summer DO concentrations of 8 to 8.6 mg/l. The highest mean DO concentration was observed in the Offshore waters (9.09 mg/l), which was significantly higher than all but the Eastern Coast value.

The ranking and comparison groupings of water bodies for mean percent saturation were similar to those observed for DO concentration (Figure 6). Four of the five waterbodies that had DO concentrations of <8 mg/l also had mean percent saturation <100%. The Presumpscot River was the fifth waterbody below 100% and had the lowest percent saturation (93.4%). Presumpscot, Harraseeket and Royal Rivers, and Portland Harbor were significantly lower than all other water bodies except New Meadows River and Quahog Bay and were not significantly different from each other. The New Meadows River was slightly undersaturated with respect to DO (98.9%) and Quahog Bay was slightly oversaturated (100.7%). The other 10 water bodies had mean percent saturation of >100% and fell into overlapping groups.

The same statistical approach was used to examine differences between sites where *in situ* fluorescence and nutrients were collected. Given the interannual and seasonal variability and the limited number of samples available (only measured since 2001), there were not many significant differences between the sites. The ranking of the sites by mean values, however, indicated particular trends in the data (Table 5).

Table 5. Site Mean for Chlorophyll (profile average) and Nutrient (surface) Data in Ranked Order

Chlorophyll (μg/l)		NO_3+NO_2 (μM)		NH_4 (μM)		SiO_4 (μM)	
Site	**Mean**	**Site**	**Mean**	**Site**	**Mean**	**Site**	**Mean**
P9LFP	9.75	SMCC	3.40	SMCC	3.58	SMCC	9.28
P7CBI	9.07	P5BSD	3.32	P5BSD	3.31	P3SMP	8.65
P10LI	8.60	P6FGG	3.28	P1RIL	2.85	P6FGG	8.18
P6FGG	7.92	P1RIL	2.75	P6FGG	2.62	P1RIL	6.59
P11QB	6.55	P3SMP	2.74	P7CBI	1.90	P7CBI	6.43
P5BSD	5.14	P2HWR	2.15	P11QB	1.66	P4BRI	6.05
P4BRI	4.76	P4BRI	1.78	P10LI	1.62	P5BSD	5.89
P2HWR	4.60	P7CBI	1.74	P3SMP	1.60	P10LI	5.42
P3SMP	4.57	P11QB	1.37	P4BRI	1.34	P2HWR	5.33
P1RIL	4.44	P9LFP	1.00	P9LFP	1.23	P9LFP	4.63
		P10LI	0.74	P2HWR	0.85	P11QB	4.48

There was a clear inshore to offshore decrease in annual mean chlorophyll levels. The highest value (9.75 μg/l) was in Maquoit Bay and the lowest was off of Cape Elizabeth (4.44 μg/l). There was a significant difference between the high values in Maquoit Bay and Foreside sites (P9LFP and P7CBI) compared to the more offshore influenced sites – P5BSD, P4BRI, P2HWR, P3SMP, and P1RIL. The highest annual mean nutrient concentration was observed off the SMCC dock site in Portland Harbor. This site had the highest annual mean NO_3+NO_2, NH_4, SiO_4, and PO_4 (Table 5). Concentrations off of SMCC were significantly higher than in Maquoit Bay (P9LFP) for all nutrient parameters. The relatively low nutrients, but high chlorophyll annual means, may indicate that nutrient inputs and primary production are tightly coupled in Maquoit Bay. Ammonium and nitrate+nitrite concentrations were also high at P5BSD mid bay, P6FGG in Portland Harbor, and P1RIL to the south of Portland Harbor. In fact, the annual mean NH_4 concentration at P5BSD (3.31 μM), in the middle of Casco Bay, was significantly higher than at P2HWR (0.85 μM) near Halfway Rock. The elevated levels of NH_4 and NO_3+NO_2 in the surface waters at site P5BSD suggests a nearby source that is anthropogenic or due to currents and upwelling or likely a combination of the two. Silicate concentrations were also elevated at P3SMP due to the Kennebec River influence and were significantly higher than concentrations in Maquoit and Quahog Bays. Overall, the nutrient trends suggest that Portland Harbor is a clear recipient of nutrients and elevated concentrations were consistently observed at the sites in the vicinity of the harbor.

Inshore to offshore patterns dominated nearly all of the spatial trends as evidenced in the contour plots that have been produced and examined for this 12-year report. Although telling, comparisons of these spatial representations on a year to year basis are often more useful for evaluating interannual variability than examining seasonal spatial patterns themselves. Collages of plots from multiple years are presented in Section 3.3, while in this section individual plots have been selected to demonstrate clear spatial patterns. As suggested earlier in the discussion of minimum and maximum temperatures, in the winter there was a clear inshore to offshore increase in surface water temperatures and in the summer this pattern is reversed (Figure 7). The 12-year summer average temperature shown in Figure 7 also suggests that the eastern half of the bay is generally warmer than the western half. The salinity plots over annual and seasonal intervals consistently showed areas of lower salinity near the primary riverine inputs to the bay and also lower salinity in eastern Casco Bay due to the influence of the Kennebec and other Maine rivers further to the east as seen in the 12-year average summer salinity in Figure 8. Secchi depth also exhibited a clear inshore to offshore pattern. There was an obvious increase in Secchi depth at the offshore sites where tidal/vertical mixing of the water column is less likely to increase turbidity (decrease Secchi depth) due to resuspension of sediments.

As had been seen with the 6-year data report, the distribution of mean DO and mean percent saturation showed groupings of generally similar sites within geographic basins or areas of the bay (Figures 9 & 10). Both were relatively low in Portland Harbor, Royal and Cousins Rivers, Harraseeket River, and in the upper reaches of a number of embayments in Eastern Casco Bay. Contour plots of summer bottom water DO concentrations at the profile stations show relatively high values over all but Quahog Bay (Figure11). The data set for the Quahog Bay site is limited to only the five years since it was first sampled in 2000 in comparison to the other stations that have been sampled since 1993, but the stark contrast in bottom water DO levels indicates the importance of adding a profile station at this location.

Generally, the distribution of DO concentration and percent saturation site means suggest that water quality with respect to DO is consistently good, but averaging over 12 years and the three summer months may obscure some of the critical aspects of the DO pattern. To examine waters with a propensity for low DO levels, the monthly mean DO minimum concentrations from each of the sites were examined (Figure 12). Three general areas are highlighted in this figure – Portland Harbor; vicinity of the Presumpscot, Royal and Cousins Rivers; and the smaller embayments in eastern Casco Bay including Harraseeket River, Maquoit and Quahog Bays, and the upper New Meadows River. A similar distribution had been observed in the 6-year examination and the cause of these low DO minima was attributed to elevated nutrient loading either directly from point sources or indirectly from riverine and other non-point sources and restricted circulation. The elevated nutrient loading would enhance levels of primary production and in turn provide an additional source of organic material to fuel respiration and utilize dissolved oxygen as temperatures increased over the summer and into the fall. The low DO conditions could be exacerbated in waters with restricted circulation that are unable to mix with more oxygenated waters further offshore. Physical oceanographic studies (Edward Laine, Bowdoin College, Pers. Comm.) have indicated that the waters in Quahog Bay are generally restricted and essentially remain within the bay on a timescale of weeks in the summer.

To look at differences between the two 6-year periods, DO minimum figures are presented for 1993-1998 and 1999-2004 in Figure 13. There appears to have been improvement with regards to DO minimum comparing the first 6-year period to the second. There were some decreases in monthly mean DO minimum over this time period such as the measurement of low DO concentrations (≤5.5 mg/l) at the Mackworth Causeway and Seameadows sites in July 2000 and September 2001, respectively. Low DO concentrations (≤5.5 mg/l) also continued to be measured for the 1999-2004 period at Peabbles Cove, Custom House Wharf and Whartons Point in upper Maquoit Bay. These sites have consistently had low DO minima over the 12-year period. Results were mixed in Portland Harbor with decreases in the DO minimum at the Stroudwater Bridge and International Ferry Terminal sites and an increase at the Channel Crossing site. Increases in the monthly mean DO minimum values were also seen in the Presumpscot River and off of Yarmouth, but the most dramatic and consistent trend of increasing DO minima was observed in the embayments in the eastern portion of Casco Bay including Harraseeket River, Maquoit Bay, Harpswell Sound, Quahog Bay, and New Meadows River (Figure 13). FOCB has cited removal of overboard discharge systems and improvements to septic systems (private and municipal) as a possible mechanism for the increasing DO minima in these eastern Casco Bay embayments. This management action was undertaken to improve and open clam flats in the area, but may have also led to improved water quality. The implementation of best management practices at marinas through the clean marina program may also have contributed to improved water quality in the bay.

Since 2001, the FOCB study has measured ambient chlorophyll and nutrient levels with which to evaluate the nutrient loading and phytoplankton productivity factors contributing to the areas of low DO levels in Casco Bay. The review of summary statistics indicated that nutrient levels are highest in the vicinity of Portland Harbor, but that elevated levels were also observed in areas farther afield. Figures 14, 15, and 16 show the seasonal mean surface nutrient concentrations for all of the sites where nutrient data were collected (profile stations and SMCC dock). Figure 17 depicts the seasonal mean chlorophyll averaged over the entire water column at each profile site.

The NO_3+NO_2 data followed typical seasonal trends for coastal waters in the Northeast (for example see Libby *et al*. 2004). The nearshore surface waters were depleted with respects to NO_3+NO_2 in the winter months, remained depleted in the spring and summer, before increasing in the fall (Figure 14). Although well-mixed in the winter, nutrient concentrations in these shallow inshore waters tended to be utilized rapidly during the winter/spring bloom that often exhibited an inshore to offshore decrease in intensity (Figure 17). Levels remained low during the spring and summer under stratified conditions. In the fall, stratification broke down due to a combination of cooling surface waters and increased mixing from storm events and nutrient levels increased over much of the bay. Elevated NO_3+NO_2 concentrations were seen further offshore in the winter, but even these offshore surface waters are depleted of NO_3+NO_2 by the spring and in the summer. In the fall, western Casco Bay tended to have higher concentrations of NO_3+NO_2 than the eastern embayments and offshore waters. The sites in Maquoit and Middle Bays seem to have low NO_3+NO_2 concentrations (0-2) over all four seasons. This is not to say that nutrients are not getting into these embayments, but that the nutrients are being utilized quickly as suggested by the elevated fluorescence values in these two embayments over all four seasons.

Silicate shows similar inshore to offshore increases in concentration in the winter and spring (Figure 15), but the levels are not as low as observed for NO_3+NO_2 except in Maquoit and Middle Bays. The low SiO_4 surface water concentrations in these bays suggest that for the last few years (nutrients have been measured since 2001) the winter/spring phytoplankton community in these waters was dominated by diatoms, as is often the case in Gulf of Maine waters. Diatoms utilize SiO_4 and NO_3+NO_2 in an approximate 1:1 ratio compared to other species of phytoplankton that have only limited nutritional SiO_4 requirements. In the spring, SiO_4 concentrations increased or remained the same over most of the sites. The input to the system due to the spring freshet is indicated by the high SiO_4 concentrations observed at P3SMP. The timing and the influence of the riverine inputs can be seen in Figure 18 that shows the daily mean flow for the Kennebec and Royal Rivers. In the summer, SiO_4 levels were lowest farther offshore, as seen for NO_3+NO_2, where the water column was more strongly stratified. By fall, SiO_4 concentrations generally decreased, but most notably at the Maquoit and Middle Bay sites, suggesting that the fall bloom at these sites was also dominated by diatoms.

The distribution of surface water NH_4 concentrations was different than seen for NO_3+NO_2 and SiO_4 during each of the seasons (Figure 16). In general, NH_4 levels are typically lower than NO_3+NO_2 and SiO_4 in Gulf of Maine waters. Elevated NH_4 concentrations can be associated with both natural and anthropogenic sources. Ammonium is rapidly utilized and recycled within the marine ecosystem and only increases in concentration under heterotrophic conditions when respiration/remineralization outpaces production/utilization. This often occurs in deeper bottom waters under stratified conditions. Ammonium is also used as a tracer of anthropogenic inputs. For instance, in Massachusetts Bay, NH_4 concentrations in the vicinity of the MWRA outfall have been used as a tracer to delineate the distribution of the effluent plume both vertically and horizontally. Elevated NH_4 concentrations (2-4 µM) were consistently seen over all four seasons in the Portland Harbor area and also at site P5BSD in the middle of Casco Bay. The overall surface water mean NH_4 concentration at P5BSD was second only to the SMCC dock site (Table 5) and was four times higher than the levels at P2HWR (3.31 vs. 0.85 µM). Although farther inshore than P2HWR, one might expect the two sites to have similar surface water NH_4 concentrations due to their proximity to the open ocean. This dramatic difference suggests a localized source of NH_4 as the surface and bottom water DO concentrations do not indicate an area of increased respiration (see Figures 9 and 11). The apparently elevated NH_4 concentrations in Harpswell Sound are a derivative of the contouring program due to the high levels measured at P3SMP.

Chlorophyll values showed a clear inshore to offshore trend of decreasing magnitude during each season (Figure 17). Winter and spring concentrations tended to be higher than summer and fall. The highest concentrations were consistently measured in Maquoit Bay with elevated levels also found off Falmouth and in Middle Bay.

3.3 Temporal Trends

The contour plots presented in Figures 14, 15, 16, and 17 suggest clear seasonal trends in the distribution, gradients, and magnitude of nutrient and chlorophyll concentrations in Casco Bay. An examination of the monthly means of these parameters conveys the temporal trends in more detail (Figure 19). Maximum monthly mean concentrations are consistently observed in November, December and January for each of the nutrient parameters. This is a period when the water column is well mixed and biological utilization is at a minimum as suggested by the lowest mean chlorophyll level in December. There is a steady decrease in NO_3+NO_2 from January to May. This is coincident with decreasing PO_4 and a sharp decrease in SiO_4 from January to February. Chlorophyll, however, increases dramatically from January to March/April from a monthly mean of ~5 µg/l to >12 µg/l at the profile sites. The increase in SiO_4 from February (<6 µM) to April (almost 10µM) likely occurs due to both direct and indirect factors. The spring freshet is a source of freshwater and silicate to the system providing a direct input of this nutrient at higher ratios than nitrogenous nutrient species. Indirectly, the transition from an early winter diatom dominated bloom to a March/April *Phaeocystis*-dominated bloom may alter the utilization rate of SiO_4 vs. other nutrients as *Phaeocystis* have a much lower nutritional requirement for silica compared to the diatoms that have siliceous frustules. Although FOCB does not collect phytoplankton data as part of their monitoring efforts, regional *Phaeocystis* blooms have been observed annually in Gulf of Maine waters from 2000 to 2004 (Libby *et al*. 2005). In October 2003, Dr. Gregory Teegarden from Saint Josephs College and his students started collecting phytoplankton samples at the profile stations. The data are being worked up by students at this time and no quantitative results are available. The identification of species is based upon specific student projects and areas of interest, but it is expected that in the future additional emphasis will be placed on toxic and nuisance species such as *Alexandrium* and *Phaeocystis*.

In the summer, nutrient and chlorophyll concentrations were generally low and consistent (Figure 19). The main exception to this is the elevated NH_4 concentrations in June as regeneration of this nutrient and degradation of the organic material from the spring bloom occurs. There is a slight increase in chlorophyll and decrease in nutrients in September that is associated with the fall phytoplankton bloom, but the main story in the fall is the remixing of the water column and subsequent increase in nutrient concentrations. The increased mixing and decreasing light availability in late fall and early winter also results in lower chlorophyll concentrations.

In addition to light, the seasonal biological cycle is subject to changes in water temperature. A plot of monthly mean temperature shows a trend we know all too well, with very cold water temperatures in the winter and steadily increasing temperatures from February minima to August maxima (Figure 20). The spatial gradients in temperature discussed previously are also suggested in this plot of monthly means with an inshore to offshore increase in temperatures in December and January and the opposite trend of decreasing temperatures offshore in the summer. The waters in Maquoit Bay, New Meadows River and Quahog Bay were a couple degrees warmer than the mean in July and August while the offshore waters were ~2°C cooler than the mean from April to September.

Water temperature affects phytoplankton production to some degree, but it has a more substantial effect on respiration rates. As the waters warm, respiration rates increase and DO levels tend to decrease. In bottom waters at the deeper sites, this decline in DO concentrations is further exacerbated by stratification that results from seasonal warming of surface waters. The seasonal trend in monthly mean DO concentrations is almost the inverse of the temperature pattern. DO concentrations are at a maximum in February and March when the water column is still well-mixed and primary production is high during the winter/spring phytoplankton bloom (Figure 21). As suggested in the seasonal contour plots of chlorophyll (see Figure 17), Maquoit Bay has very high fluorescence values in the winter and exhibits DO concentrations of more than 1 mg/l higher than the bay wide mean in January and February (Figure 21). From March to August there was a steady decline in surface water DO concentrations that was coincident with a corresponding increase in temperatures. Summer concentrations in the selected waterbodies in Portland Harbor and in the eastern portion of the bay (Maquoit Bay, New Meadows River, and Quahog Bay) were about 0.5 to 1.0 mg/l lower than overall mean. Offshore DO concentrations remained ~1.0 mg/l higher than the mean over most of the summer, but continued to decline into October when the monthly mean surface water minimum of 8.5 mg/L at the offshore sites was reached (Figure 21). From September/October to December, there was a steady increase in DO concentrations across all areas of the bay coincident with the fall bloom and onset of winter mixing.

As observed for the 6-year report, there were a number of differences between monthly trends in DO concentration and percent saturation, but there was a shift in the overall mean percent saturation trend towards a pattern more consistent with that observed for DO concentrations. DO maximum concentrations occurred somewhat earlier during the winter months (January-March) coincident with minimum temperatures than the percent saturation maximum, which was reached later in March and April. Overall surface waters in Casco Bay were undersaturated with respect to DO in January due to cold temperatures. Colder waters are able to maintain higher DO concentrations at 100% saturation and even limited utilization of DO during the winter leads to percent saturation values of less than 100%. In February and March, the elevated production during the phytoplankton blooms that may have been more prevalent in 1999-2004 than 1993-1998 led to high DO concentrations and percent saturation. DO percent saturation in Maquoit Bay was more than 5% higher than the mean for the entire winter period likely due to elevated chlorophyll and associated production that were observed there from 2001-2004.

Later in the spring, DO concentration decreases with increasing temperature. This can obfuscate the biological effect of continued primary production and production of DO. This biological production of DO, beyond the physical decrease in the amount of DO at saturation, results in an increase in percent saturation values and the persistent supersaturated conditions through early summer in many of the water bodies within Casco Bay. Levels were especially high in Maquoit Bay and Offshore (Figure 21). Surface waters at the offshore sites averaged percent saturation levels of ≥110% from May to August. In the fall and early winter, the opposite is the case. The increase in DO concentration is not on par with the decrease in temperatures because of the continued utilization of DO for respiration and degradation of organic material. A few trends of note at other selected waterbodies are that in Quahog Bay monthly mean percent saturation was not substantially different from the overall mean values until the fall when it was ~5% below the mean from September to November. In New Meadows River, there was a sharp decline in DO percent saturation from May to June and levels remained 5-10% below the overall mean from June through August. In Portland Harbor, DO percent saturation was 5 to 10% lower than the overall mean from January through November and undersaturated with respect to DO during all months except March to June (Figure 21).

A time series of monthly mean temperature and DO concentration (based on surface data from all estuarine sites) clearly shows the seasonality of these parameters, as well as their inverse relationship (Figure 22). Though there are small year-to-year variations in range, the cycle is relatively consistent. An examination of data for individual selected sites shows similar patterns, but also gives an indication of the variability of the cycle in different locations in Casco Bay. The New Meadows Marina site is consistently about 5°C warmer than the overall mean in the summer (Figure 23). Site P9LFP in Maquoit Bay is a few degrees warmer than the mean in the summer and cooler than the mean in the winter, which is the typical pattern for the more inshore sites (Figure 23). The site near Halfway Rock exhibits a much tighter range in temperatures with maximum and minimum values generally a few degrees cooler and warmer than the overall mean, respectively. The two sites in Portland Harbor (CST15 and P6FGG) are usually comparable to the overall mean temperature. The most glaring exception was in the summer of 1994 when the waters at Custom House Wharf were nearly 7°C cooler than the other sites and mean.

The anomalously low summer temperatures at CST15 in 1994 were coincident with low, yet somewhat typical for this site, DO concentrations of 5.5 to 7 mg/l (Figure 24). However, the presence of cooler than normal waters resulted in one of the lowest DO percent saturation values (55%) recorded over the 12-year program. The surface waters at CST15 consistently had annual minima below 6 mg/l from 1994 to 1999 with values below 5mg/l in both 1995 and 1998. Over this period, the DO percent saturation minima at CST15 was below the State standard for SC waters of 70% on four occasions and was likely lower in 1995 also, but no salinity data were available to calculate percent saturation. Thus for the six year period from 1994 to 1999, water quality at CST15 was below State standards for class SC waters. In the five years since 1999, DO concentration and percent saturation minima have increased at this Portland Harbor site and only been out of compliance with the standard once in 2003 (Figure 24). The New Meadows Marina site, sampled since 1996, has also consistently exhibited low DO concentration and percent saturation values. As seen for CST15, the NMM79 minima appear to be increasing over the last few years. However, unlike the site in the SC harbor waters this site is in class SB waters and has had DO percent saturation minima below the 85% State standard during all but one year (2003). The annual DO concentration minima at NMM79 are also below or close to 6 mg/l during most of the nine years it has been sampled.

The surface water DO concentrations and percent saturation for the overall mean at the three profile stations presented in Figure 24 (P2HWR, P6FGG, and P9LFP) are well above 6 mg/l and 85%. The three profile sites had consistently higher DO concentrations than the overall site mean during the winter months and higher DO percent saturation values than the mean during most of the year. Both P6FGG and P9LFP are located in areas that were shown to have relatively high chlorophyll concentrations during most of the year in 2001-2004 that contributed to the higher than average DO levels.

These three profile sites were also selected for the examination of trends in bottom water temperature, DO concentration, and DO percent saturation (Figure 25 and 26). The inshore to offshore gradients in temperature that have been discussed for surface water data are more clearly evident in the bottom water data at these three sites that not only cover three distinct areas of the bay, but also cover a range of stations depths from about 10 to 30 meters (Figure 25). In the winter, the bottom waters are generally 2-5°C cooler at P9LFP in Maquoit Bay than the deeper waters near Halfway Rock with the values near Fort Gorges usually midway between the two. In the summer, the opposite trend is observed with the bottom waters of Maquoit Bay being 5-8°C and near Fort Gorges 4-7°C warmer than at Halfway Rock. The temperature maximum is also reached about a month earlier at the two inshore sites compared to P2HWR. Also, the water column at these two sites begins mixing earlier than at P2HWR. This is shown by the decreasing temperatures at P6FGG and P9LFP that are concurrent with continued increasing temperatures at P2HWR (Figure 25).

DO minima were consistently observed in the bottom waters during August at the inshore site P9LFP in Maquoit Bay and in September to October at the deeper offshore site P2HWR near Halfway Rock (Figure 26). The Fort Gorges site tended to follow the September/October trend of the offshore site, but the DO minima were not as low. The inshore to offshore progression in annual bottom water DO minima is often observed in other regional waters (Libby *et al.* 2004). This is due to a combination of temperature and the timing of the breakdown of seasonal stratification. The shallower inshore waters are generally warmer and, accordingly, respiration rates are higher leading to a quicker decrease in bottom water DO concentrations in comparison to deeper offshore waters. Seasonal stratification breaks down earlier in the late summer or fall in the shallow inshore waters, as surface winds and waves are able to penetrate to the bottom waters more quickly. The relative degree of stratification at the profile sites was examined and showed a clear inshore to offshore increase in the strength of stratification. The take away message is that the offshore waters are more strongly stratified and are stratified over a longer period allowing deep bottom waters to remain isolated and respiration to draw down DO levels into October during many years.

Low bottom water DO values for each of the selected profile sites were observed during the summer/fall of 1994 (Figure 26). Evidence from other Gulf of Maine coastal waters indicates that this was a regional trend in low DO (Kelly and Turner, 1995). DO concentrations at the Maquoit Bay site were below 6 mg/l in 1994. This was the only time levels <6 mg/l were observed at these three profile sites. In most years, the lowest annual DO minimum was found in the bottom waters at the deep offshore site. Bottom water DO concentrations appear to be somewhat higher in 2000-2004 compared to 1992-1999 at some profile stations (e.g. P6FGG and P9LFP, Figure 26). However, DO levels at P2HWR are comparable and quite variable across both of these time periods suggesting that this trend may be limited to the inshore sites and shallower sites.

DO percent saturation in the bottom waters exhibited a more variable interannual signal, but there are some interesting trends in the data (Figure 26). The State standard for class SB waters is consistently exceeded each year at Halfway Rock even though this site is in SA waters. The percent saturation minima were well below 85% at Halfway Rock during 10 of the 12 years examined. In October 1998, values were <70% (SC standard) and in September 2002 the minimum value was 70.4% at Halfway Rock (no sampling was conducted in October 2002). At the other two selected profile sites, bottom water DO percent saturation was <85% in August 1994 at P9LFP and October 1994 at P6FGG. This was the only year in which percent saturation was below 85% at these sites in Maquoit Bay and Portland Harbor. The harbor is classified as SC waters (70% standard). The interannual trends in DO percent saturation suggest that exceedances of the 85% standard are often due to naturally occurring conditions.

Data from the GoMOOS C buoy, which is located a few miles to the south of Halfway Rock, shows that DO concentrations in these offshore waters may routinely reach levels of 6 mg/l and below. In 2004, DO concentrations at 20 m depth on the GoMOOS C buoy reached 6 mg/l by mid-September (Figure 27) and remained between 5-6 mg/l until early October. The sharp increase in October is due to servicing the mooring and changing out the sensors and suggests that the DO concentration data were not as low as indicated by the graphic. These data have not been post calibrated or post corrected. Thus, it is unclear what the actual DO concentrations were at this location. The trend is likely correct, though the relative magnitude of the concentrations may be off. The GoMOOS temperature and salinity data corroborates many of the trends discussed for the FOCB data (surface vs. deeper water offsets in temperature/salinity and stratification, etc.). It would be beneficial to FOCB if they could work more closely with GoMOOS to ensure that the DO data are calibrated/corrected and available for future comparisons.

Direct comparisons of FOCB bottom water DO data to MWRA data from comparable depths are presented in Figures 28 and 29. The class SA and SB DO standards for Massachusetts marine waters are an interval of 10% lower than the Maine class SB and SC DO percent saturation standards. Both the standards and the actual DO levels are higher in Casco Bay in comparison to the nearfield and Stellwagen Basin waters of Massachusetts Bay. However, the relative trends are the same – when levels are low in Massachusetts Bay (e.g. 1994 and 1999) they are low both inshore and offshore and they are low in Casco Bay (Figure 28). Over the last four and a half years, the bay outfall has been discharging secondarily treated effluent into the nearfield area of Massachusetts Bay (time period indicated on the plots). Note that the variability in DO levels (concentration and percent saturation) with higher values in 2001 and 2004 versus lower values in 2002 and 2003 is expressed in all three sets of data (Figures 28 and 29). These figures also present an example of how baseline approaches are used to assess the impact of an environmental management action in this case the diversion of the MWRA outfall from Boston Harbor to Massachusetts Bay. In this case, there has been no discernable change in bottom water DO levels between the baseline and post-diversion period (Libby *et al.* 2004).

In the 6-year report, interannual trends of increasing DO minima were observed in waters that were areas of concern such as Portland Harbor, Quahog Bay, and Maquoit Bay. The report noted that DO minima in these waters increased from 1993 to 1996 before decreasing in the summer of 1997. It was unclear if 1997 was a short deviation from an overall long-term trend of increasing DO minima in Casco Bay, or if the apparent trend was just part of the overall variability of the system. To examine the interannual trends for the 12-year dataset, the annual mean, minima, and maxima were calculated for each year and plotted in Figure 30. The trend line for each of the annual statistics has a positive slope and the regression for the minimum, mean, and maximum DO values have R^2 of 0.19, 0.41 and 0.40, respectively. The mean and maximum regressions are statistically significant (p value <0.05) and indicate that DO concentrations have been increasing over the course of the 12-year monitoring program. Although significant, the low R2 values suggest that there is substantial variability in the regression. This is certainly due to interannual variability and variability in sampling, but the trend does suggest a general increase in DO concentrations in Casco Bay.

Given that DO levels appear to be increasing and that trends in the DO data are somewhat different between the 6-year and 12-year analyses, it seems appropriate to compare these two 6-year datasets as an example of how the first six years (1993-1998) could serve as a baseline period compared to the last six years (1999-2004). Figure 31 shows the mean DO concentrations for April to October for both of the 6-year periods and the entire 12-year period. DO concentrations have increased in 13 of the 16 waterbodies decreasing only in Cape Elizabeth (0.2 mg/l), Maquoit Bay (slightly), and New Meadows River (~0.4 mg/l). To see if this was a consequence of changes in the sampling schema (i.e. changing from twice to once per month sampling, etc.), a similar comparison was examined for temperatures (Figure 32). The results of the comparison for temperature show that temperatures actually increased to varying degrees in all of the 16 areas. This suggests that changes in the sampling schema were not the cause of the increased DO levels and that the coincident increase in temperatures make the higher DO more compelling. Given that both DO concentrations and temperatures increased across most of Casco Bay, DO percent saturation values increased at 14 of 16 waterbodies with increases in six waterbodies of ≥5% (Portland Coast, Presumpscot River, Harraseeket River, Quahog Bay, Eastern Coast, and Offshore).

3.4 Casco Bay Health Index

The monitoring data have been used to develop the Casco Bay Health Index. The index is calculated based on DO percent saturation and the clarity of the water. Both of these parameters are strong indicators of water quality and the impacts of eutrophication. For each monitoring site, the summer means of these two parameters are scored based on their relative position between conservatively set low and high thresholds (65 to 95% and 0.5 to 3.5 m – The Casco Bay Health Index, 2005) using the following equations:

DO score = [ln(summer mean DO percent saturation)-ln(65)]/[ln(95)-ln(65)]

Secchi Score = [ln(summer mean Secchi depth)-ln(0.5)]/[ln(3.5)-ln(0.5)]

The mean of these two values is the final index score. By summarizing these environmental indicators into one score, sites can be ranked, areas of concern identified, and trends in water quality may become more apparent over time.

The index has been calculated on an annual basis as well as a 12-year average. The site index values based on the 12-year averages are presented in Table 6. On average, the lowest scores are found in Portland Harbor, in the vicinity of the Presumpscot and Royal Rivers, and in the restricted embayments in Northeastern Casco Bay (Figure 33). There is a clear inshore to offshore increase in the index with the highest scores consistently calculated for the site near Halfway Rock. This is due to both higher DO levels and greater water clarity the further removed from anthropogenic and riverine inputs. Year-to-year variability is evident in the distribution of the index as indicated by the plots for each of the years 1993-2004 in Figure 34. In 1994, low DO concentrations were observed at numerous locations along the northeastern coastline (e.g. Massachusetts Bay, Libby *et al.* 2004) and are depicted here as lower scores seen further offshore. In 2001, water quality was better throughout much of Casco Bay, though low scores were still seen at a few of the areas of concern. Note that most of the sites scores are ≥1 indicating that even when using relatively conservative low and high thresholds water quality appears to be good throughout most of Casco Bay.

Table 6. Casco Bay Health Index scores by site (ascending index values) based on the 12-year average DO and Secchi data.

Site Number	Water Body	Mean DO Percent Saturation	Mean Secchi Depth	DO Score	Secchi Score	Health Index (all)
PRV70	PR	94.3	1.06	0.98	0.39	0.68
STR54	PH	91.4	1.34	0.90	0.51	0.70
NMM79	NMR	89.6	1.48	0.85	0.56	0.70
RRY47	RR	94.8	1.15	0.99	0.43	0.71
CST15	PH	83.1	2.84	0.65	0.89	0.77
WIN82	NMR	94.0	1.51	0.97	0.57	0.77
SFP51	HR	93.1	1.71	0.95	0.63	0.79
MIL34	HS	96.5	1.49	1.04	0.56	0.80
RRC46	RR	97.7	1.60	1.07	0.60	0.83
SEA62	FS	99.9	1.57	1.13	0.59	0.86
HHY22	HS	97.1	1.91	1.06	0.69	0.87
PRY41	QB	98.7	1.82	1.10	0.66	0.88
MRE64	PH	95.6	2.16	1.02	0.75	0.88
IND66	NMR	103.0	1.54	1.21	0.58	0.89
BAS68	NMR	96.0	2.25	1.03	0.77	0.90
DYQ17	QB	99.2	2.14	1.11	0.75	0.93
BMR02	PC	98.6	2.30	1.10	0.78	0.94
CHX09	PH	98.5	2.35	1.10	0.80	0.95
BEN03	QB	99.9	2.25	1.13	0.77	0.95
STK52	HR	99.4	2.43	1.12	0.81	0.97
CSH07	EC	98.4	2.64	1.09	0.85	0.97

Site Number	Water Body	Mean DO Percent Saturation	Mean Secchi Depth	DO Score	Secchi Score	Health Index (all)
SMT50	PC	101.4	2.36	1.17	0.80	0.98
P8LBI	EB	103.4	2.29	1.22	0.78	1.00
INT23	PH	98.3	3.07	1.09	0.93	1.01
JOR24	MB	108.0	1.90	1.34	0.69	1.01
PYS44	PH	99.1	2.98	1.11	0.92	1.01
GGL20	EB	105.1	2.22	1.27	0.77	1.02
P10LI	MB	106.3	2.09	1.30	0.74	1.02
BTH04	QB	97.3	3.33	1.06	0.97	1.02
PKT42	QB	99.9	2.94	1.13	0.91	1.02
LNM75	NMR	107.5	2.05	1.33	0.73	1.03
MAC30	FS	106.2	2.25	1.29	0.77	1.03
LFP26	MQ	106.3	2.26	1.30	0.78	1.04
PYC43	FS	101.9	2.82	1.18	0.89	1.04
PKP38	WB	102.1	2.84	1.19	0.89	1.04
OBY35	HS	101.9	2.87	1.19	0.90	1.04
P6FGG	PC	104.0	2.68	1.24	0.86	1.05
P9LFP	MQ	107.5	2.37	1.33	0.80	1.06
CLP11	WB	100.4	3.58	1.15	1.01	1.08
STV53	HS	105.8	2.75	1.28	0.88	1.08
PPT45	FS	108.2	2.51	1.34	0.83	1.09
BIR05	NMR	108.6	2.47	1.35	0.82	1.09
WAI56	FS	109.9	2.34	1.38	0.79	1.09
CUS14	WB	102.5	3.49	1.20	1.00	1.10
GRD21	WB	103.4	3.52	1.22	1.00	1.11
GOS19	EB	109.4	2.66	1.37	0.86	1.12
LPT74	MB	110.0	2.70	1.39	0.87	1.13
CMP61	WB	111.1	2.67	1.41	0.86	1.14
GUN65	QB	106.7	3.33	1.31	0.97	1.14
P11QB	QB	114.3	2.55	1.49	0.84	1.16
P5BSD	EB	107.8	3.54	1.33	1.01	1.17
P7CBI	WB	111.1	3.11	1.41	0.94	1.18
SEB49	EC	110.1	3.26	1.39	0.96	1.18
CHB10	WB	112.4	2.94	1.44	0.91	1.18
LWC28	HS	105.0	4.19	1.26	1.09	1.18
P4BRI	EC	111.7	3.32	1.43	0.97	1.20
P1RIL	OFF	106.5	4.27	1.30	1.10	1.20
P3SMP	OFF	111.0	4.02	1.41	1.07	1.24
P2HWR	OFF	112.3	5.09	1.44	1.19	1.32

This is also suggested by qualitatively ranking and plotting the 12-year index scores for each of the surface water sites (Figure 35). The ranking system was developed by FOCB to clearly convey the degree of concern with regards to water quality at each site. This system converts the calculated index scores into percentages and then ranks them as Good (≥ 95), Fair (85-94), and Poor (< 85). Figure 35 highlights sites of concern in Portland Harbor, Presumpscot and Royal Rivers, Harraseeket River, Harpswell Sound, and New Meadows River. The spatial trends in this plot are similar to that conveyed by the contour in Figure 33.

A review of the index on an annual baywide basis indicates that on average the Casco Bay Health Index over the 12-year period remains within a range of 1±0.05 (Table 7). This suggests that water quality is generally good on average even though there are localized areas within the bay that are impacted as measured by this index.

Table 7. Annual mean values and index scores for data from all Secchi sites.

Year	DO Percent Saturation	Secchi Depth (m)	DO Score	Secchi Score	Health Index
1993	100.6	2.99	1.15	0.92	1.04
1994	98.1	2.65	1.08	0.86	0.97
1995	100.7	2.64	1.15	0.86	1.00
1996	102.8	2.53	1.21	0.83	1.02
1997	99.9	3.06	1.13	0.93	1.03
1998	101.7	2.53	1.18	0.83	1.01
1999	101.9	2.53	1.19	0.83	1.01
2000	100.4	2.52	1.14	0.83	0.99
2001	107.5	2.56	1.33	0.84	1.08
2002	102.5	2.35	1.20	0.79	1.00
2003	108.8	2.35	1.36	0.80	1.08
2004	104.4	2.52	1.25	0.83	1.04

A variety of approaches were explored for development of an index for the data collected at the profile sites. These sites not only provide data over the entire water column that can be used for the index, but since 2001 have had data collected for chlorophyll and nutrient concentrations. This allows for the inclusion of causal (nutrients) and primary response (phytoplankton biomass as measured by fluorescence) factors in the index. Three general scenarios were explored 1) depth specific indices, 2) site average based index, or 3) modified driver/response based index. The last appeared to be the most compelling and involved using an average measure of fluorescence (surface layer [1-10 m] or entire profile), Secchi depth, bottom water DO concentration or percent saturation, and a measure of nitrogen (dissolved inorganic nitrogen [DIN] or NH_4 and either surface or surface layer). The relative impact of the various approaches of using fluorescence and nitrogen data and for the temporal scale of the index were examined. Four of the scenarios that were deemed most applicable are presented in Table 8. The same general approach to calculating the surface water index was used for the profile index. For each parameter, a score is based on the relative position between conservatively set low and high thresholds and then the mean of the four values is the final index score for that site.

The fluorescence averaging that was selected was for the surface layer (1-10 m) with the thresholds set at 5 and 15 µg/l. Both bottom water DO concentration and percent saturation based scores are included in Table 8 using the same threshold as for the surface water index. Likewise the same range of values was used for scoring the Secchi depth data. The nutrient based score was calculated using both DIN and NH_4 with threshold values of 5-20 µM and 0.5-5 µM, respectively. These values are based on expected ranges for coastal waters plus possible inputs from anthropogenic sources. For example, the DIN value incorporates NO_3 concentrations of up to 5-10 µM that often occur in coastal waters plus any inputs of NO_3 and NH_4 from terrestrial and anthropogenic sources. The selection of the temporal range of data to include also took a similar driver/response approach using annual mean values for the nutrients, Secchi Depth, and fluorescence in order to capture all inputs and bloom events and the summertime bottom water DO values were used to best capture the DO minima.

Table 8. Overall mean index scores for 2001-2004 data from all profile sites under four different scenarios. They all include average Secchi depth and fluorescence averaged over 1-10 m. SAT10 = DO percent saturation and NH_4 averaged from 1-10 m; DO10 = DO concentration and NH_4 averaged from 1-10 m; DO2 = DO concentration and NH_4 averaged from 1-2 m; and DODIN10 = DO concentration and DIN averaged from 1-10 m.

Site Number	Sat10	DO10	DO2	DODIN10	Mean	Std
P7CBI	0.76	0.71	0.72	0.93	0.78	0.10
P6FGG	0.79	0.72	0.72	0.90	0.78	0.08
P10LI	0.81	0.73	0.73	0.86	0.78	0.06
P11QB	0.68	0.72	0.76	0.97	0.78	0.13
P5BSD	0.84	0.82	0.81	0.97	0.86	0.08
P9LFP	0.87	0.79	0.78	1.07	0.88	0.14
P4BRI	0.86	0.87	0.90	1.07	0.92	0.10
P3SMP	0.90	0.90	0.90	1.06	0.94	0.08
P1RIL	0.93	0.91	0.91	1.21	0.99	0.15
P2HWR	0.98	1.00	0.99	1.20	1.04	0.11

Although there is variability in the values calculated using the different methods, there is little variability in how the sites are ranked under each of them (Table 8). The four sites that consistently exhibit the lowest scores are located in or near Portland Harbor (P6FGG), Presumpscot River (P7CBI), and Middle and Quahog Bays (P10LI and P11QB). The highest scores are found at the three offshore sites – P1RIL, P2HWR, and P3SMP. Site P5BSD (mid bay) and P9LFP (Maquoit Bay) fall in between and tend to be more closely associated with either the low or high score group depending on the scenario used. The development of a consensus index for these profile sites will take a number of iterations and discussions focusing on the relative merit of the parameters included, methods used, and thresholds values that are most applicable. Of the four presented here, we recommend using the DO10 index as it incorporates a combination of parameters that appear to be most fitting for Casco Bay. The DO10 index provides a measure of bottom water DO concentration, which has been suggested as a better indication of impact in these waters than DO percent saturation. The DO10 index also uses surface water NH_4 concentrations, which are more indicative of anthropogenic impacts than DIN that combines natural variability in both NO_3 and NH_4 with their terrestrial loadings. The expansion of nutrient measurements to additional surface water stations would provide the opportunity to develop a modified index for the bay based on DO, Secchi depth and nutrient concentrations.

4.0 Conclusions and Recommendations

Overall, the FOCB 1993-2004 data indicate that water quality is generally good in Casco Bay as was concluded in the 6-year data review (Battelle 2001). Dissolved oxygen is usually well above State standards and levels that would impair biological processes. However, there are areas of potential concern with respect to DO, chlorophyll, and nutrient levels. Nevertheless, low DO events and elevated chlorophyll and nutrient concentrations tend to be the exception rather than the rule in Casco Bay.

The temperature and salinity data illustrate the dynamic nature of Casco Bay spatially and temporally with changing seasons. Chlorophyll follows predictable seasonal trends and displays characteristic spatial patterns. Nutrient concentrations also follow seasonal trends and spatial distributions in response to meteorological/physical oceanographic processes and biological utilization/regeneration. DO concentrations, an important indicator and integrator of coastal water quality, naturally follow a seasonal pattern that is directly related to temperature and influenced by biological processes and local freshwater inputs. As a basic necessity for aquatic life, DO levels directly affect ecosystem health. Anthropogenic impacts such as organic material and nutrient loading, along with the associated increase in the production of organic material have the potential to intensify problems associated with naturally low summer DO concentrations.

For the surface water stations, the lowest DO readings were observed in Portland Harbor, upper New Meadows River, and Peabbles Cove. The sites in these areas had nearly all of the readings below <5 mg/l and <70% (<1% of total in both cases) and most of the readings <6mg/l (only 1% of total). Portland Harbor is an urban port in class SC waters with numerous sources of nutrients and organic materials. Upper New Meadows River has restricted flow and may have non-point sources of nutrient loading. Peabbles Cove has been shown to be a natural settling area for seaweed, algae, and other detritus that eventually degrades and decreases DO levels (FOCB 1996a).

Percent saturation readings of <85% were measured at 74 different sites throughout the bay. In fact, surface water values of <85% were even measured at Halfway Rock. Low DO levels were also measured in the deep bottom waters at this site (P2HWR - <6.5 mg/l and ≤70%). The percent saturation minima were well below 85% at Halfway Rock during 10 of the 12 years examined. In October 1998, values were <70% and in September 2002 the minimum value was 70.4% at Halfway Rock (no sampling was conducted in October 2002). The lowest DO levels (concentration and percent saturation) for the profile stations were consistently observed in Quahog Bay (class SB waters). All DO concentrations of <6 mg/l and all of the percent saturation measurements of <70%, except those noted at P2HWR, were found in Quahog Bay at site P11QB. In contrast, bottom water DO percent saturation was relatively high at the profile sites P9LFP and P6FGG and 1994 was the only year in which percent saturation was below 85% at these sites in Maquoit Bay and Portland Harbor. This disconnect between DO percent saturation levels and the relative influence of anthropogenic versus natural factors on this parameter suggests that the existing State DO standards may not consistently distinguish between impacted and non-impacted waters.

In the 6-year report, it was necessary to make a number of assumptions regarding the relative nutrient loading and levels of phytoplankton production because of the limited amount of nutrient and phytoplankton biomass data that were available. The historical nutrient information cited specified areas of direct loading from point sources and combined sewer overflows in Portland Harbor (CBEP, 1996) and sites in the vicinity of freshwater inputs and potential nonpoint source loading (Royal River, Presumpscot River, and Harraseeket River; Kelly, 1997). However, as noted in this and previous reports, low DO concentrations are also observed in less developed areas in Eastern Casco Bay where restricted circulation may exacerbate anthropogenic impacts (New Meadows River and Quahog Bay). Septic systems in Maquoit Bay have been cited as a significant source of nutrients into that bay (Horsley and Witten, 1996). Overboard discharge systems (OBDs) in use along the shores of Harpswell Sound, Quahog Bay, and New Meadows River (CBEP, 1996) along with more traditional septic systems are a potential source of nutrients in these bays.

In order to corroborate these findings and assumptions, it was recommended that FOCB add nitrogenous nutrients and phytoplankton biomass to the list of parameters measured at a set of primary sites. In 2001, dissolved inorganic nutrients and *in situ* fluorescence began to be measured at the profile sites and nutrient samples were also collected off the SMCC dock. On the whole, these data have supported the previous measurements and assumptions. Although the potential impact of nutrient loading from OBDs and septic systems in Eastern Casco Bay cannot be evaluated based on ambient nutrient concentrations, nutrient concentrations in these embayments were relatively low in comparison to other areas of Casco Bay. Overall, the mean nutrient concentrations measured by FOCB are typical of northeastern coastal waters. Although high nutrient concentrations were measured at various times at each station, the sites off the SMCC dock and near Fort Gorges were consistently higher in relation to the other stations. Profile site P3SMP, located offshore south of Phippsburg, was often elevated in silicate due to the influence of the Kennebec River at this station.

The highest concentrations for each of the nutrient parameters (NO_3+NO_2, NH_4, SiO_4, and PO_4) were observed at the SMCC dock site. Ammonium and nitrate+nitrite concentrations were also high at P5BSD mid-bay, P6FGG outside of Portland Harbor, and P1RIL to the south of Portland Harbor. In fact, the annual mean NH_4 concentration at P5BSD was second only to the SMCC dock site and was four times higher than the levels at Halfway Rock site P2HWR. Although further inshore than P2HWR, one might expect the two sites to have similar surface water NH_4 concentrations. This dramatic difference suggests a localized source of NH_4 as the surface and bottom water DO concentrations are not indicative of high respiration/regeneration rates. The source could be anthropogenic or due to currents and upwelling or likely a combination of factors. Overall, the nutrient trends confirm that Portland Harbor is a clear recipient of nutrients and the signal of elevated concentrations was consistently observed at the sites in the vicinity of the harbor. The local and regional rivers are also a source of nutrients to the bay. On the whole, the assumptions made in the 6-year report have been substantiated by the last four years worth of nutrient data. The most anomalous finding is the elevated concentrations at the mid-bay site and this is worth further site investigation to attribute the cause.

Nutrient levels in the embayments in Eastern Casco Bay were relatively low. In fact, the concentrations of all nutrients at the Maquoit Bay site were significantly lower than at the SMCC dock. This was contrasted by the highest mean chlorophyll values being measured at site P9LFP in Maquoit Bay (also relatively high in Middle and Quahog Bay). This is not to say that nutrients are not getting into these embayments, but that the nutrients are being utilized quickly. The combination of low nutrient concentrations and high chlorophyll levels suggests that nutrient inputs and primary production are tightly coupled in Maquoit Bay and the other embayments in Eastern Casco Bay. Elevated chlorophyll values were also found in the waters off Portland Harbor and the Presumpscot River (P6FGG and P7CBI) that exhibited elevated nutrient concentrations over much of the year. The high fluorescence values in Maquoit Bay (P9LFP) and the Foreside area (P7CBI) were significantly higher than at the more offshore sites – P5BSD, P4BRI, P2HWR, P3SMP, and P1RIL. Fluorescence data at the SMCC site was collected only at the surface and not included in this analysis; a cursory review of this data suggests that surface water fluorescence levels were relatively low at this Portland Harbor site in comparison to the mean values at the profile sites. Unfortunately, this is a comparison of surface versus profile values that include the subsurface chlorophyll maximum that is present over much of the year. Collection of fluorescence data throughout the water column within the harbor would be more useful for assessing the impact of high nutrient loading conditions.

The results of this data evaluation are similar to those found for Casco Bay water bodies in the 6-year FOCB report and 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 has found that Casco Bay DO levels are generally high and not problematic, though they all highlight 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.

The 2001-2004 FOCB data for surface chlorophyll showed overall site means of 4.4 to 9.7 μg/l. Note that the FOCB values are "relative" chlorophyll concentrations as the *in situ* fluorometer used was not calibrated against actual/extracted chlorophyll measurements, but rather a dye fluorescence standard and therefore cannot be compared to the 1996 results. The site to site comparison and temporal trends that have been discussed in this report are valid. However, the actual magnitude of the values for comparisons to other datasets and regions is not recommended. The nutrient values measured by the FOCB program do show indications of anthropogenic inputs, but the mean concentrations of the parameters measured do not suggest levels associated with eutrophication. This is not to say that areas within Portland Harbor, that were not sampled, are not higher and potentially more problematic.

The evaluation of the 12-years of data confirmed that there are specific areas of concern with regards to DO levels and that the seasonal and annual cycles seen in Casco Bay are part of a larger regional signal. This was especially evident in the comparison of bottom water DO levels in the bay versus those measured in Massachusetts Bay (see Figures 28 and 29). The interannual trends observed for the Casco Bay data are the same as trends observed in Massachusetts Bay over this same time period. Statistical analyses indicate that DO concentrations in Massachusetts Bay are governed by regional, rather than local, processes (Geyer *et al.* 2002). These regional processes include advection and currents within the Gulf of Maine system and river flows and the FOCB data suggest similar regional scale processes drive the interannual variability in Casco Bay DO levels. The data also indicate that DO levels in Casco Bay are much higher than those in Massachusetts Bay. The annual DO concentration minima were generally ~1 mg/l higher and the DO percent saturation minima were about 10-20% points higher in Casco Bay. Even qualitatively, the fact that the class SA and SB DO standards for Massachusetts marine waters are comparable to the Maine class SB and SC standards suggests that the Maine waters are in better condition than those to the south.

In an effort to provide more easily accessible comparisons of sites within Casco Bay and between years, FOCB has worked on the development of the Casco Bay Health Index. The index has been developed to provide a reliable, uncomplicated composite indicator of the bay's overall health with regard to water quality. This index allows the water quality data collected at each site to be assigned a score that can be recalculated each year. By summarizing independent environmental indicators into one score, sites can be ranked and trends identified on a year-by-year basis. The results for the first 12 years of monitoring data were used to calculate annual and a 12-year mean index for each site. The spatial and temporal trends in the index scores are comparable to those observed for the individual parameters (DO and Secchi depth) and highlight similar areas of concern in Portland Harbor, in the vicinity of the Presumpscot and Royal Rivers, and in the restricted embayments in Northeastern Casco Bay (see Figure 33). As with most water quality parameters examined, there is a clear inshore to offshore improvement in index scores with the highest scores, and thus best water quality, consistently calculated for the site near Halfway Rock. Year-to-year variability was evident in the distribution of the index suggesting that the index can be used to compare conditions across years and between sites/locations.

The various scenarios proposed for the profile site index that incorporates chlorophyll and nutrient data also show patterns similar to those seen in the examination of the data for the individual parameters. This indicates that a profile site based index may be appropriate, but the lack of data (only the 10 profile sites) from areas that have been shown to be possible areas of concern minimizes the effectiveness of this index. Rather than drop this effort, it is recommended that nutrient and chlorophyll data be collected from additional sites. The deeper surface water CWQM monitoring sites that were included in the surface water index would be a good starting point for selecting additional locations for nutrient and profile measurements. These other sites would have to be determined based on a combination of expected level of impact and logistics in the collection of these additional parameters.

The objective that was set for the creation of the Casco Bay Health Index was to present water quality information rapidly and clearly by taking a large amount of existing data and presenting it as a single value for each monitoring site. The index developed for the surface water sites appears to meet this objective. The trends exhibited by the index scores are the same as those seen upon closer examination of the data. One aspect that had been discussed was to formulate the index so that it would be compatible with other regional or national indicators. This may not be necessary or even appropriate as the index is designed for local water quality characteristics (i.e. the 0-100 scores) as recommended in one of the national water quality assessments (USEPA 2004) and as such provides little information when compared to even similarly calculated indices from other regions. National water quality assessments would be more apt to utilize the FOCB data on DO, Secchi depth, chlorophyll, and nutrients directly as has been the case in the past (Bricker *et al*. 1999; USEPA 2004).

The NOAA National Estuarine Eutrophication Assessment (Bricker et al. 1999) indicated that Casco Bay had a “high” eutrophic condition along with Boston Harbor, Sheepscot River, and three sites Downeast. The scores for the parameters listed in Table 9 for the NOAA program are slightly more liberal than those for the EPA program, but additional indicators were used in this assessment. Most notably, for Casco Bay and the other Maine estuaries listed as “high”, was the secondary expression of eutrophication represented by the prevalence and intensity of nuisance/toxic blooms. The report noted that these blooms are not necessarily due to local influences and this was especially true in the Maine estuaries where the other factors suggested a low to moderate risk of eutrophication. Casco Bay was ranked moderate based on eutrophication symptom expression for chlorophyll *a* and low for DO. The bay was also ranked low for each of the influencing conditions cited in the report - overall human influence, susceptibility, and nitrogen input.

Table 9. Relative risk for eutrophication as defined in NOAA and EPA national coastal assessments (Bricker et al. 1999 and USEPA 2004) compared to mean and maximum values from the FOCB monitoring data.

	Risk	NOAA	EPA[1]	FOCB
DIN (μM)	Low	<7	<7	5.17 mean
	Medium	7-70	7-35	34.06 maximum
	High	>70	>35	
DIP (μM)	Low	<0.32	<0.32	
	Medium	0.32-3.2	0.32-1.6	0.95 mean
	High	>3.2	>1.6	3.23 maximum
Chlorophyll *a* (μg/l)	Low	<5	<5	
	Medium	5-20	5-20	5.9 mean[2]
	High	20-60	>20	116 max[2]
DO (mg/l) (Summer)	Low	>5	>5	99% ≥6
	Medium	2-5	2-5	Only 0.3% <5
	High	<2	<2	

[1] EPA values are based on summertime measurements only.
[2] Note that chlorophyll was only a relative measure in this program.

The National Coastal Condition Report II (USEPA 2004) took a more quantitative approach than the NOAA effort and indicated that overall water quality scores were fair to good for sites within Casco Bay. The only factors in their water quality index [DO, chlorophyll *a*, dissolved inorganic nitrogen and phosphorous (DIN and DIP), and water clarity] that were rated as fair on an individual basis were DIN and DIP concentrations. The other factors were all considered 'good' or 'low' as defined in Table 9. Casco Bay and all Northeast waters north and east of Cape Cod were considered good or fair. Many of the estuaries to the west of Cape Cod were found to be fair to poor including Long Island Sound, New York Harbor, Delaware River, and Chesapeake Bay, which exhibited many poor scores for both primary and secondary indicators of eutrophication.

A comparison of the 12-year (DO) and 4-year (nutrients and chlorophyll) FOCB results with the reported risk levels for eutrophication provided in the EPA and NOAA assessments suggests that Casco Bay lies somewhere in the middle of the range (Table 9). A direct comparison cannot be made as the EPA and NOAA assessments are based on a myriad of information from monitoring, models, literature and best professional judgment. The values included in Table 9 are gleaned from the reports and serve as a general basis for comparison. The NOAA values are based on peak nutrient and chlorophyll concentrations that may occur at various times of the year and DO minima that are primarily confined to the late summer (Bricker *et al*. 1999). The EPA values are somewhat lower for nutrients and chlorophyll as they are based on National Coastal Assessment (NCA) monitoring data (USEPA 2004). The NCA surveys were conducted primarily during the summer months. Thus, the EPA concentrations are lower than those used in the NOAA report. The FOCB nutrient and chlorophyll data used for this comparison are based on mean and maximum concentrations collected year-round from 2001-2004. The DO concentrations are based on summer time measurements made over the entire 12 years of the monitoring program.

The mean DIN concentrations for Casco Bay are within the low range, but some values fall in the medium risk group. These are primarily from the SMCC dock site, but even the values that fall within the 7-35 µM range are not necessarily indicative of anthropogenic inputs as there are many NO_3+NO_2 concentrations that are >7 µM that are natural, ambient levels for coastal waters. The DIP concentrations in Casco Bay are slightly higher by comparison with the mean values falling within the medium risk range and the maximum value in the high range. The DIP concentration ranges are quite low and it is not surprising to see concentrations in the 0.32 to 1.6 µM range in Northeast coastal waters (see Libby *et al.* 2004). The chlorophyll values also fall into the medium and high ranges based on the mean and maximum values measured. However, as stated previously, the chlorophyll measurements made by FOCB are relative measurements and should not be compared quantitatively with levels measured by other programs. Note that FOCB should consider the possibility of conducting regular calibrations against actual chlorophyll measurements to gain a more accurate and comparable results. The DO levels in Casco Bay, as stated throughout this and other reports, are indicative of waters with a low risk of eutrophication with 99% of the values measured being ≥6 mg/l. Over the 12-year monitoring program only seven (out of 2271) summertime DO concentrations have been ≤5 mg/l.

On the whole, the FOCB monitoring program provides data with which to adequately characterize Casco Bay and identify areas of concern with respect to the parameters measured. There are, however, features of the monitoring program that could be expanded and improved upon. It is recognized that there are constraints under which FOCB, as a nonprofit organization, must operate. The recommendations are made with the thought that they may help FOCB to prioritize modifications and improvements to their already successful volunteer monitoring program. The recommendations focus on modifying data storage and analysis procedures, changing how some parameters are measured, on adding the nutrient and chlorophyll measurements to additional sites, and increasing the number of parameters measured. As in the previous report, it is also recommended that FOCB continue to seek out partnerships with other organizations both within and outside of the State with which to share data and receive additional support.

The utility of the MURPHY database should be examined. This database was developed by FOCB at the beginning of the CWQM program and the potential transfer of the data into a more suitable structure should be examined. MS Access database software was used for this set of analyses and could be a useful format for FOCB. A more powerful and costly (software and maintenance) option would be to use a relational database such as Oracle. Nevertheless, database options should be explored. Coincident with any migration to a new database structure, "real-time" procedures for examining the data should be put in place. Although six-year reviews of the data are useful, many of the most important details and insights would be best evaluated on shorter time frames. Not necessarily survey by survey, but certainly on a seasonal and annual basis. These procedures could be a simple as graphing monthly contour plots of surface site data. This not only gives near real time information on water quality, but also could serve as a step in established QC protocols. If monthly plots could be done retrospectively on the historic data, then comparisons could highlight possible changes that are occurring or 'extreme' events. To this end, one potentially useful tool would be summary time series plots for specific sites of interest or waterbodies of concern. Figure 36 presents monthly mean DO concentrations for Harraseeket River. The data are presented for a 'baseline' period of 1993 to 2003 versus data from 2004. Of note from this particular comparison, the 2004 DO concentrations were higher than the baseline mean and standard deviation (as expressed by the error bars) in June and September, but lower than the mean in August. This type of comparison could also include monthly mean minima and maxima or other metrics, but the goal would be to compare the current data against historic data in an easy and clear manner. A set of comparisons such as this could be established for various sites or waterbodies of interest, linked to output from the database, and generated almost automatically once the data are loaded providing FOCB with a useful tool for 'real-time' examination of the data.

The addition of fluorescence measurements has increased the ability of the program to describe some of the possible causes of low DO conditions and to understand what is happening with regards to phytoplankton production in the various areas of the bay. Unfortunately, the fluorescence data is not calibrated against extracted chlorophyll concentrations and does not allow for reliable comparisons to other areas across the region or in established national assessment programs. The added cost necessary to provide calibrated fluorescence data would be well worth the investment.

We continue to recommend the adoption of a "Primary Station" approach that keys in on the areas of concern discussed in this evaluation. This entails adding the suite of nutrient and chlorophyll measurements to a set of sites within areas of interest. In Portland Harbor, the SMCC dock (surface nutrients and fluorescence already measured here) and Custom House Wharf sites would be appropriate along with sites in the vicinity of the Presumpscot and Royal Rivers. There are profile sites within some of the Eastern Casco Bay embayments, but additional surface based sites in Harraseeket River, New Meadows River, and the upper reaches of Maquoit, Middle, Harpswell and Quahog Bays would also be informative. The analysis of organic nutrients (N and C) at the profile sites and these additional sites would provide additional information for understanding the potential impacts of eutrophication in these waters. However, given the limited resources available for expanding the program, this recommendation is a much lower priority compared to expanding the spatial extent of dissolved inorganic nutrient and chlorophyll measurements.

Nuisance and toxic phytoplankton blooms have been noted in the examination of the FOCB results (i.e. *Phaeocystis* blooms) and in the national assessments (Bricker et al. 1999). The *Alexandrium* bloom in 2005 was one of the largest seen since 1972 and combined with the extraordinary *Alexandrium* bloom in the fall of 2004 have served as a shot across the bow of local shell fishermen and State environmental managers. It seems like an opportune time for FOCB to add phytoplankton analyses to the suite of parameters measured at these primary stations. The set of phytoplankton analyses could be limited to the identification of key nuisance/toxic species or could expand to provide data on species composition and enumeration of the phytoplankton community depending upon the level of funding available. These types of analyses would not only be useful in understanding the water quality of Casco Bay, but would be especially valuable for alerting the public, shell fishermen, and aquaculturists to the presence of potentially toxic or nuisance phytoplankton species in the bay.

In October 2003, FOCB began a collaborative effort with Dr. Gregory Teegarden at Saint Josephs College to sample phytoplankton from surface and subsurface chlorophyll maximum depths. Samples from this effort are still being analyzed and results evaluated. Future efforts are focused on a more quantitative and comprehensive approach to analysis of phytoplankton community structure with special emphasis on toxic and nuisance species. Collaborations such as this one provide FOCB with important information and valuable technical expertise while providing area scientists a platform for sampling and research. Similar collaborative efforts with other colleges (such as other ongoing work with Bowdoin College and University of Maine) and research entities (i.e. GoMOOS, Gulf of Maine Research Institute, Bigelow Laboratory, etc.) would be extremely beneficial to FOCB. In addition to the GoMOOS C buoy in Casco Bay, a collaborative effort between scientists at Saint Joseph's, Bowdoin, and Bigelow laboratories expects to deploy an moored instrument array in Harpswell Sound in 2006 (Dr. Greg Teegarden, pers. comm.). Exciting initiatives such as this will provide unique opportunities to learn more about Casco Bay waters and allow FOCB monitoring data to be placed into proper context regarding higher temporal resolution events.

The Casco Bay Health Index was shown to be a useful tool for simplifying the findings while still representing the more detailed data examinations accurately. The profile site index is a work in progress. The various scenarios will need to be looked at in more detail and, if nutrients and chlorophyll are measured at additional sites, the basis for these scenarios may need to be revisited. The FOCB program has contributed to the national assessment efforts referenced in this report and the addition of calibrated fluorescence and expansion of the nutrient/chlorophyll measurements to more sites will allow for a more thorough examination of conditions in Casco Bay and comparisons to other estuaries.

The 12-year FOCB dataset suggests that water quality conditions in Casco Bay are generally quite good, but areas of concern continue to be highlighted in the DO, chlorophyll, and nutrient data. The Casco Bay Health Index draws attention to these same areas and appears to be a useful tool for comparing across years and between locations and for disseminating this information to the public. Although an in depth statistical examination of the 12-year dataset was beyond the scope of the current report, indications from this examination suggest that there are apparent trends over the time series of FOCB data. Trends in the 12-year dataset indicate that DO concentrations are increasing and that the data may be able to be grouped based on the changes observed (i.e. 1993-1999 vs. 2000-2004 as suggested in Figure 13). A more comprehensive statistical examination of the data would be needed to understand the variability inherent in the data and to establish "baseline" groupings of data. However, as noted in the introduction a baseline is typically established as a period of data collection prior to a major change in the system – usually related to man made changes and associated regulatory requirements (i.e. the MWRA monitoring program associated with the diversion from the Boston to the offshore outfall). If a major environmental project were planned for Casco Bay, the 12-year (and counting) dataset that FOCB has collected would be instrumental in understanding water quality conditions and their spatial and temporal variability in the bay. As such, the FOCB data are a valuable resource for understanding the system today and for understanding changes to Casco Bay into the future.

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5.0 References

Battelle. 2001. Six-year water quality data analysis: 1993-1998. Portland, ME: Friends of Casco Bay. 72 pp.

Bricker, S.B., C.G. Clement, D.E. Pirahalla, S.P. Orlando, and D.R.G. Farrow, 1999. National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, MD, 71 pp.

Casco Bay Estuary Project, 1996. Casco Bay Plan: Protect the Health and Integrity of Our Bay for the Future. 234++pp.

Diaz, R.J. and R. Rosenberg, 1995. *Marine Benthic Hypoxia: A Review of its Ecological Effects and the Behavioral Responses of Benthic Macrofauna*. Oceanography and Marine Biology: An Annual Review 33:245-303.

Friends of Casco Bay, 1996a. Citizens Water Quality Monitoring Program 1995 Data – Volume I. 39 pp.

Friends of Casco Bay, 1996b. Citizens Water Quality Monitoring Program 1995 Profile Data – Volume I. 39 pp.

Friends of Casco Bay, 2001. Quality Assurance Project Plan for The Friends of Casco Bay Citizens Water Quality Monitoring Program. Final Rev. 2 QAPP to Casco Bay Estuary Project and US EPA Region 1. 58 pp.

Friends of Casco Bay, 2005. The Casco Bay Health Index. Prepared for the Casco Bay Estuary Partnership, May 2005.

Geyer WR, Libby PS, Giblin A. 2002. Influence of physical controls on dissolved oxygen variation at the outfall site. Boston: Massachusetts Water Resources Authority. Letter Report ENQUAD. 20 p.

Kelly, J.R. and J. Turner, 1995. Water Column Monitoring in Massachusetts and Cape Cod Bays: Annual Report 1994. Boston: Massachusetts Water Resources Authority. Report ENQUAD 95-17. 163 pp.

Kelly, J.R. and P.S. Libby, 1996. Dissolved Oxygen Levels in Select Maine Estuaries and Embayments – Summer 1995. Final Report to Wells NERR. February 1996. 14++pp.

Kelly, J.R., 1997. Dissolved Oxygen in Maine Estuaries and Embayments – 1996 Results and Analyses. Final Report to Wells NERR. August 1997. 18++pp.

Libby PS, Geyer WR, Keller AA, Turner JT, Borkman D, Oviatt CA. 2004. 2003 Annual Water Column Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2004-07. 154p.

Libby PS, Mansfield AD, Geyer WR, Keller AA, Turner JT, Borkman D, Oviatt CA. 2005. 2004 Annual Water Column Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2005-18. 142p.

Nixon, S.W., 1995. Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns. Ophelia 41: 199-219.

Sokal, R.R. and Rohlf, F.J., 1981. Biometry: The Principles and Practice of Statistics in Biological Research. Second Edition. W.H. Freeman and Company, San Francisco, 859 pp.

United States Environmental Protection Agency. 1990. EPA Volunteer Water Monitoring: A Guide for State Managers. EPA 440/4-90-010. Office of Water. Washington, D.C.

United States Environmental Protection Agency. 2004. National Coastal Condition Report II. EPA-620/R-03/002. Office of Research and Development and Office of Water. Washington, D.C.

Whitledge TE, Veidt DM, Mallow SC, Patton CJ, & Wirick CD. 1986. Automated Nutrient Analyses in Seawater. Publ Brookhaven Natl Lab (BNL) NY 38990.

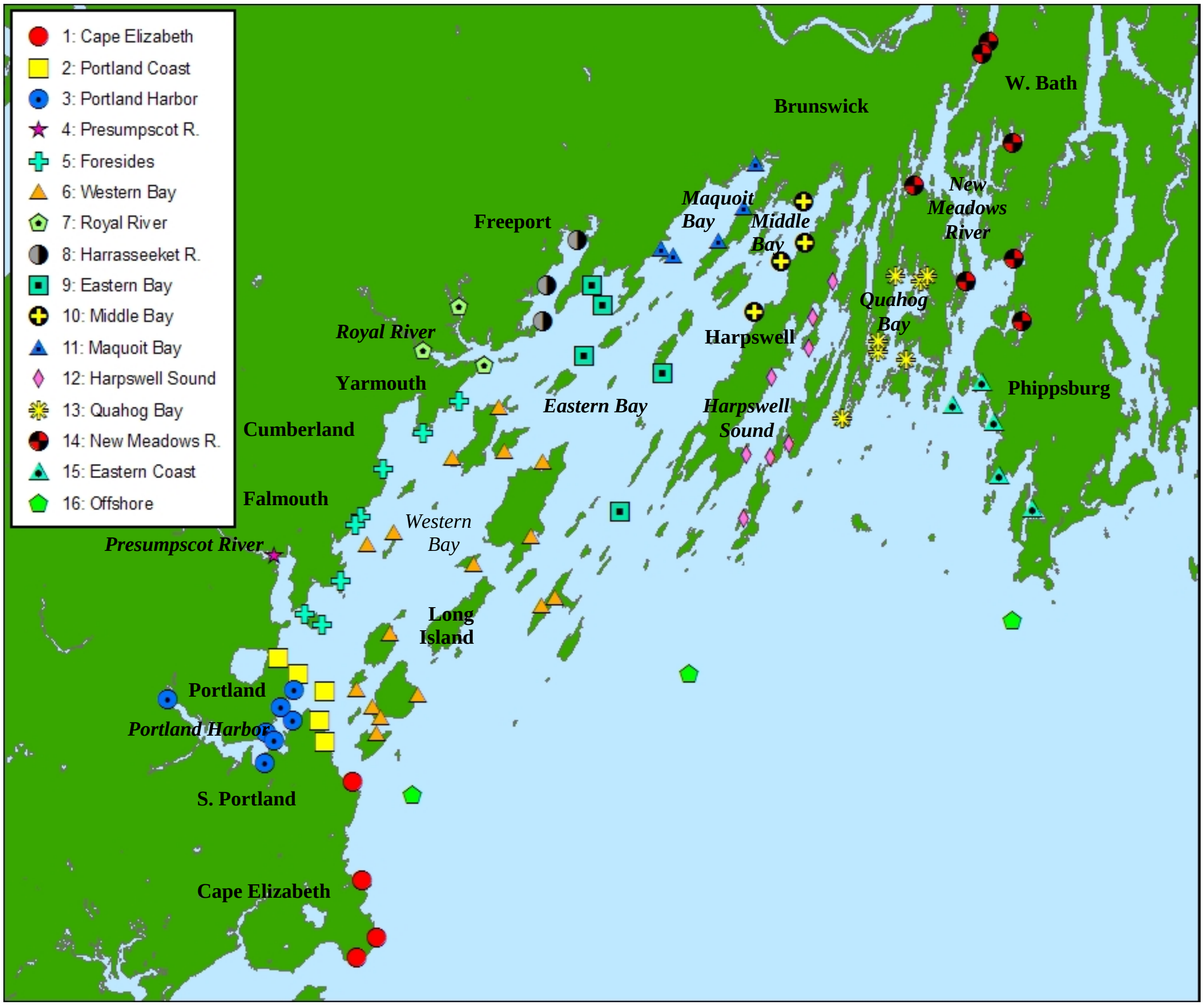


Figure 1. FOCB Water Quality Monitoring Sites Color-Coded by Water Body.

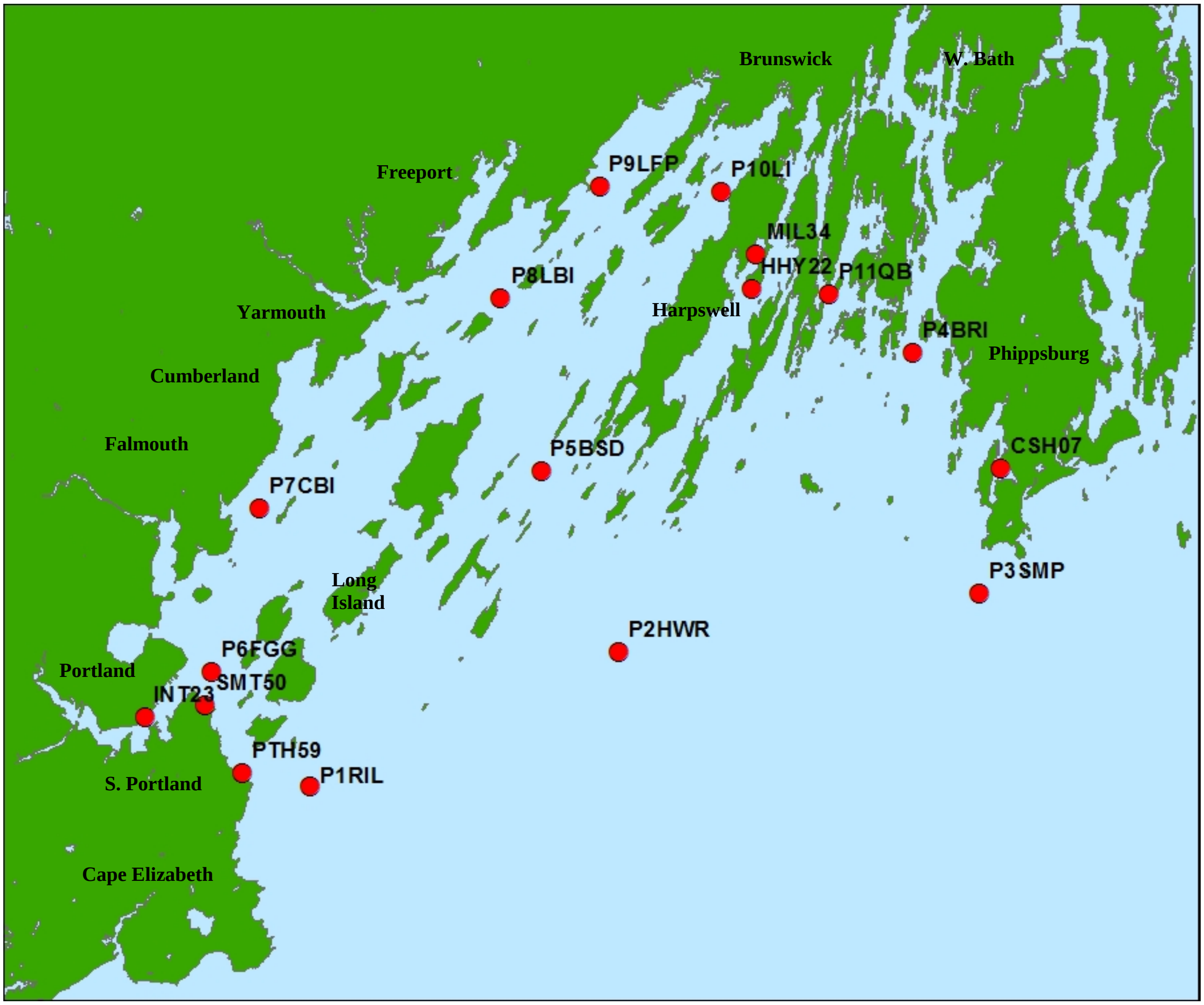


Figure 2. FOCB Water Quality Monitoring Year-round Sites.

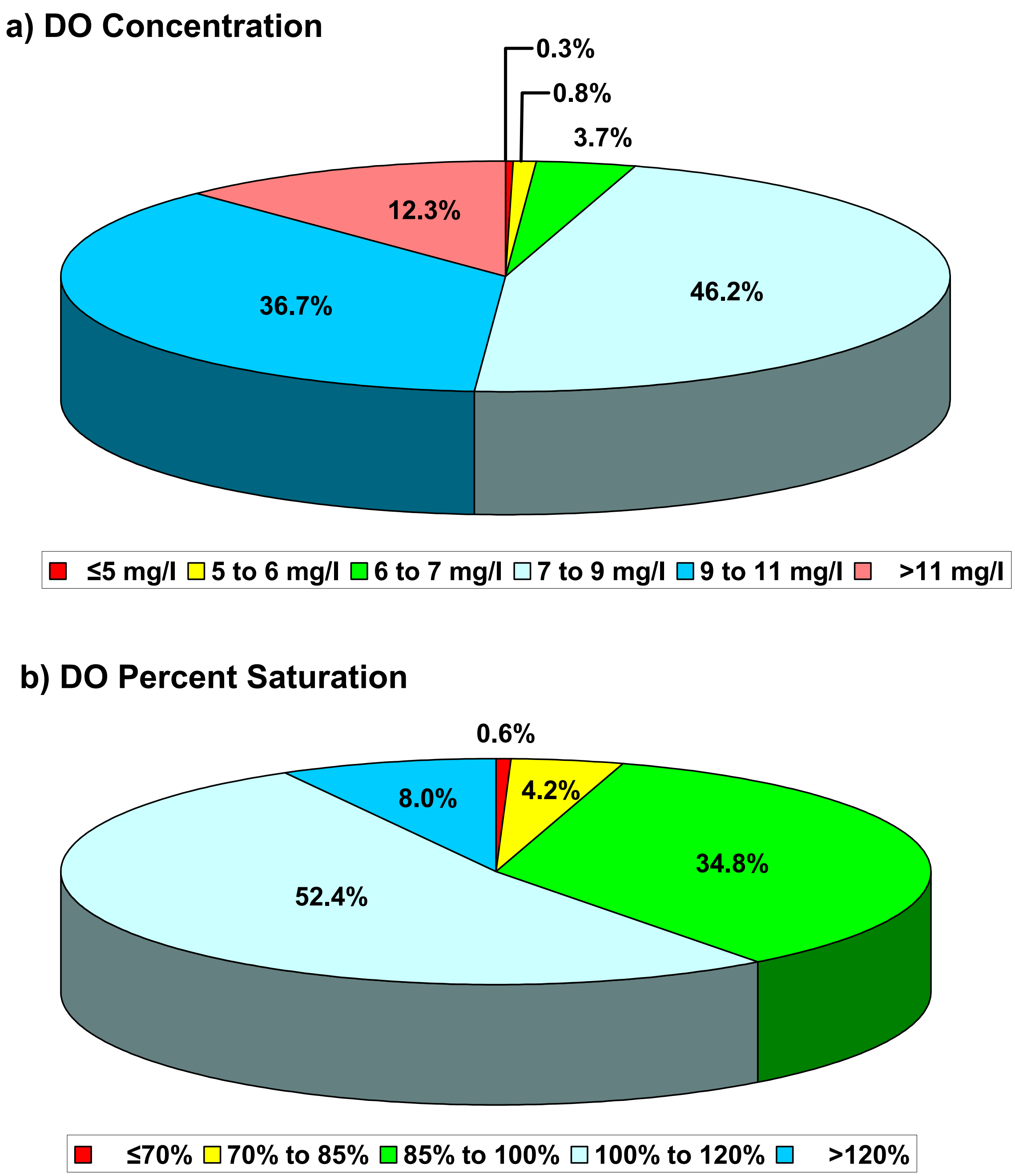
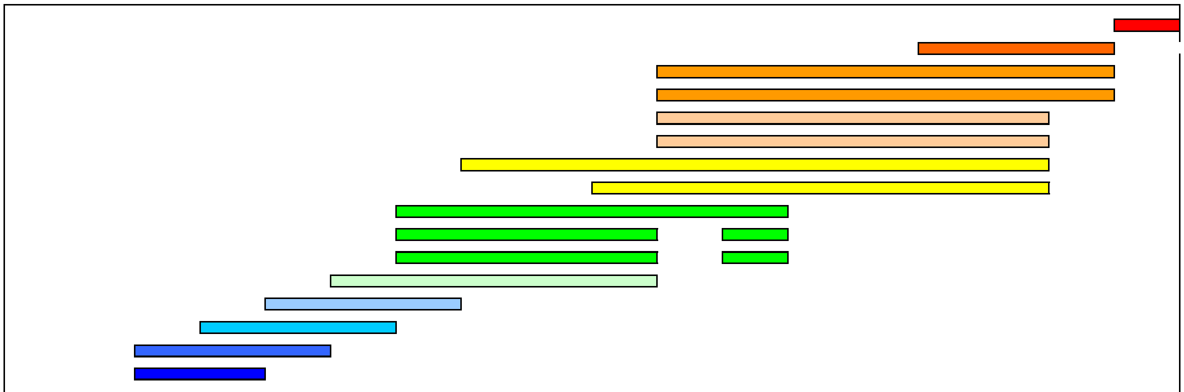


Figure 3. Pie Charts of a) DO concentration and b) DO percent saturation for all surface water data from 1993-2004.

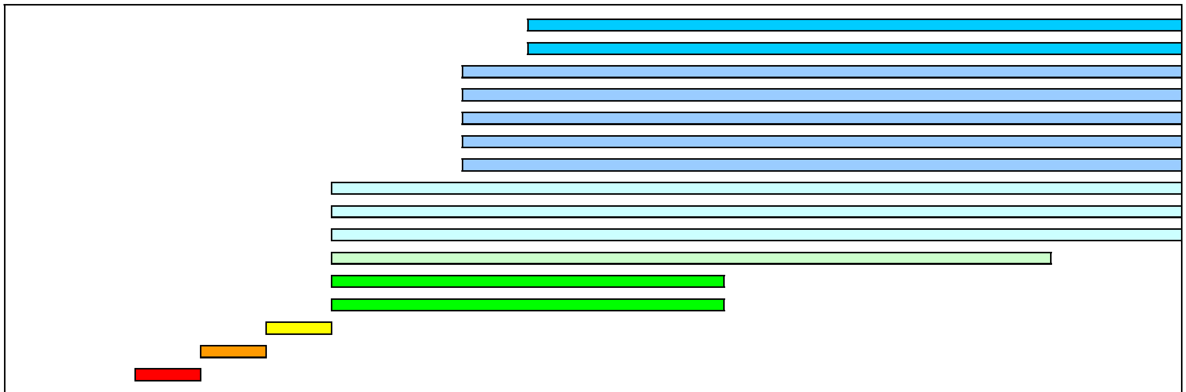


Water Body	CE	OFF	PC	WB	EC	PH	HS	EB	FS	HR	QB	NMR	MB	RR	MQ	PR
Mean	15.37	15.53	16.27	16.56	17.15	17.31	17.33	17.56	18.17	18.23	18.34	18.48	18.81	19.01	19.75	22.26
Standard Deviation	1.72	1.42	1.44	2.18	1.97	2.04	2.06	2.05	2.03	2.34	2.26	2.53	2.07	2.19	2.80	2.66
Minimum	5.0	12.2	11.5	10.5	12.2	10.8	12.0	12.5	12.0	14.6	13.6	13.8	14.0	14.5	14.0	16.0
Maximum	18.5	19.4	21.0	27.0	22.0	24.0	27.0	22.0	24.2	24.5	23.0	24.3	23.8	23.5	29.3	26.5
Count	113	100	162	305	126	203	198	146	190	75	217	130	114	69	77	27

Figure 4. Summary statistics for Temperature (˚C) by water body and results of comparison test for monthly mean data by water body for July-September (includes all sites sampled 3 or more years). Each line represents the planned comparison of one water body with the other 15 and connects systems that are not significantly different from one another. Water body codes and names are listed below for reference.

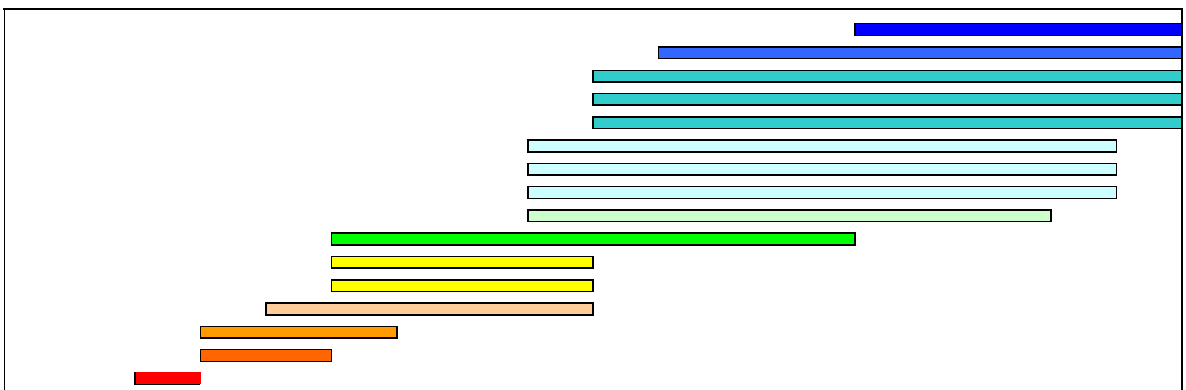
Water Body Code	Water Body Name
CE	Cape Elizabeth
EB	Eastern Bay
EC	Eastern Coast
FS	Foresides
HR	Harraseeket River
HS	Harpswell Sound
MB	Middle Bay
MQ	Maquoit Bay
NMR	New Meadows River
OFF	Offshore
PC	Portland Coast
PH	Portland Harbor
PR	Presumpscot River
QB	Quahog Bay
RR	Royal River
WB	Western Bay

(a) Salinity



Water Body	PR	RR	PH	PC	FS	OFF	MQ	EC	HR	WB	HS	QB	EB	NMR	MB	CE
Mean	3.10	23.76	28.33	29.34	29.63	29.66	30.00	30.07	30.48	30.52	30.68	30.68	30.73	30.86	30.98	31.15
Standard Deviation	1.96	7.92	4.82	2.35	2.70	1.43	1.83	1.60	3.05	1.89	1.55	1.86	1.34	1.69	1.43	1.43
Minimum	0.00	5.08	2.80	15.05	18.56	25.40	19.08	22.73	13.22	20.39	25.86	15.18	25.08	25.34	26.25	20.39
Maximum	7.62	33.03	33.42	32.77	32.77	32.03	32.08	32.64	33.94	33.81	35.24	34.07	33.42	33.81	33.42	33.81
Count	27	69	204	161	190	100	76	126	75	301	198	217	146	129	114	113

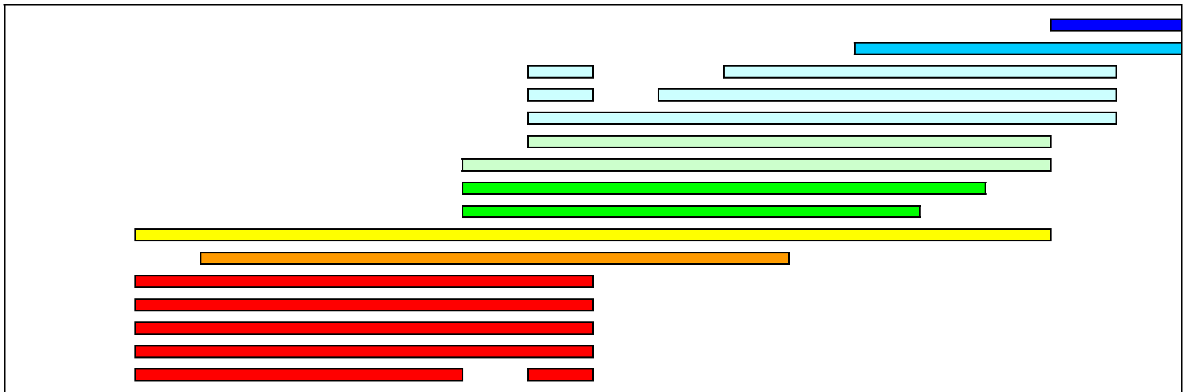
(b) pH



Water Body	PR	PH	RR	HR	FS	PC	NMR	QB	WB	HS	EB	MB	OFF	CE	MQ	EC
Mean	7.57	7.79	7.80	7.88	7.91	7.91	7.92	7.96	7.97	7.97	7.98	7.99	8.01	8.02	8.04	8.06
Standard Deviation	0.39	0.18	0.12	0.14	0.13	0.13	0.17	0.12	0.14	0.13	0.11	0.15	0.12	0.17	0.16	0.19
Minimum	6.9	7.1	7.4	7.6	7.6	7.6	7.5	7.7	7.6	7.7	7.7	7.5	7.7	7.3	7.6	7.0
Maximum	8.3	8.3	8.3	8.3	8.3	8.5	8.3	8.4	8.3	8.3	8.3	8.4	8.3	8.3	8.3	8.6
Count	27	204	69	75	190	159	128	209	298	198	145	112	97	111	74	126

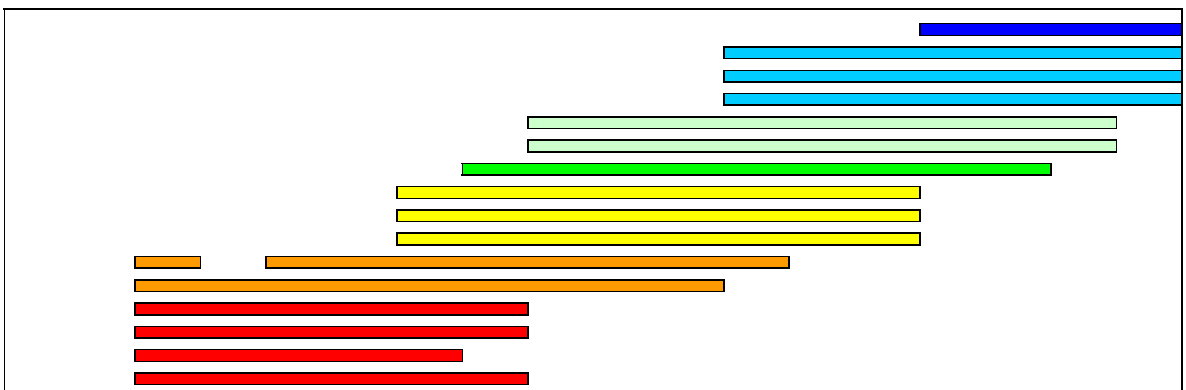
Figure 5. Summary statistics for (a) salinity and (b) pH by water body and results of comparison test for monthly mean data by water body for July-September (includes all sites sampled 3 or more years). See Figure 4 for Water Body names.

(a) DO concentration



Water Body	HR	PH	NMR	RR	QB	MQ	PR	HS	FS	MB	PC	CE	EB	WB	EC	OFF
Mean	7.56	7.70	7.74	7.77	7.88	8.04	8.07	8.18	8.30	8.43	8.44	8.47	8.54	8.56	8.82	9.09
Standard Deviation	0.75	0.97	0.98	0.58	0.70	1.01	0.88	0.75	0.78	0.69	0.61	1.07	0.63	0.81	1.00	0.54
Minimum	5.8	4.9	4.8	6.4	4.8	4.7	6.2	6.1	5.4	6.7	6.9	3.2	6.8	5.2	6.8	8.0
Maximum	10.5	10.7	10.3	9.6	9.8	11.6	11.0	11.1	10.9	10.4	9.7	11.1	10.4	11.2	11.5	10.2
Count	74	202	128	69	217	76	26	198	188	114	160	113	145	305	126	100

(b) DO percent saturation



Water Body	PR	PH	HR	RR	NMR	QB	HS	CE	PC	MQ	FS	WB	EB	MB	OFF	EC
Mean	93.9	95.1	96.1	96.3	98.9	100.7	102.4	102.6	102.8	104.3	105.0	105.4	107.6	108.9	109.4	109.8
Standard Deviation	8.7	12.7	10.0	6.6	11.9	9.6	10.1	13.5	7.8	12.8	10.5	10.8	8.8	10.0	8.0	13.7
Minimum	74.1	60.7	74.4	77.5	67.2	59.2	81.5	37.6	84.8	62.8	67.7	66.5	87.1	87.1	92.8	79.6
Maximum	113.6	145.5	127.5	109.9	133.2	127.5	142.6	141.5	123.0	146.6	142.3	137.2	140.6	137.3	129.5	148.0
Count	26	201	74	69	127	217	198	113	159	75	187	299	145	114	100	126

Figure 6. Summary statistics for (a) DO concentration and (b) DO percent saturation by water body and results of comparison test for monthly mean data by water body for July-September (includes all sites sampled 3 or more years). See Figure 4 for Water Body names.

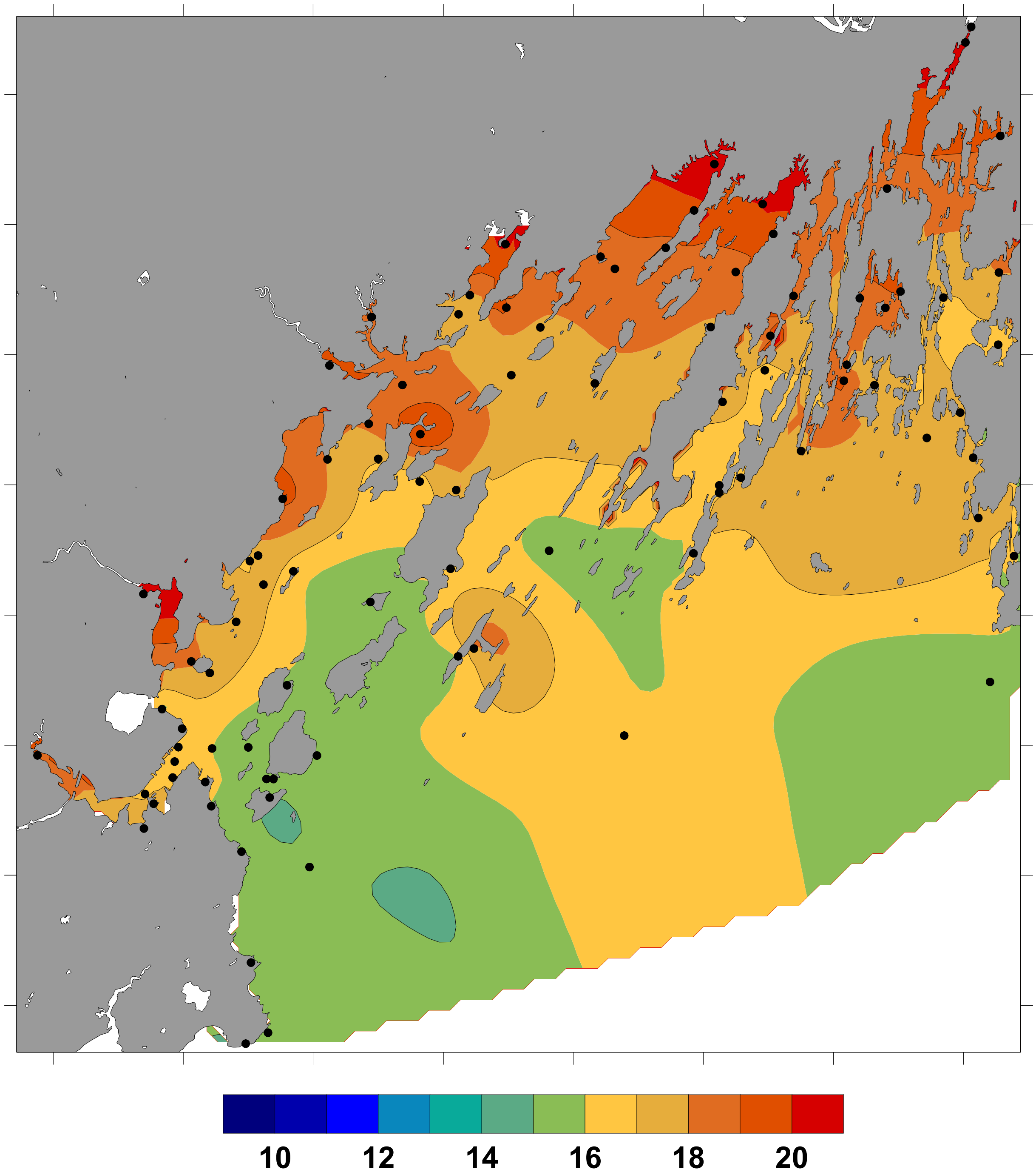


Figure 7. Spatial distribution of 12-year mean summer surface temperature (°C).

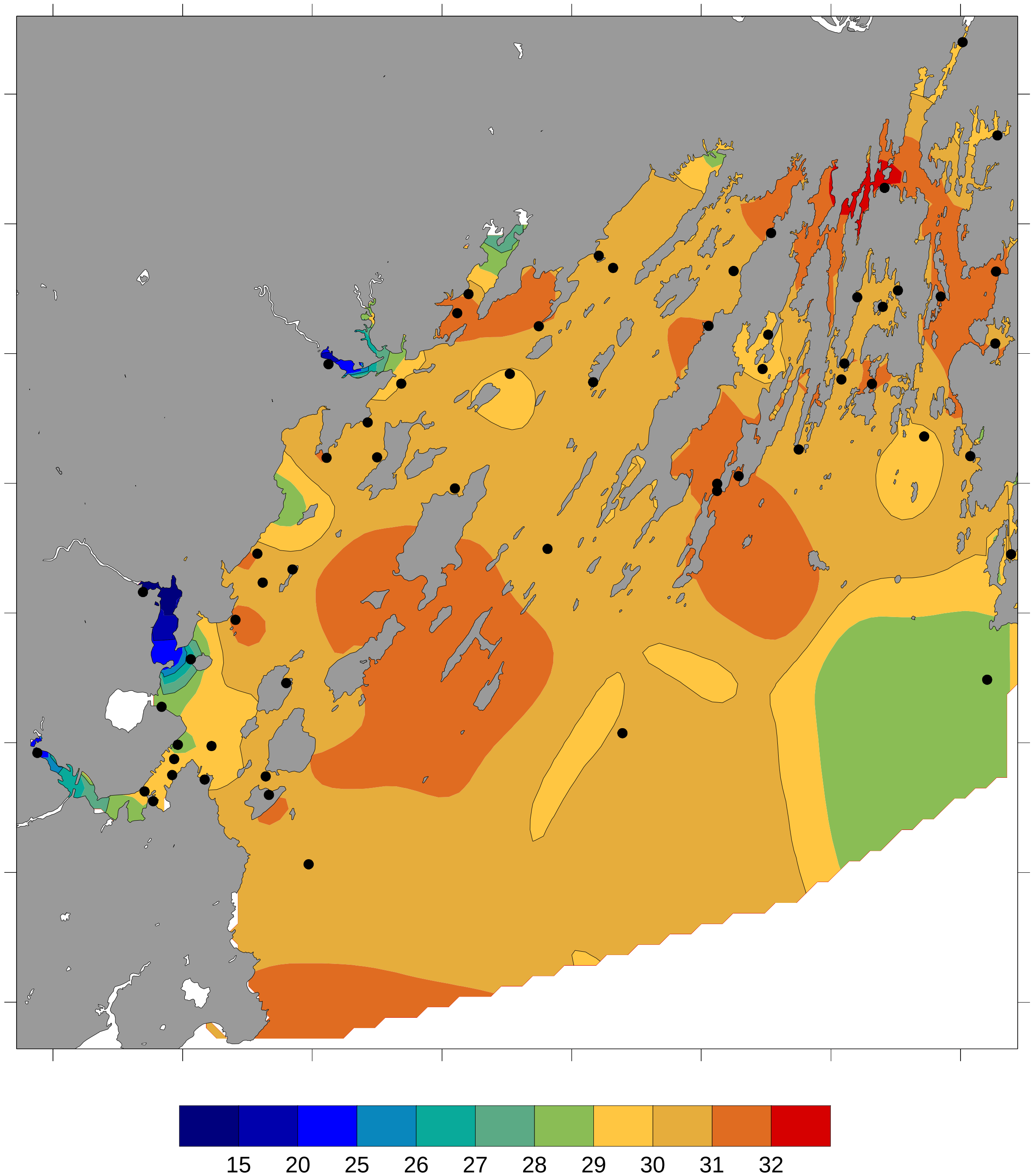


Figure 8. Spatial distribution of 12-year mean summer surface salinity (ppt).

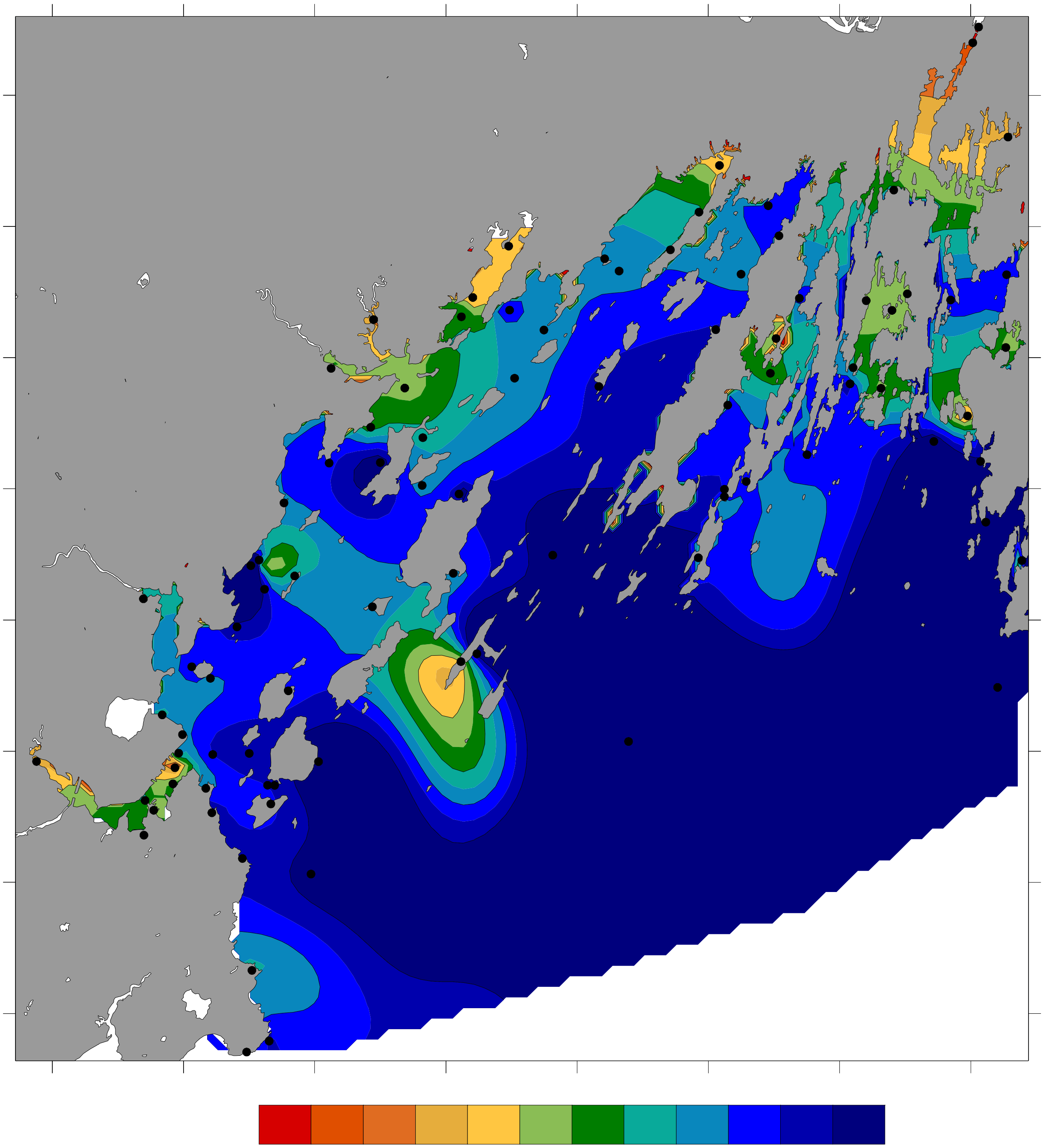


Figure 9. Spatial distribution of 12-year mean summer surface DO concentration (mg/l).

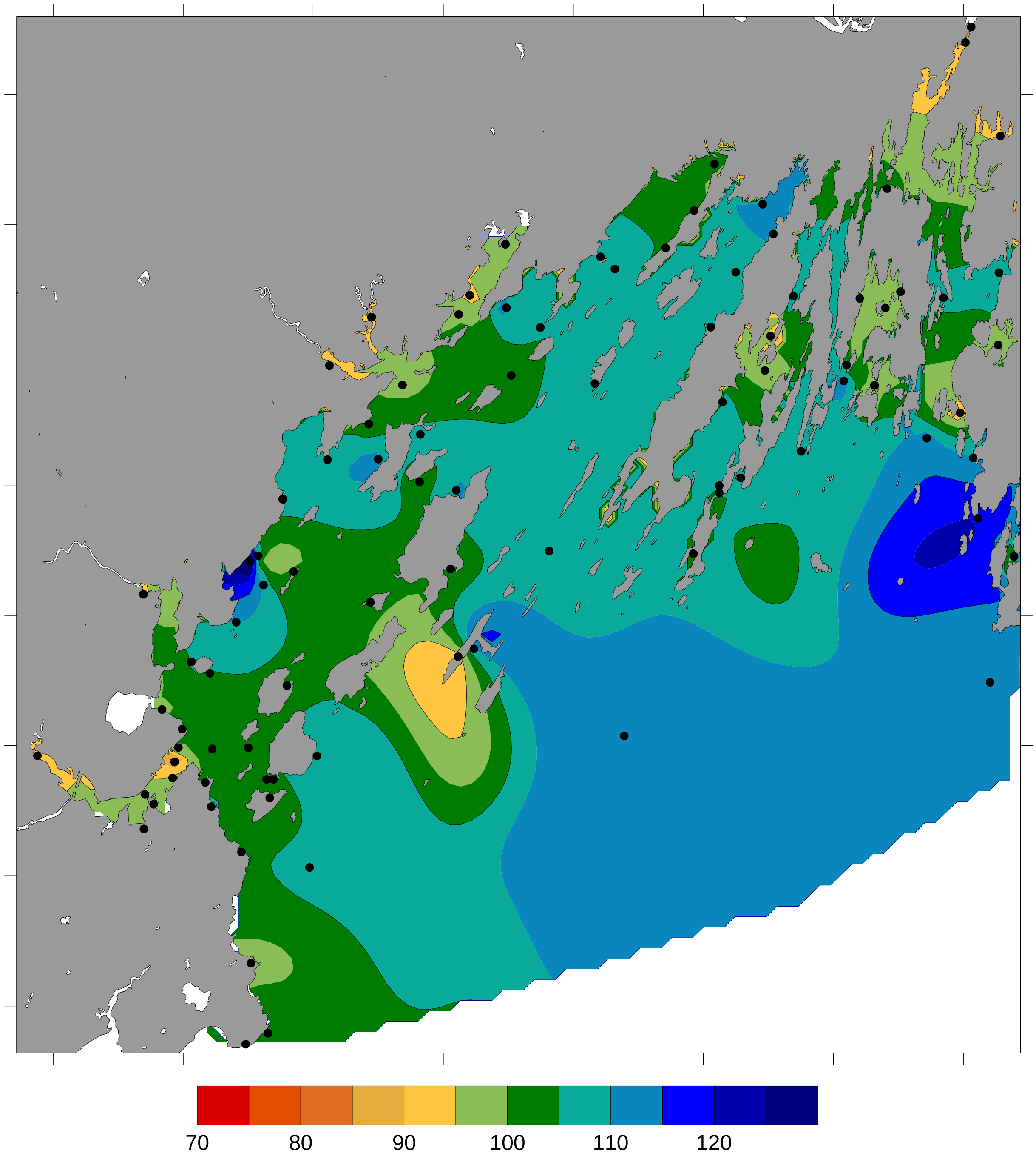


Figure 10. Spatial distribution of 12-year mean summer surface DO percent saturation (%).

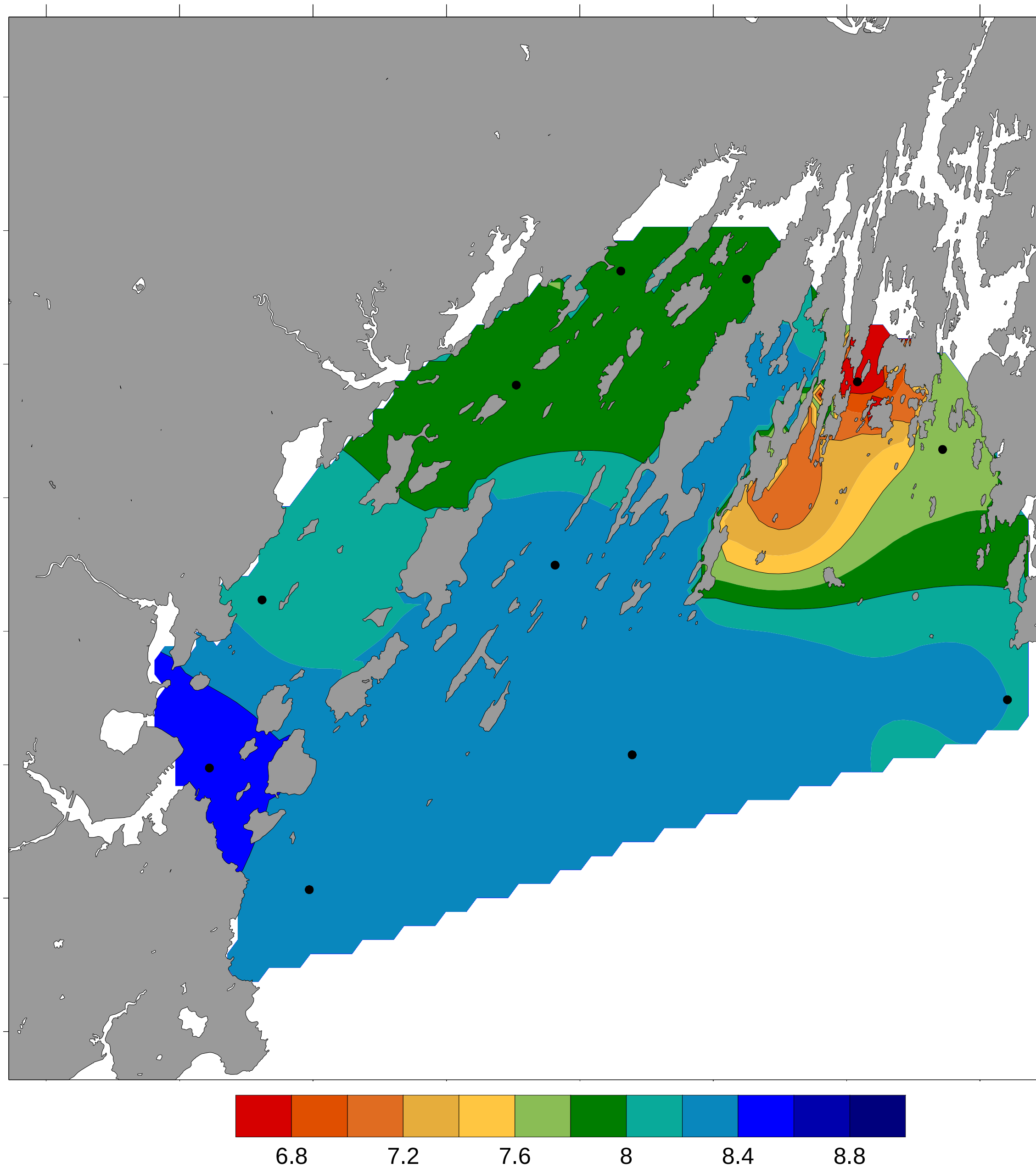


Figure 11. Spatial distribution of 12-year mean summer bottom water DO concentration (mg/l).

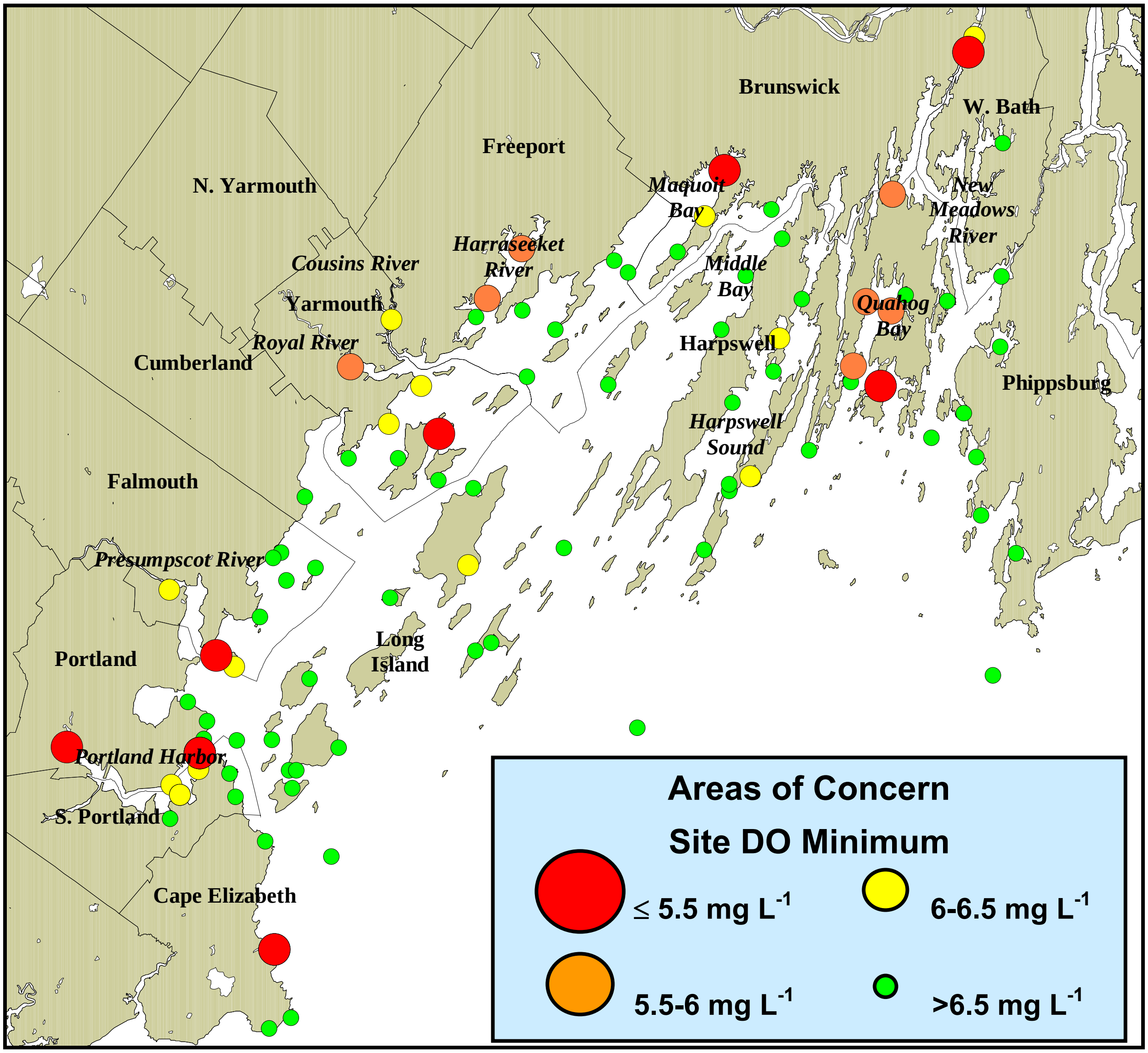


Figure 12. Spatial distribution of surface site minimum monthly mean DO concentrations observed during the entire 93-04 period.

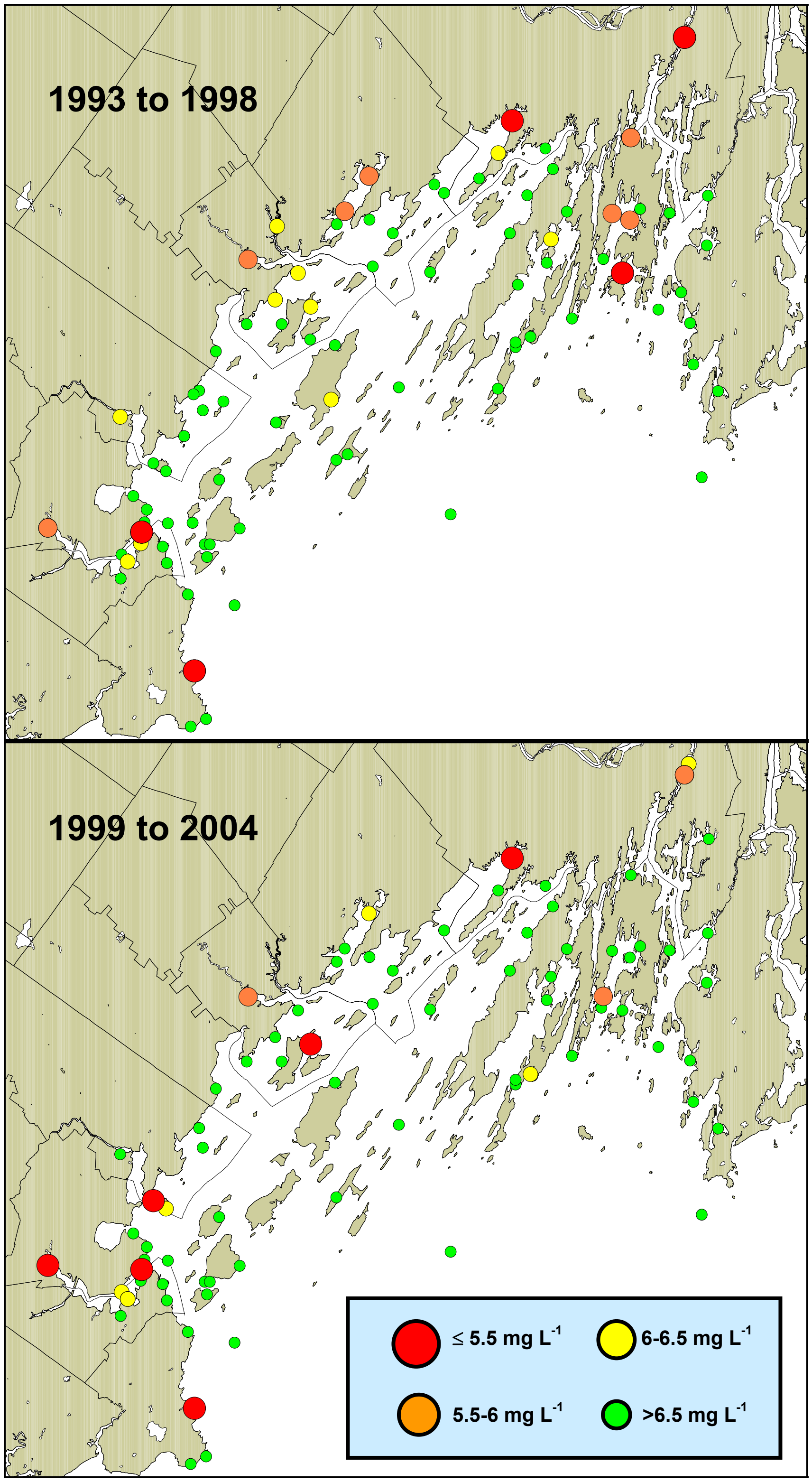


Figure 13. Spatial distribution of surface site minimum monthly mean DO concentrations observed over the 1993-1998 (top) and 1999-2004 (bottom) periods.

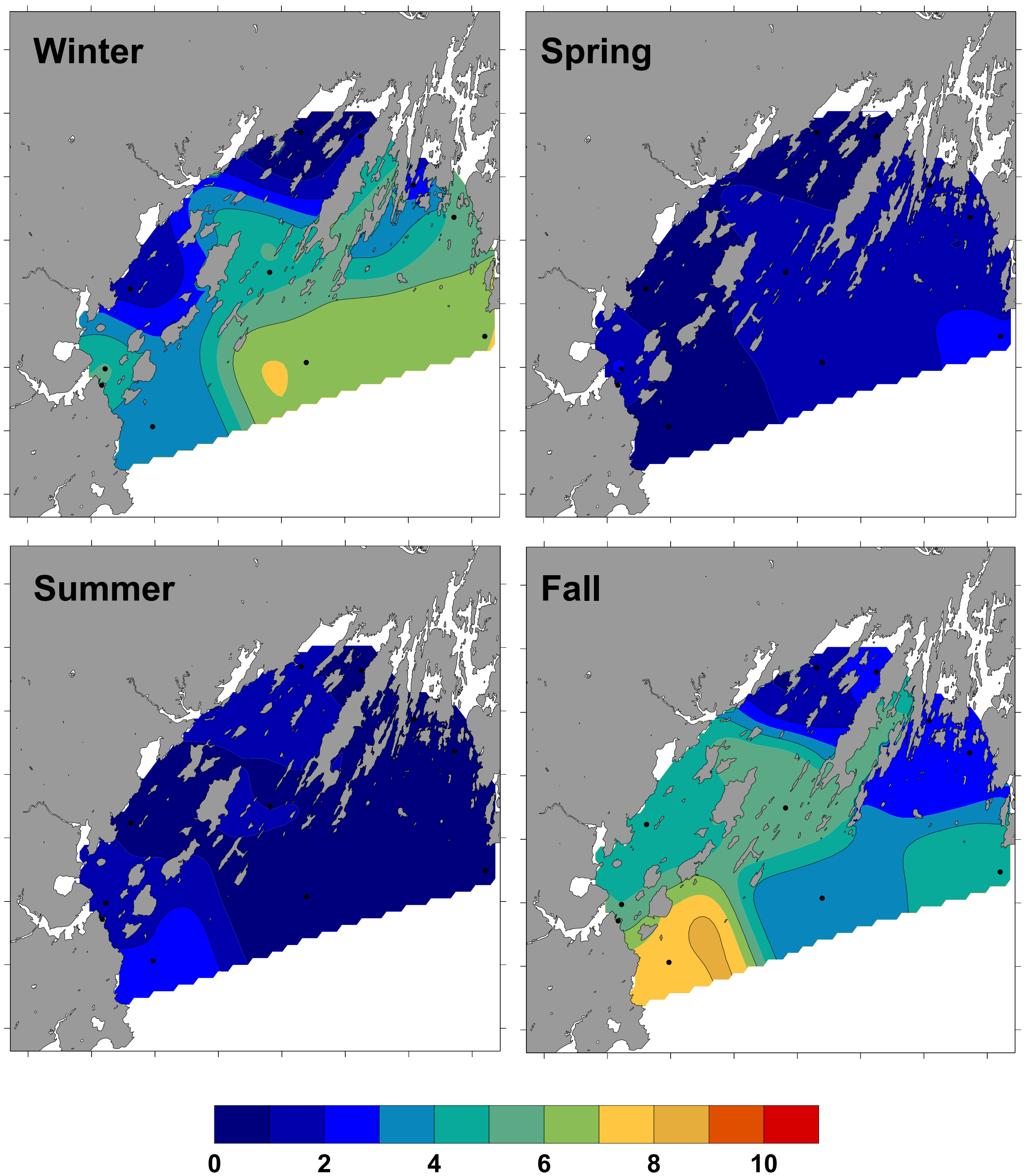


Figure 14. Spatial distribution of seasonal surface water NO_3+NO_2 concentrations (µM). Seasonal means based on 2001-2004 data.

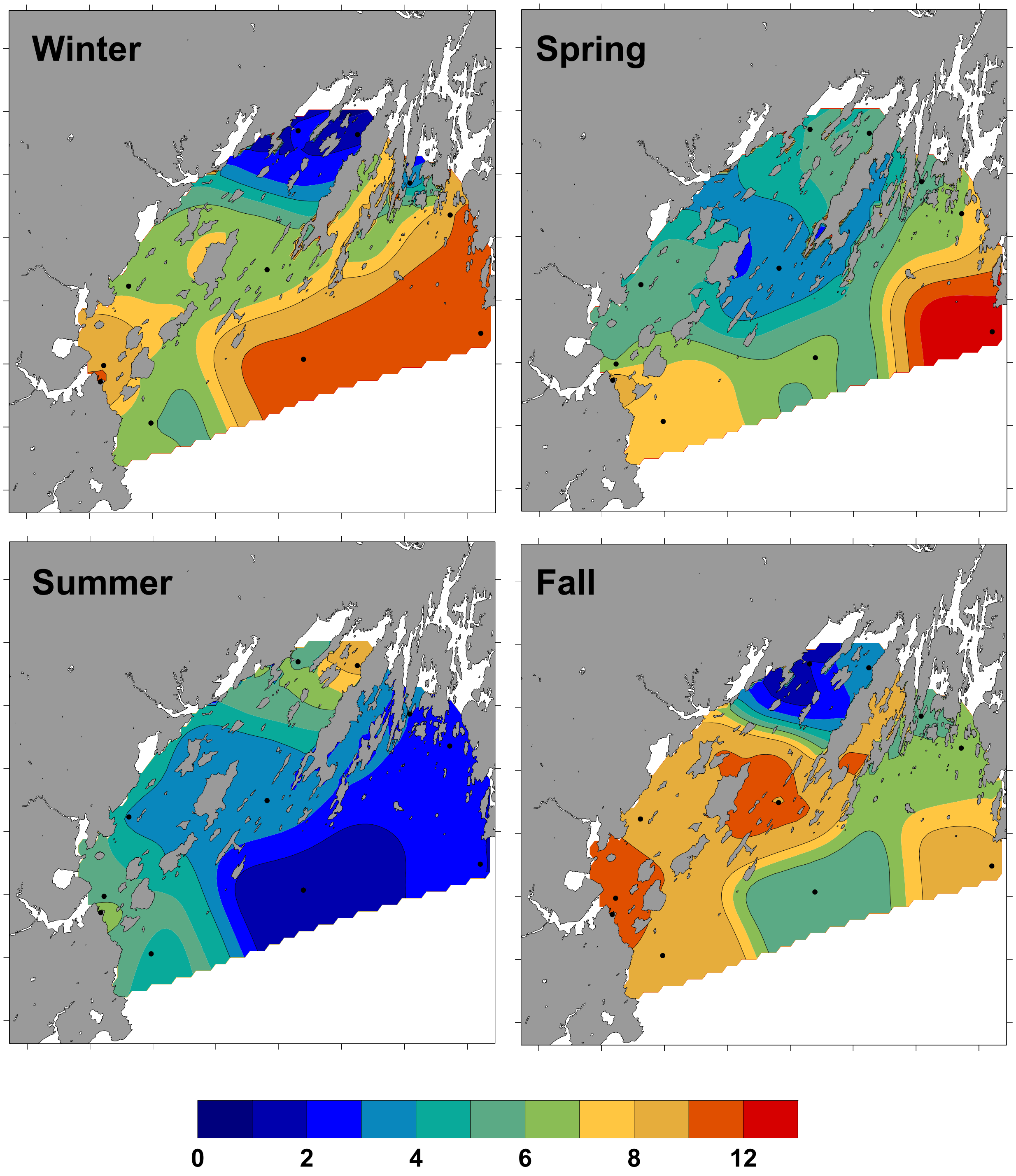


Figure 15. Spatial distribution of seasonal surface water SiO_4 concentrations (μM). Seasonal means based on 2001-2004 data.

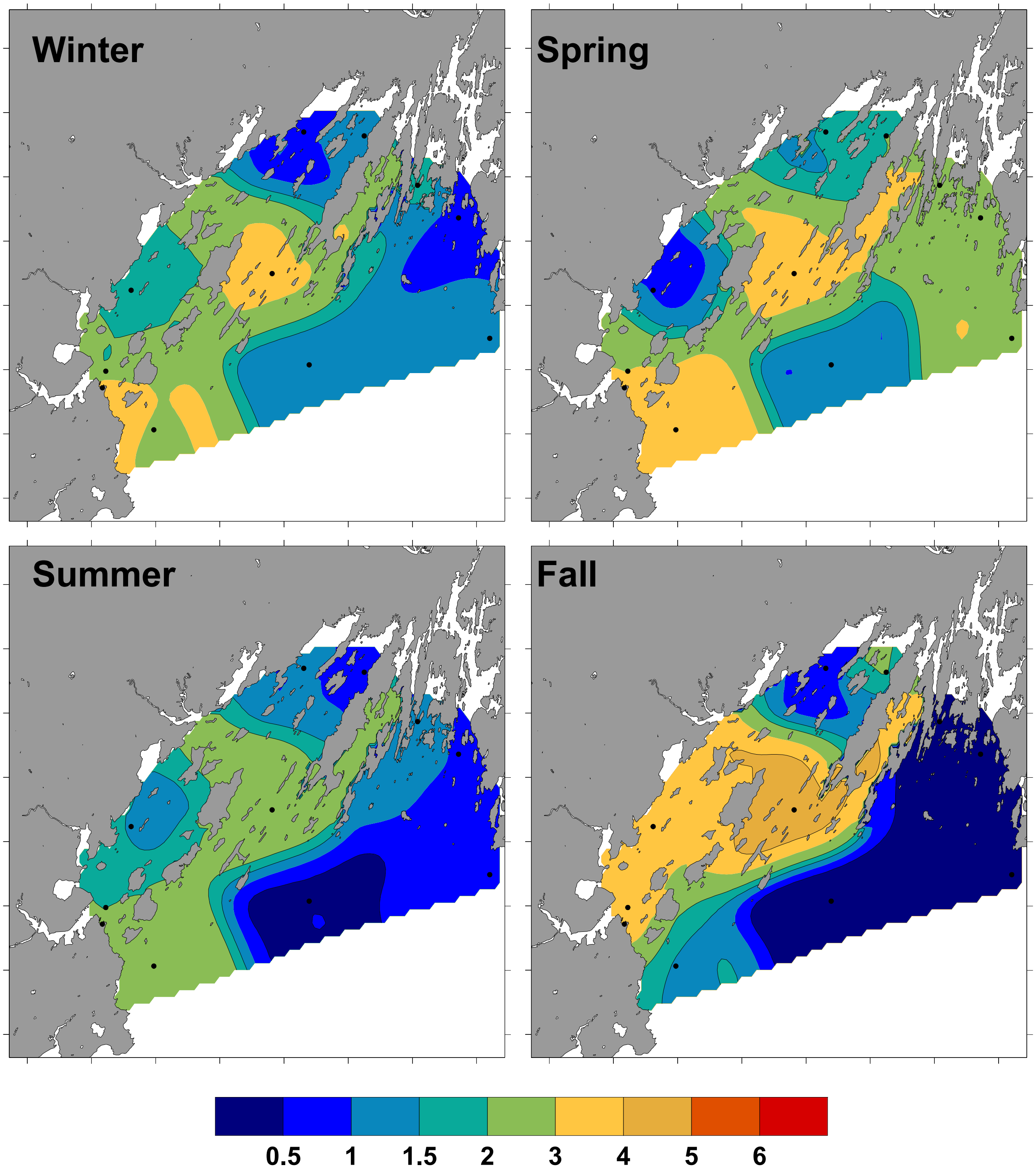


Figure 16. Spatial distribution of seasonal surface water NH_4 concentrations (µM). Seasonal means based on 2001-2004 data.

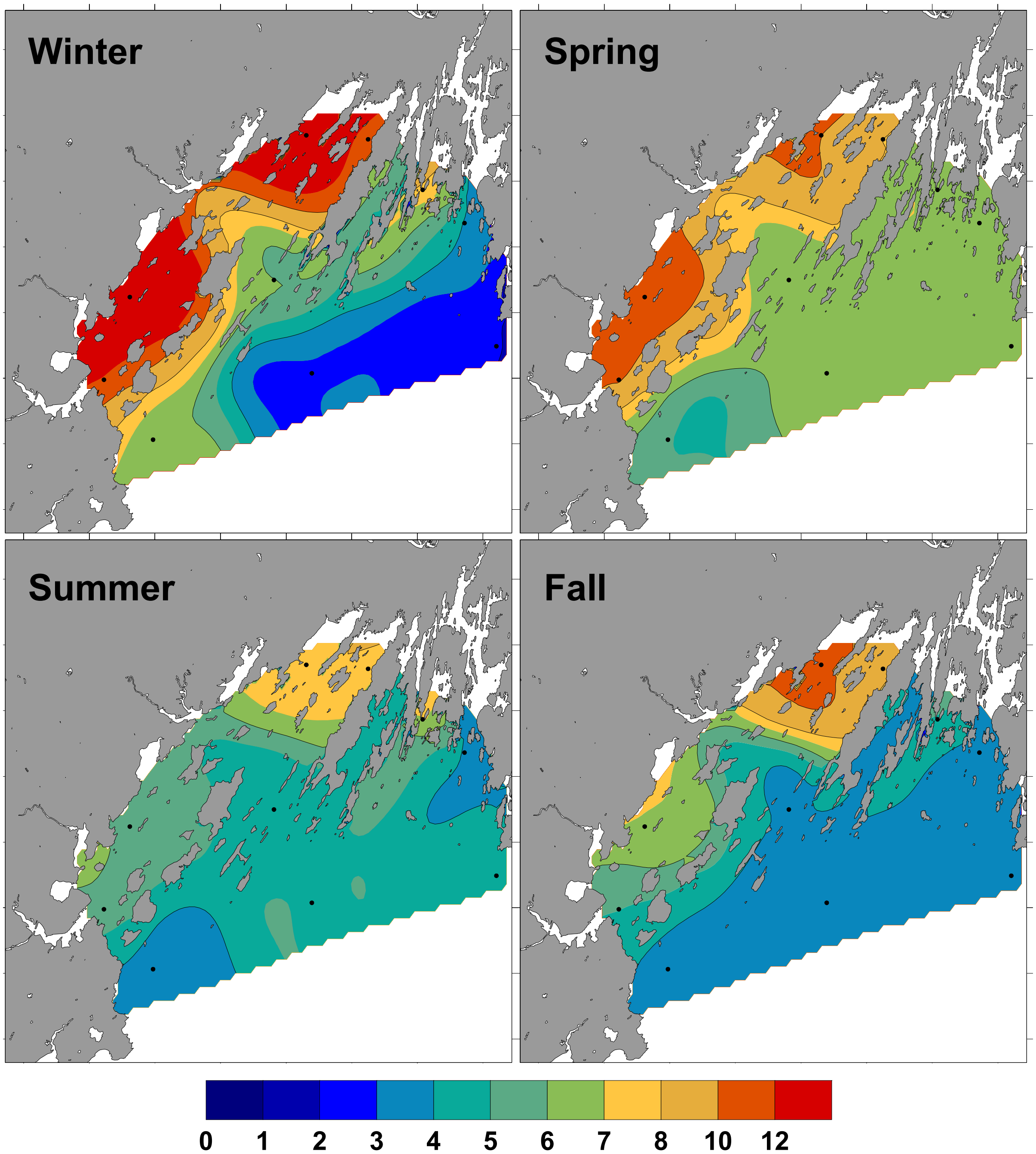
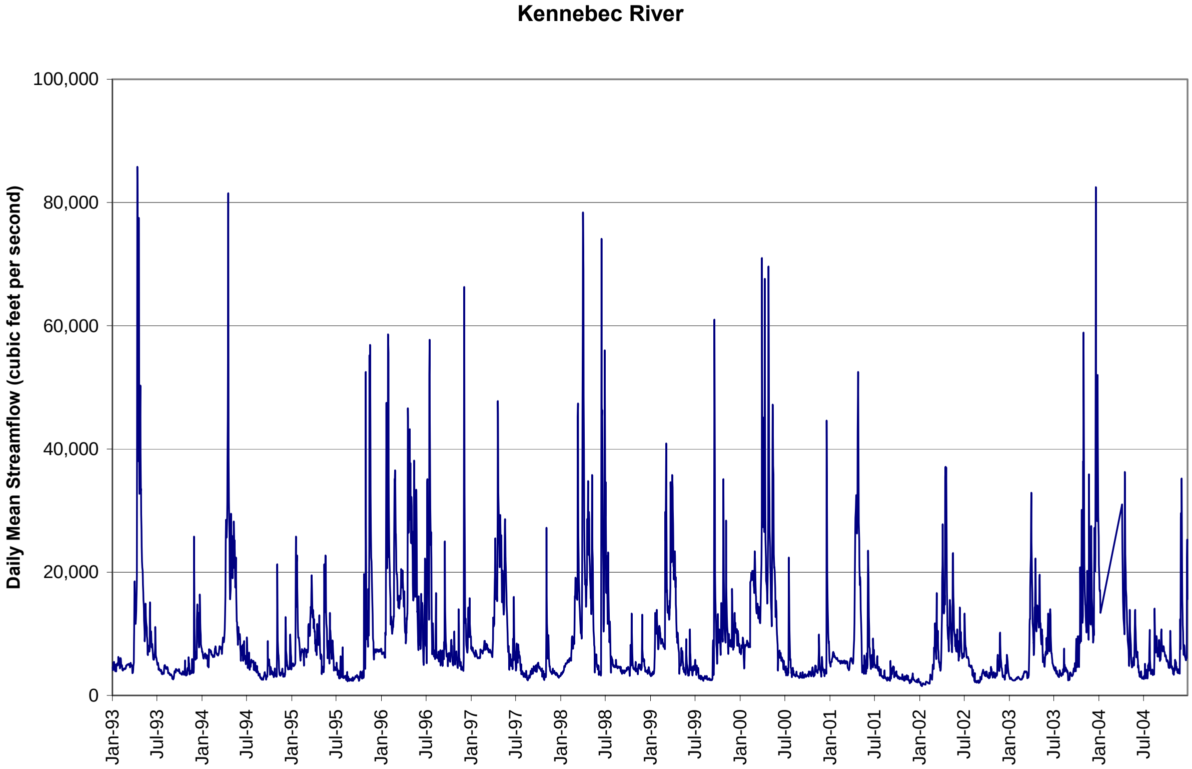


Figure 17. Spatial distribution of seasonal depth averaged chlorophyll concentrations (μg/l). Seasonal means based on 2000-2004 data.



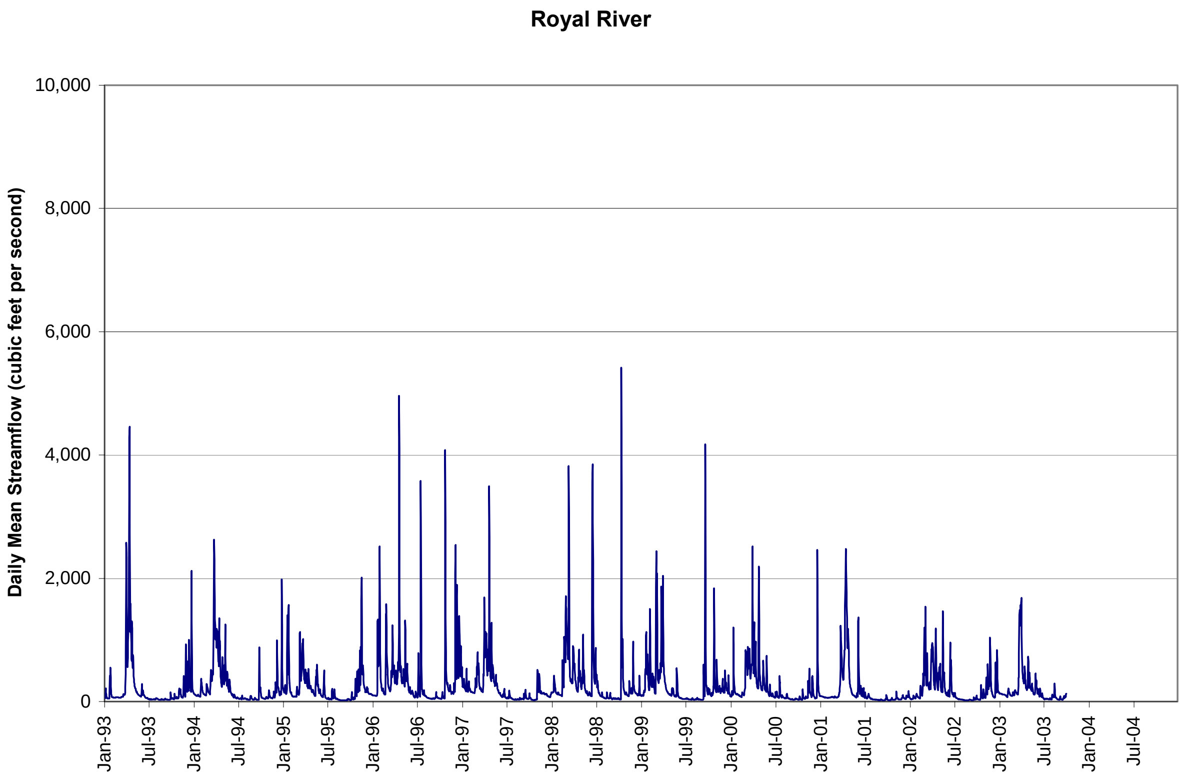


Figure 18. River flow along the Kennebec and Royal Rivers (cfs) from 1993-2004. Data provided by USGS and available at http://nwis.waterdata.usgs.gov/me/nwis/.

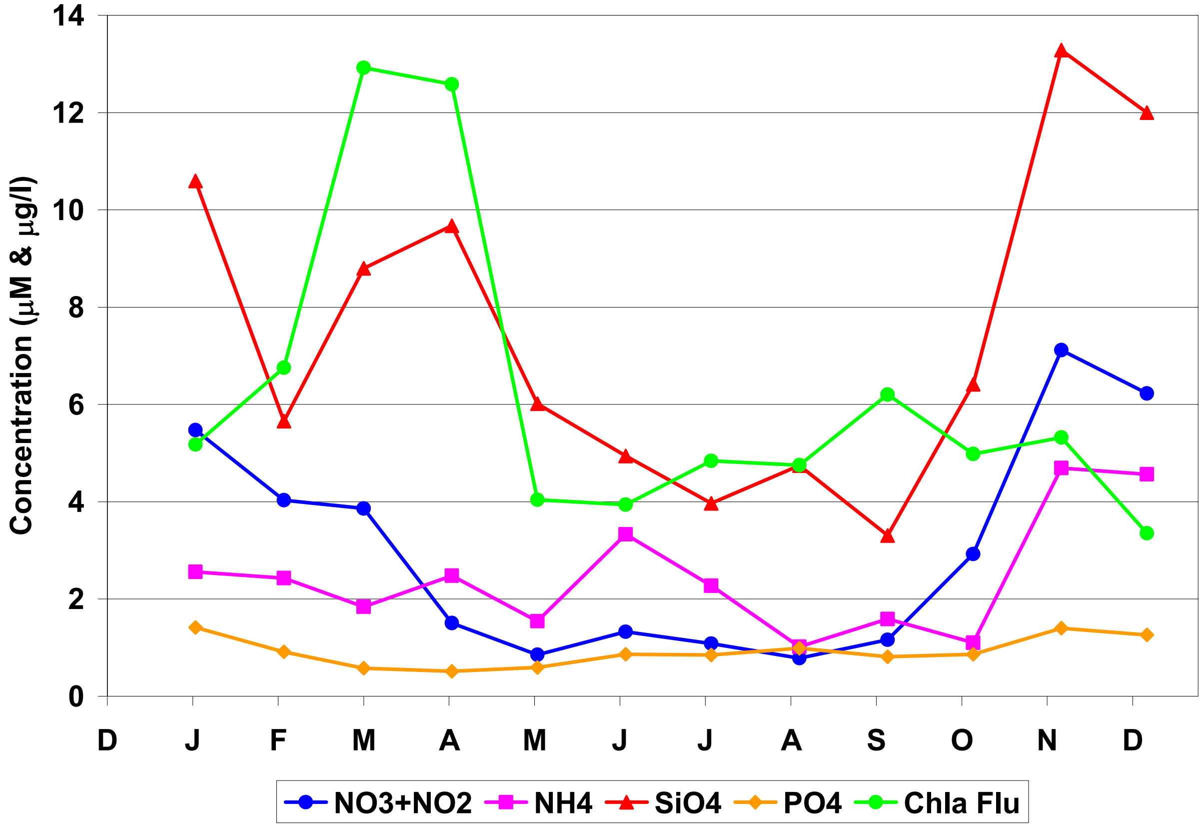


Figure 19. Seasonal Cycles of nutrient and chlorophyll concentrations (μM and μg/l, respectively). Monthly means for nutrient and chlorophyll data collected 2001-2004.

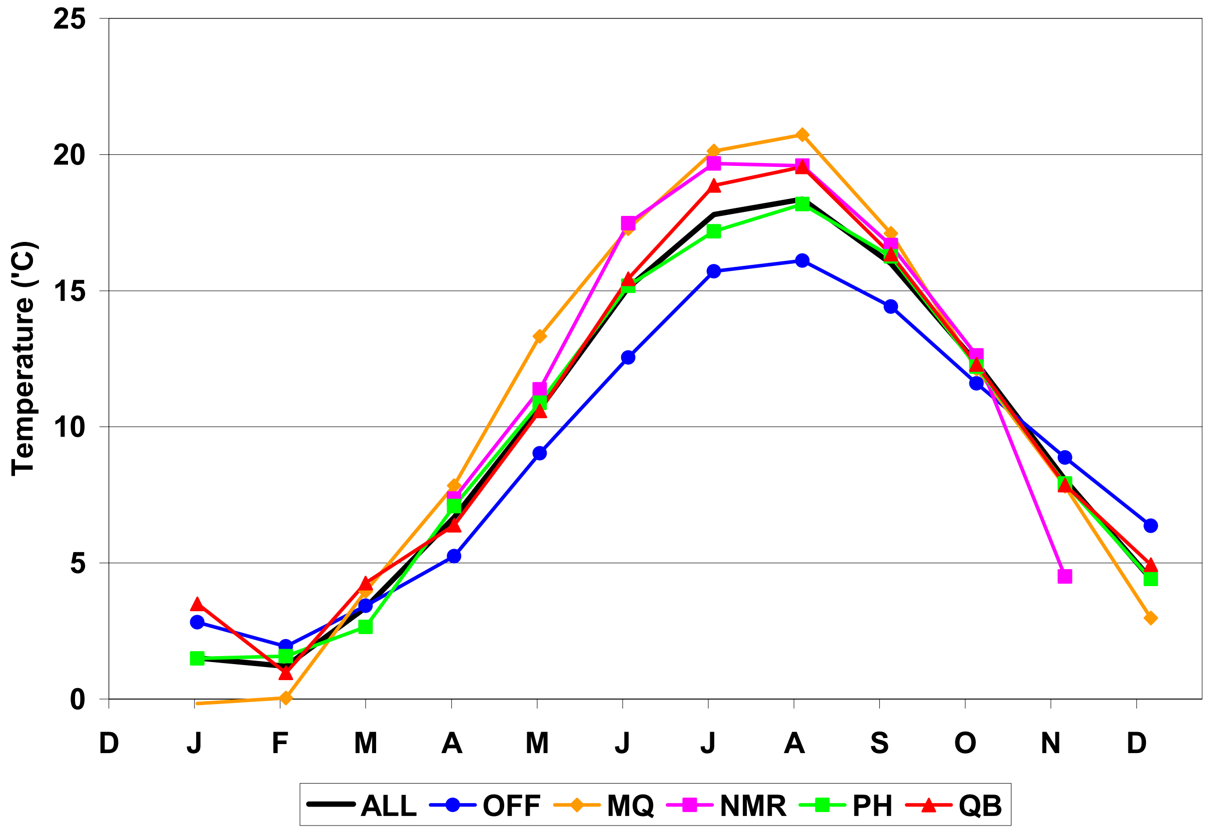


Figure 20. Seasonal cycles of Temperature (°C) for selected waterbodies. Monthly means for entire 12-year period. See Figure 4 for Water Body names.

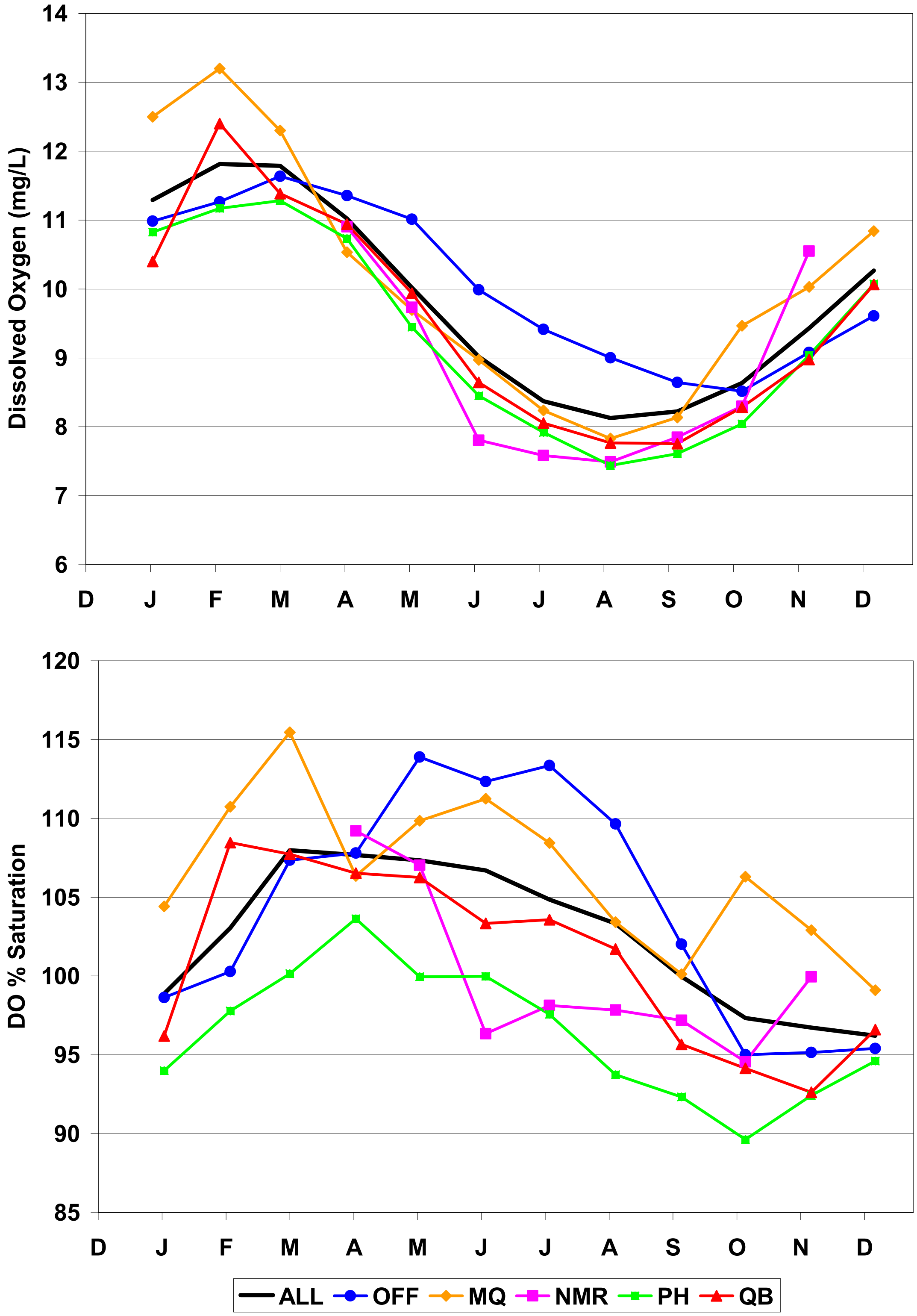


Figure 21. Seasonal cycles of DO concentration (mg/l) and DO percent saturation for selected waterbodies. Monthly means for entire 12-year period. See Figure 4 for Water Body names.

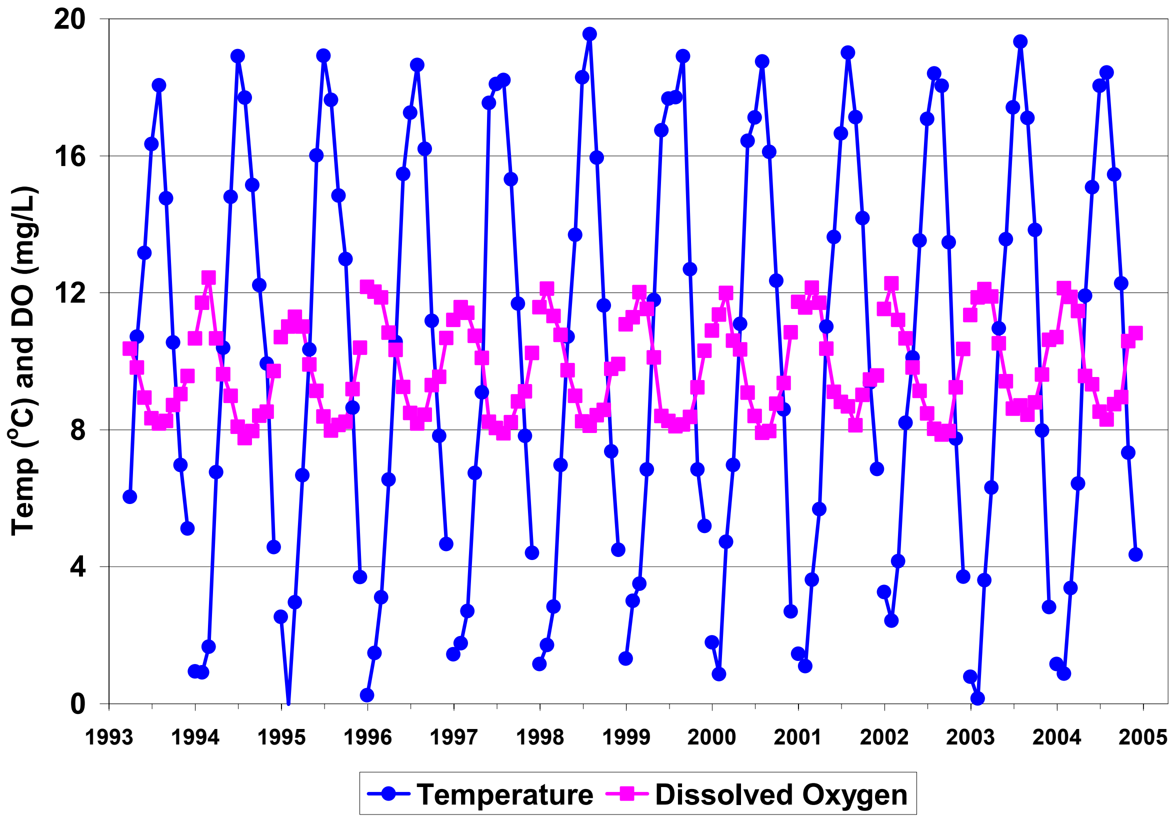


Figure 22. Time series of monthly mean temperature (°C) and DO concentration (mg/l) from all sites from 1993-2004.

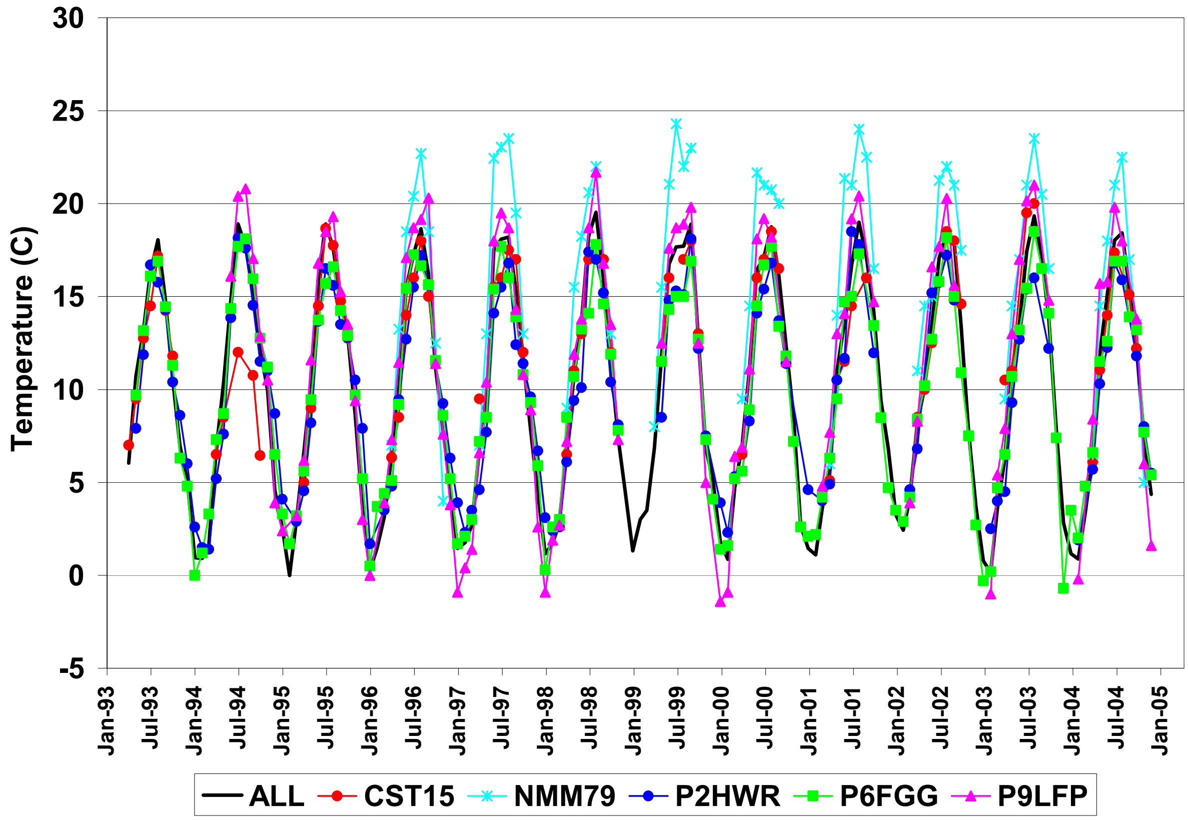


Figure 23. Seasonal cycles of Temperature (°C) for selected sites. Monthly means for entire 12-year period.

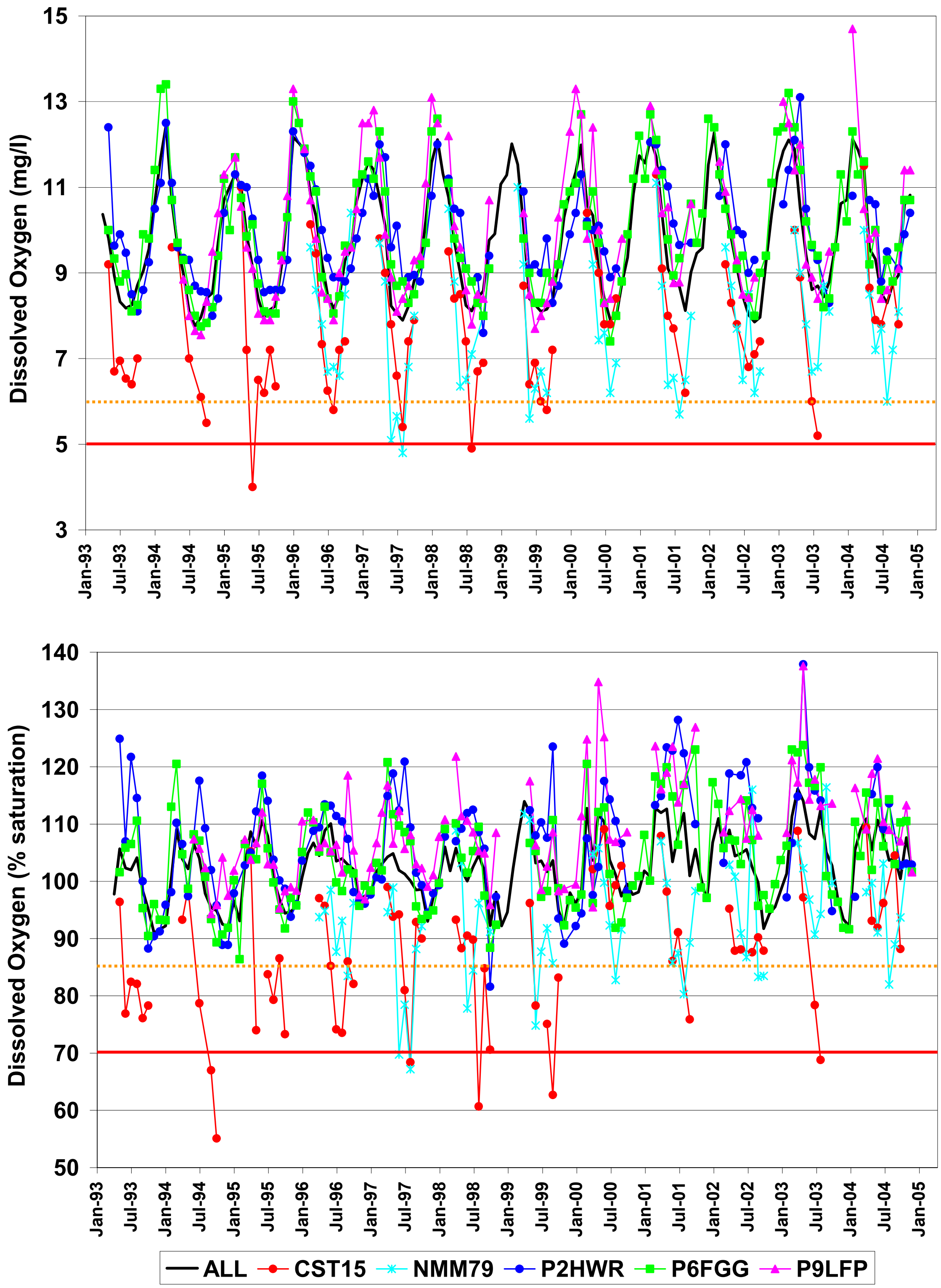


Figure 24. Seasonal cycles of DO concentration (mg/l) and percent saturation for selected sites. Monthly means for entire 12-year period. Orange dashed and red solid lines represent the current (%saturation) and proposed (concentration) State standards for SB and SC water, respectively.

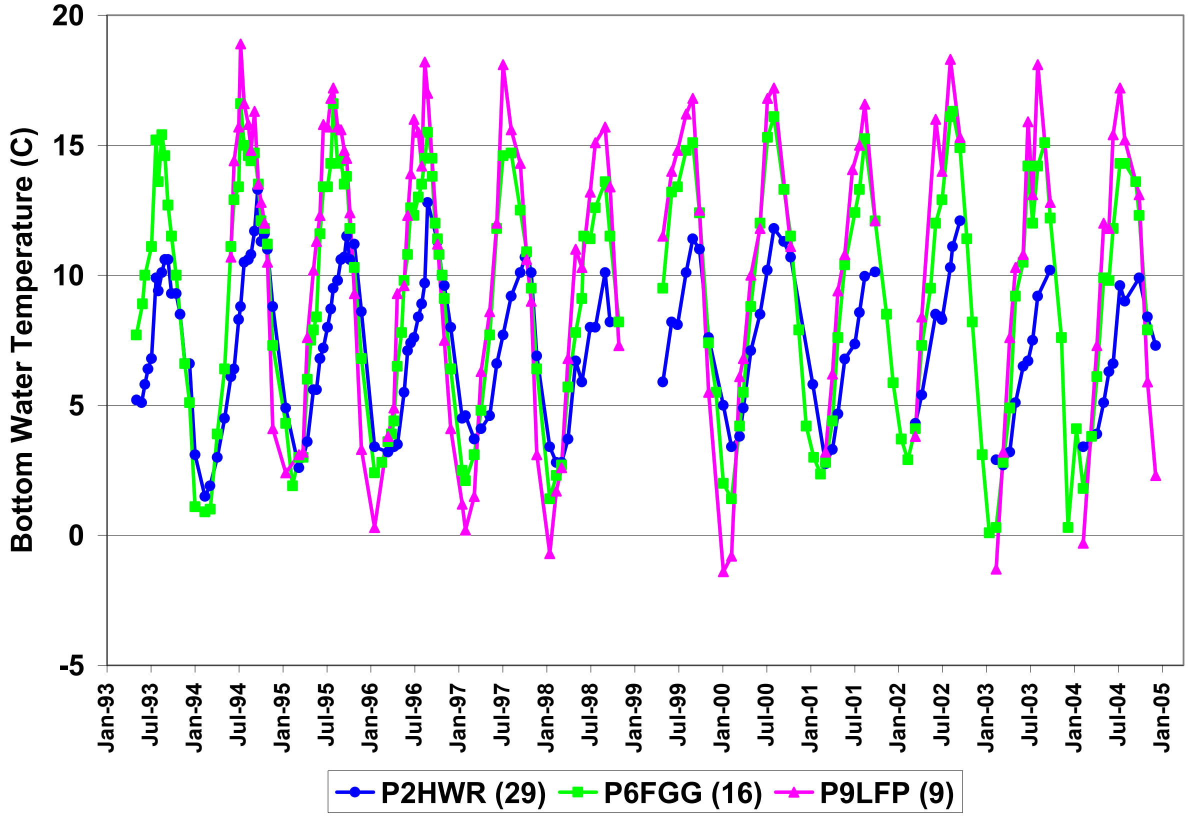


Figure 25. Seasonal cycles of bottom water temperature (°C) for selected profile sites. The numbers in parentheses are the average depths at each station.

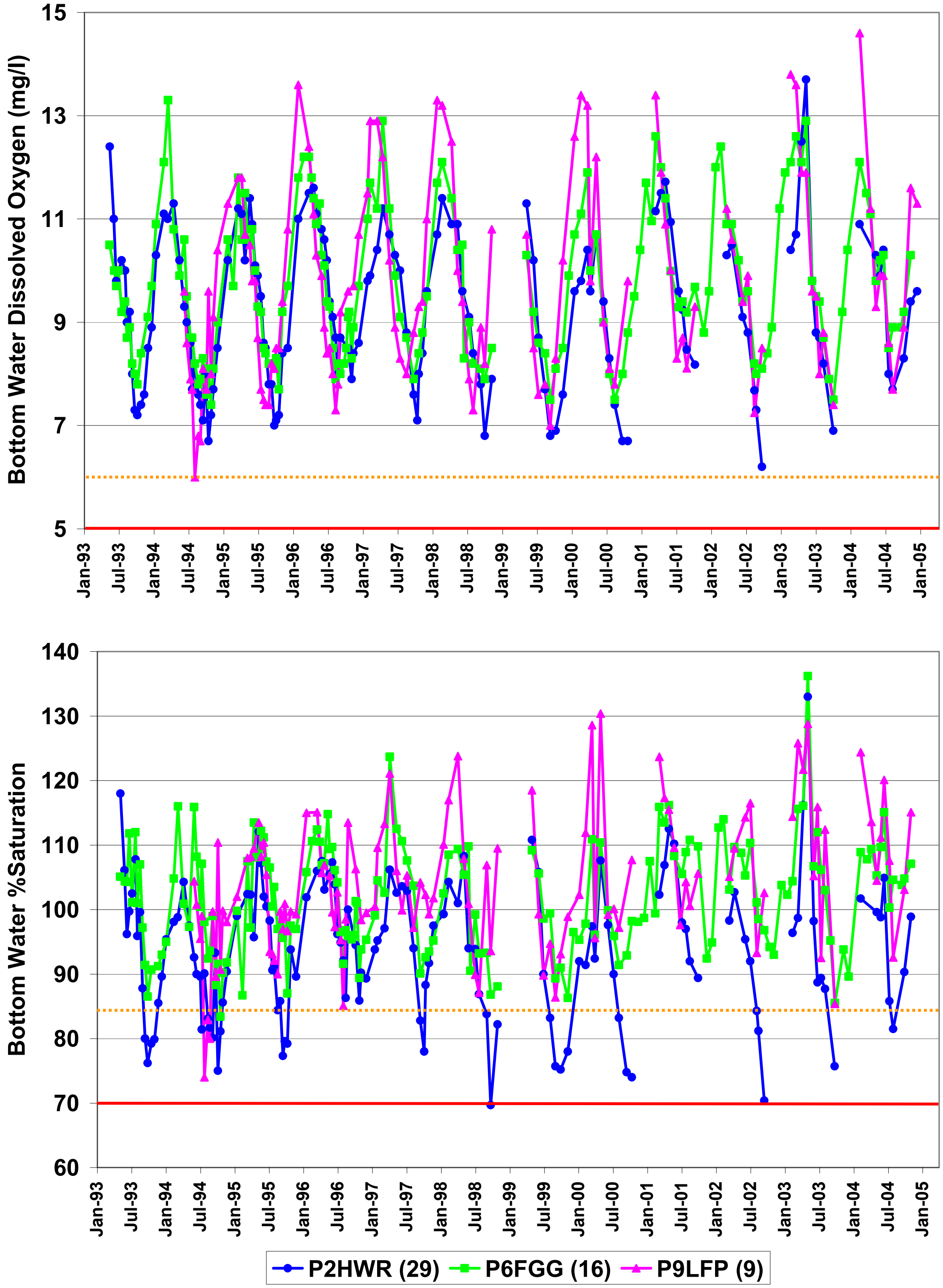


Figure 26. Seasonal cycles of bottom water DO concentration (mg/l) and percent saturation for selected profile sites. Orange dashed and red solid lines represent the current (%saturation) and proposed (concentration) State standards for SB and SC water, respectively.

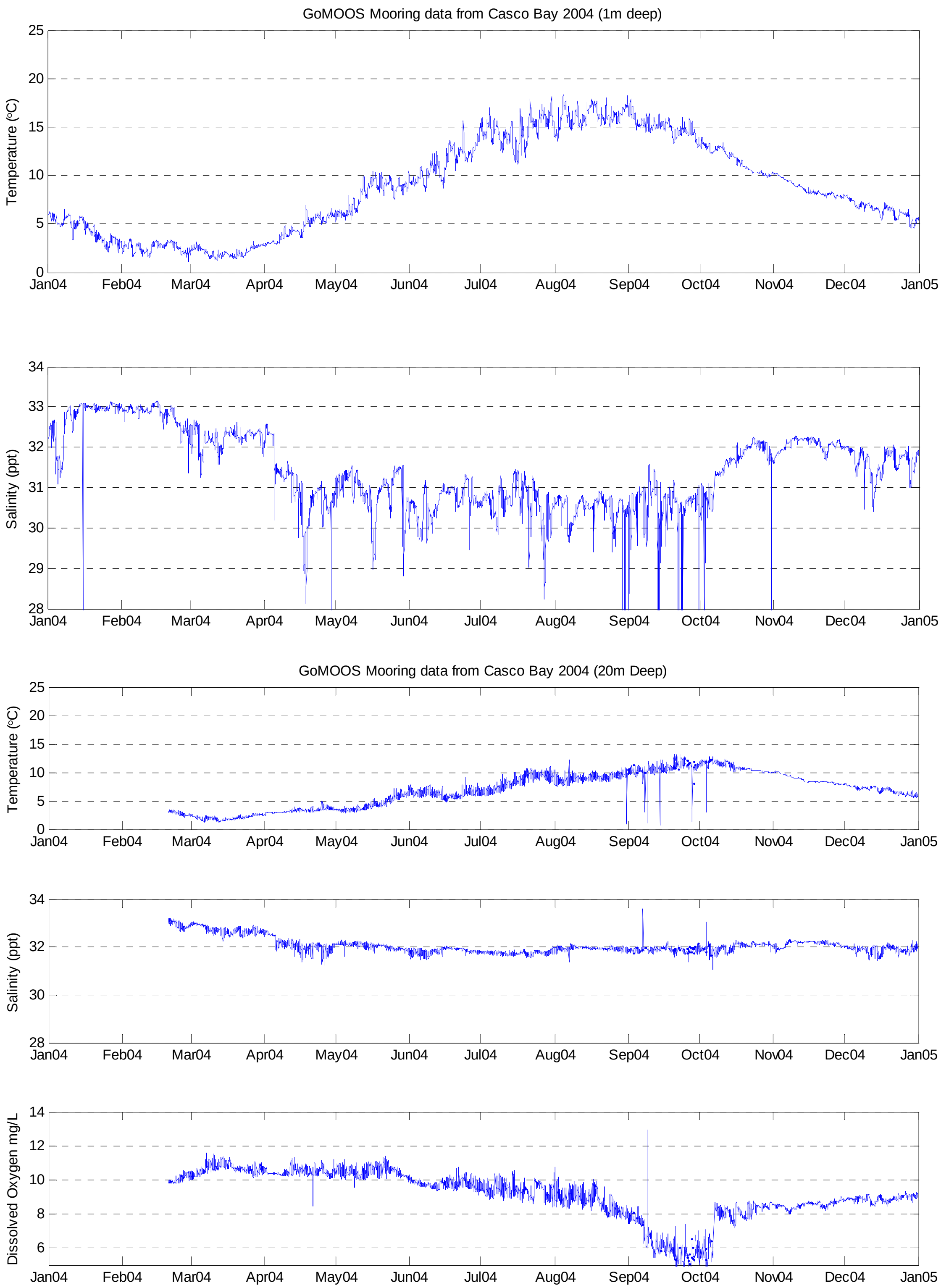


Figure 27. Surface and 20 m temperature (°C), salinity (ppt), and DO concentration (mg/l) data for 2004 from the GoMOOS C buoy in Casco Bay (http://www.gomoos.org/). Note that the sharp increase in DO in early October was due to a change in sensors suggesting the low DO in late September may be suspect.

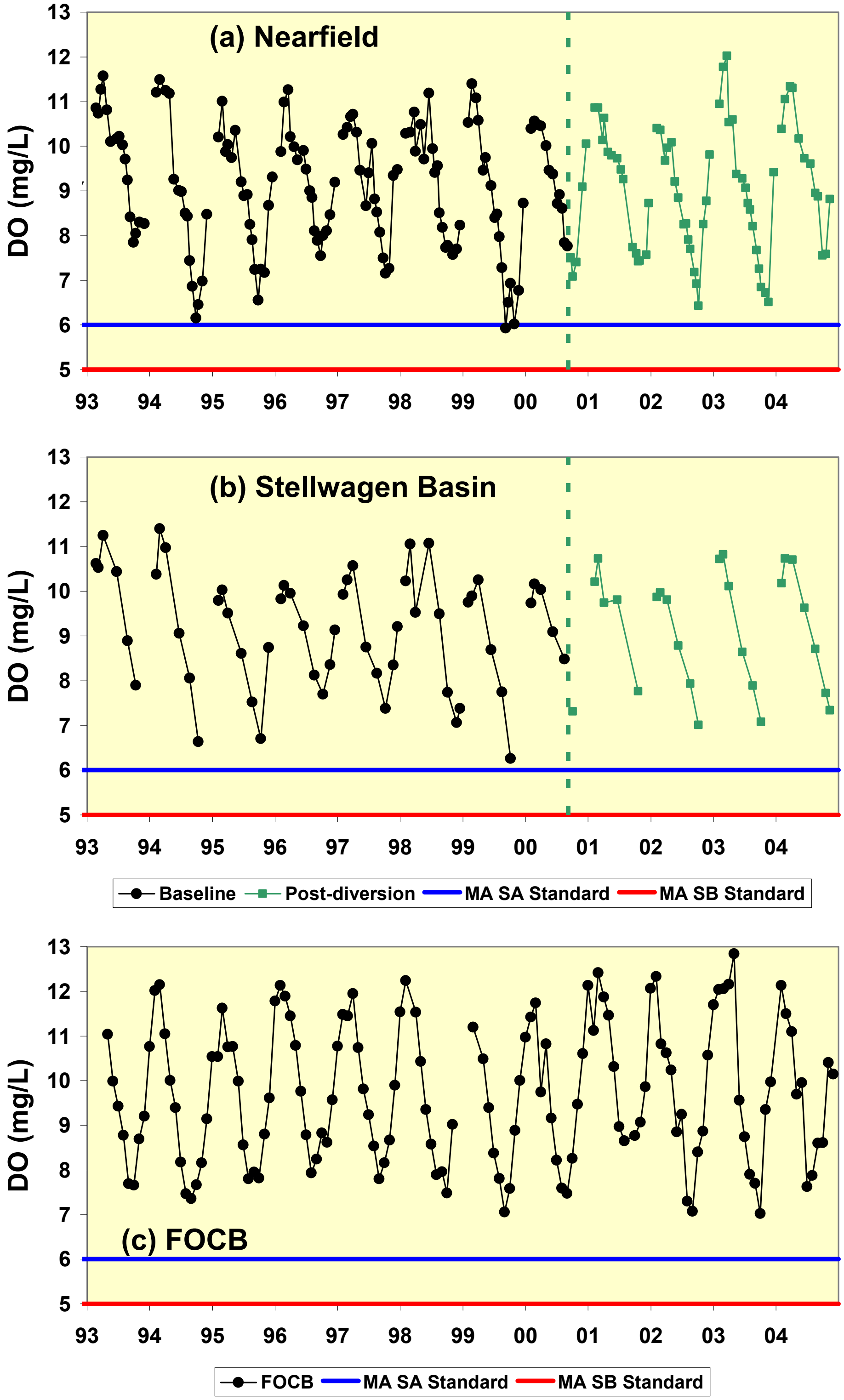


Figure 28. Bottom water DO concentration in Massachusetts and Casco Bays from 1993-2004. (a) MWRA nearfield area (15-35 m), (b) MWRA Stellwagen Basin area (75-90 m), and (c) FOCB profile stations (5-35 m)

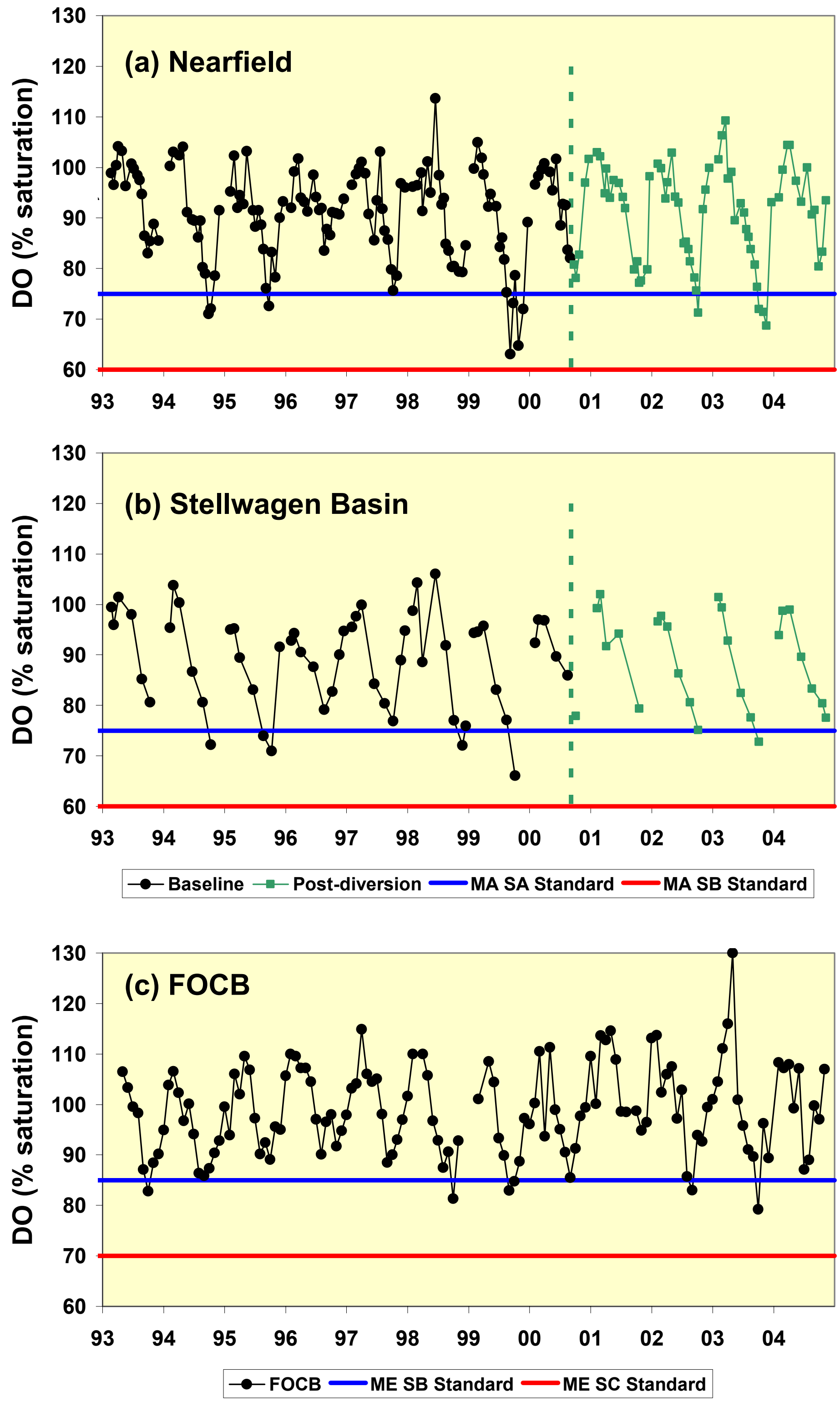


Figure 29. Bottom water DO percent saturation in Massachusetts and Casco Bays from 1993-2004. (a) MWRA nearfield area (15-35 m), (b) MWRA Stellwagen Basin area (75-90 m), and (c) FOCB profile stations (5-35 m)

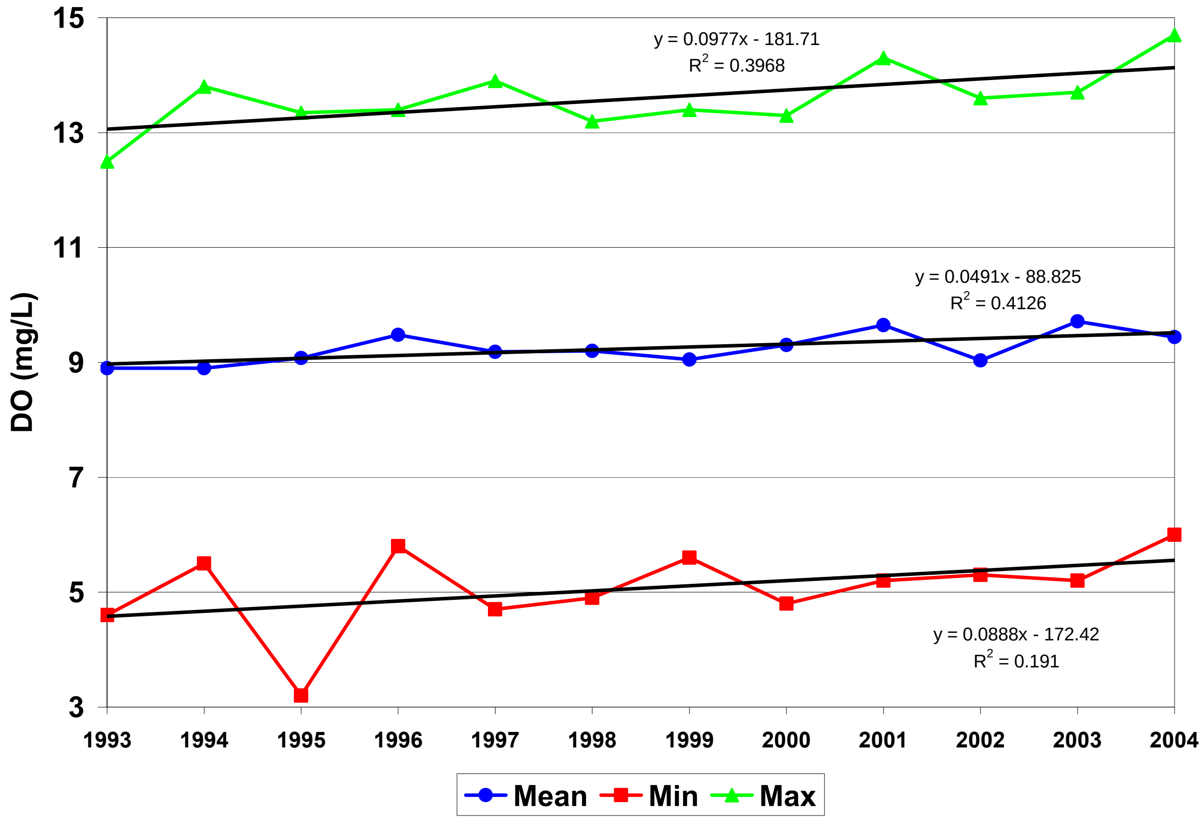


Figure 30. Annual mean, minimum and maximum for DO concentration (mg/l) using all estuarine surface data.

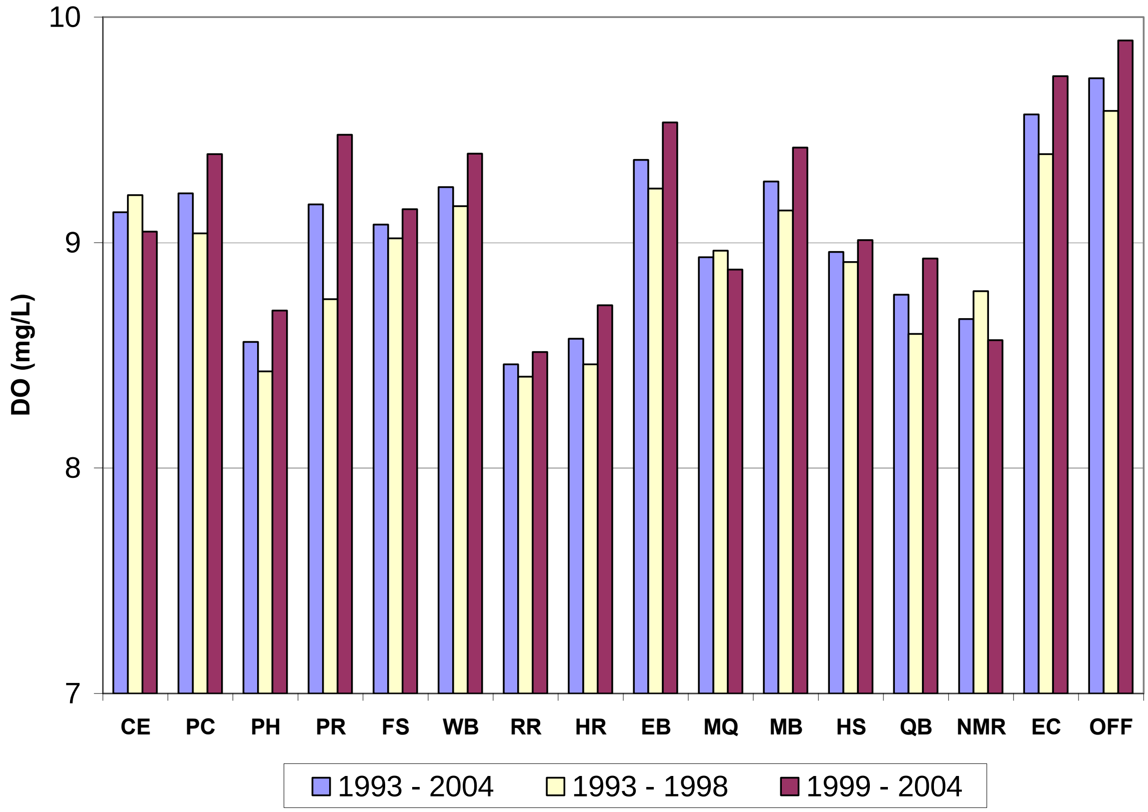


Figure 31. Mean DO concentration (mg/l) over all twelve years and in six year groupings of April to October surface data for all water bodies. See Figure 4 for Water Body names.

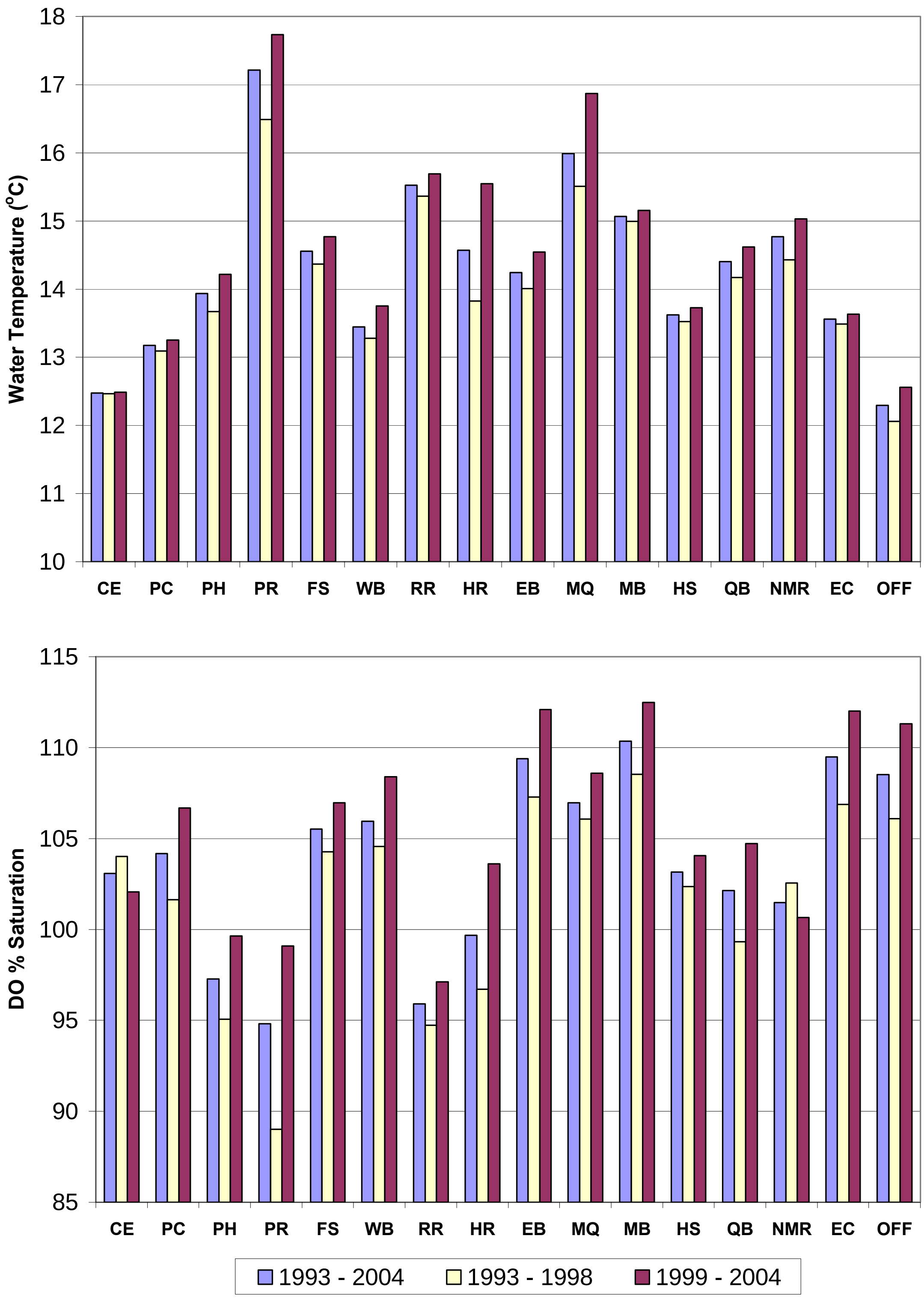


Figure 32. Mean Temperature (°C) and DO percent saturation over all twelve years and in six year groupings of April to October surface data for all water bodies. See Figure 4 for Water Body names.

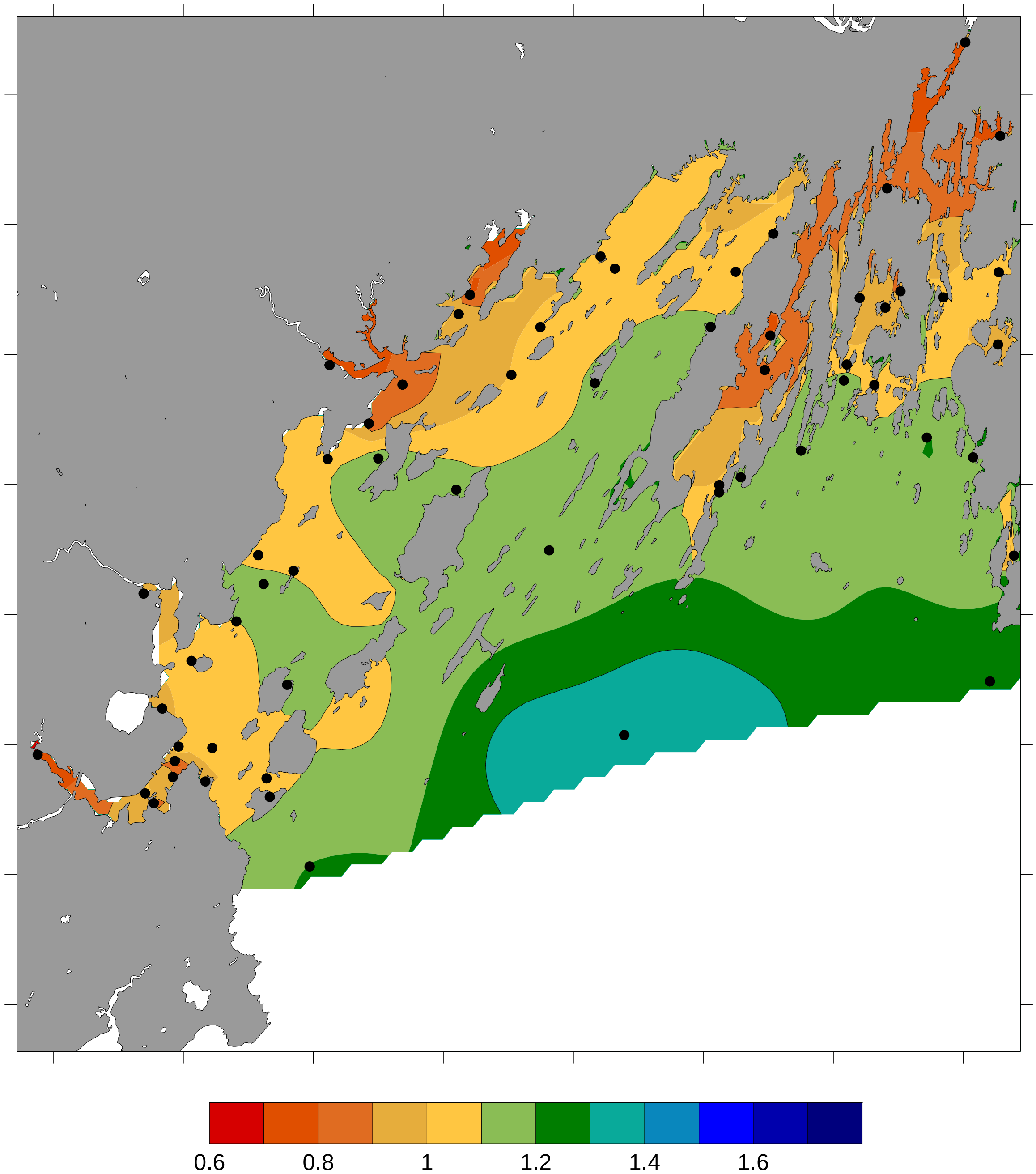


Figure 33. Spatial distribution of 12-year average Casco Bay Health Index. Data from 59 surface sites with sufficient Secchi depth data.

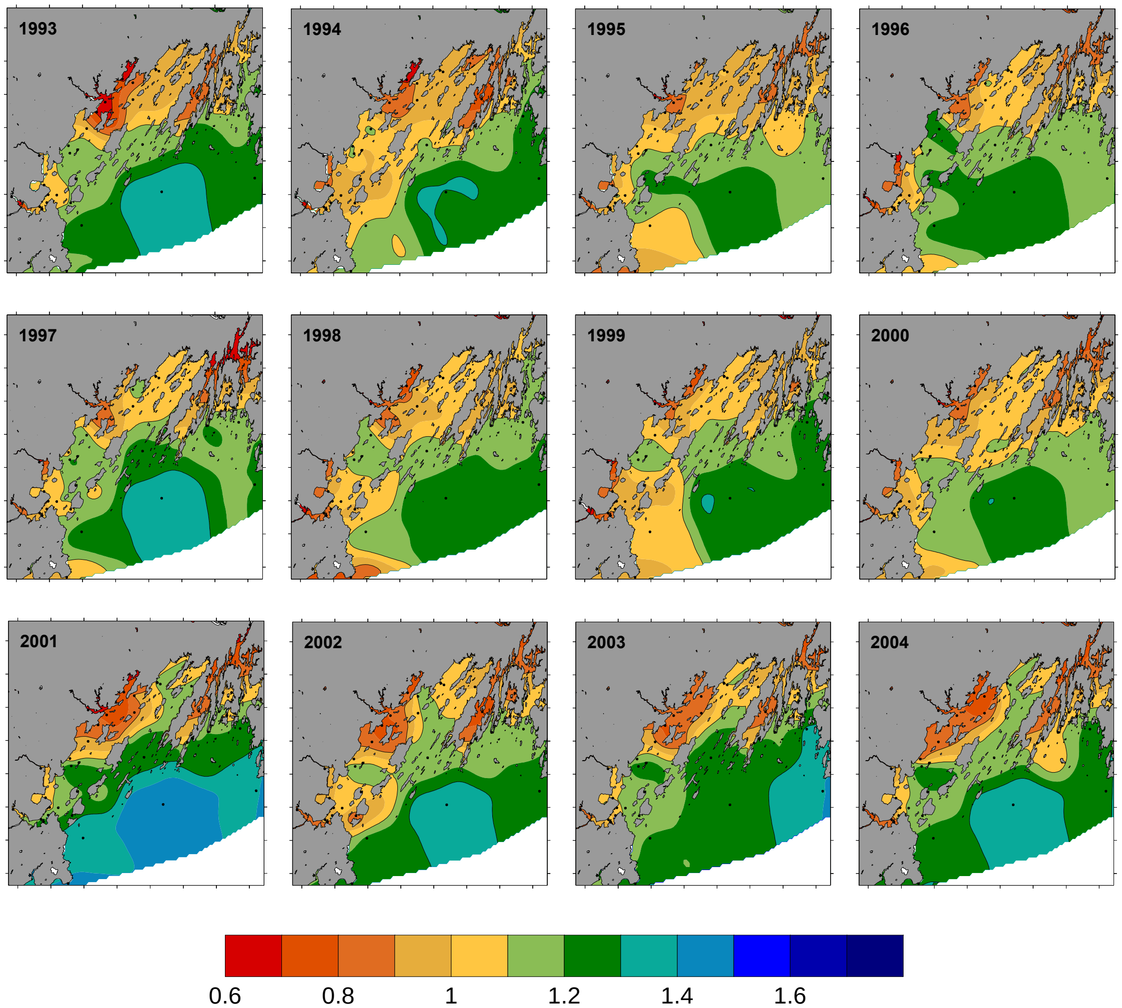


Figure 34. Spatial distribution of Casco Bay Health Index from 1993-2004.

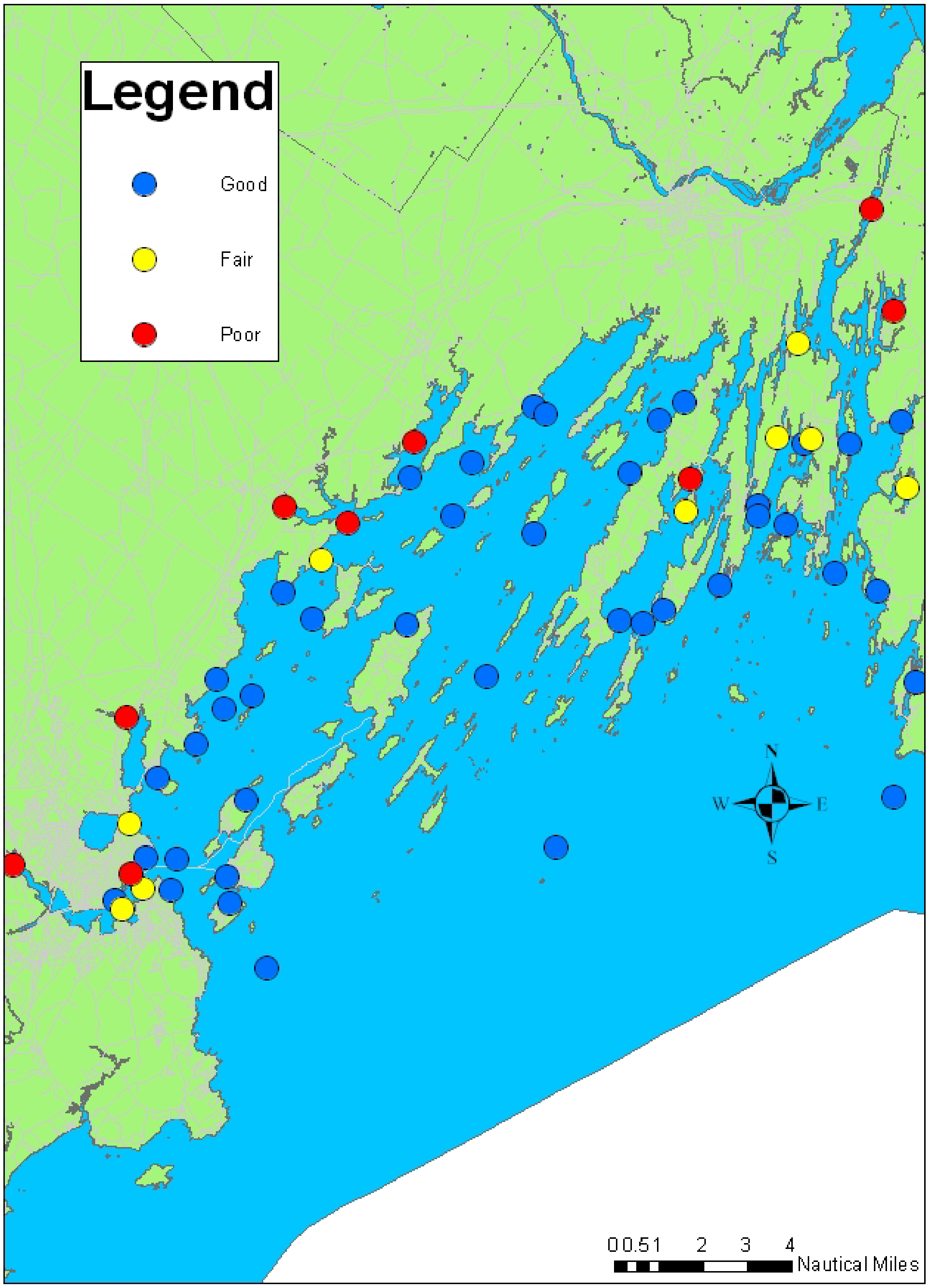


Figure 35. Casco Bay Health Index ranked by individual surface water quality monitoring site scores. Index scores are based on averaged data from the 12-year period 1993-2004. Data from 59 surface sites with sufficient Secchi depth data.

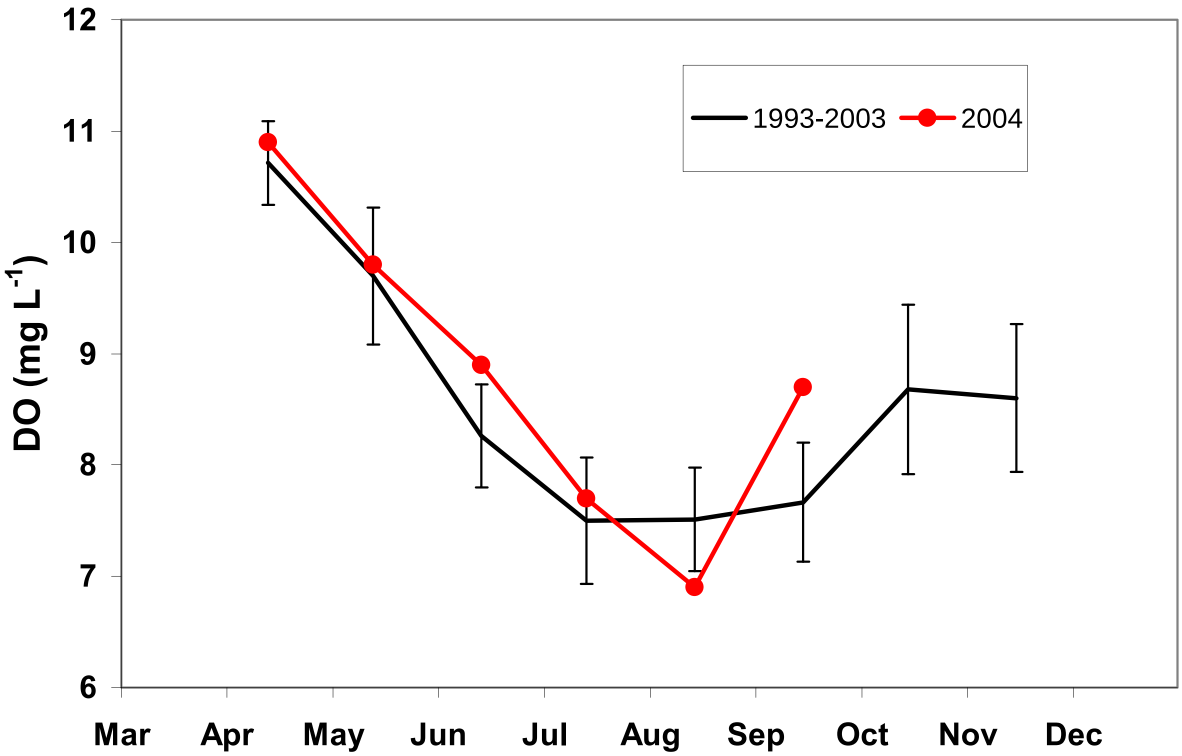


Figure 36. Example of a time series comparison of monthly mean DO concentration (mg/l) between a 'baseline' period of 1993-2003 versus 2004. Data are from Harraseeket River. The error bars represent the standard deviation about the mean based on the 11 years of data.

APPENDIX A: FOCB Site Datasheets

THE FRIENDS OF CASCO BAY CITIZENS' MONITORING PROGRAM

WATER QUALITY DATA SHEET (SIDE 1 OF 2) ☐

Site name: ______________________ Collection date (mo/dy/yr): ___/___/___

Monitor name(s): __________________ Time (24-hour time): ___________ hours

____

Air temperature: __ __ . __ °C

Wind direction: _____ (N,NE,E,SE,S,SW,W,NW)

Wind speed: _________ mph

Weather (check one): ☐ clear ☐ snow ☐ overcast ☐ fog/haze ☐ drizzle ☐ downpour ☐ partly cloudy

Rainfall in previous 24 hours (check one): ☐ none ☐ light (___ inches) ☐ heavy (___ inches)

Number of days with similar weather (including today): ______ days (must be >0)

Tidal stage (check one): ☐ high ☐ high ebb ☐ ebb ☐ low ebb ☐ low ☐ low flood ☐ flood ☐ high flood

High tide: ___________ hours

Low tide: ___________ hours

Water surface (check one): ☐ calm ☐ ripple ☐ waves ☐ whitecaps

Indicators (check all that apply):

☐ fishkills ☐ dead crabs ☐ oil on surface ☐ debris
☐ erosion ☐ foam ☐ bubbles ☐ odors
☐ abnormal color ☐ birds ☐ animals ☐ other

Please elaborate on the above: ____

____

____

Secchi depth: __ __ . __ meters

Water depth: __ __ . __ meters

Water temperature: __ __ . __ °C

pH: __ . __ N, W, O, mtr (circle one)

Specific gravity: __ . __ __ __ __ read at temp of __ __ . __ °C

Salinity: __ __ . __ ppt

Dissolved oxygen: Test 1: __ __ . __ mg/l Test 2: __ __ . __ mg/l

Test 3: __ __ . __ mg/l Avg: __ __ . __ mg/l

Monitor signature(s): ____

____

THE FRIENDS OF CASCO BAY CITIZENS' MONITORING PROGRAM

WATER QUALITY DATA SHEET (SIDE 1 OF 2) ☐

Site name: ____________________ Collection date (mo/dy/yr): ___/___/___

Monitor name(s): ____________________ Time (24-hour time): __________ hours

____

Air temperature: __ __ . __ °C

Wind direction: _____ (N,NE,E,SE,S,SW,W,NW)

Wind speed: ________ mph

Weather (check one) ☐ clear ☐ snow ☐ overcast ☐ fog/haze ☐ drizzle ☐ downpour ☐ partly cloudy

Rainfall in previous 24 hours (check one): ☐ none ☐ light (___ inches) ☐ heavy (___ inches)

Number of days with similar weather (including today): ______ days (must be >0)

Tidal stage (check one): ☐ high ☐ high ebb ☐ ebb ☐ low ebb ☐ low ☐ low flood ☐ flood ☐ high flood

High tide: __________ hours

Low tide: __________ hours

Water surface (check one): ☐ calm ☐ ripple ☐ waves ☐ whitecaps

Indicators (check all that apply):

☐ fishkills ☐ dead crabs ☐ oil on surface ☐ debris

☐ erosion ☐ foam ☐ bubbles ☐ odors

☐ abnormal color ☐ birds ☐ animals ☐ other

Please elaborate on the above: ____

____

Secchi depth: __ __ . __ meters Water depth: __ __ . __ meters

GoMOOS Nutrient Sampling

Bottle #	1	2	3	4	5	6
Depth (m)						
DIN Vial #						

Monitor signature(s): ____

____

THE FRIENDS OF CASCO BAY CITIZENS' MONITORING PROGRAM
WATER QUALITY DATA SHEET (SIDE 2 OF 2)

WATER COLUMN PROFILE DATA	TEMPERATURE (°C)	SALINITY (ppt)	DISSOLVED OXYGEN (mg/l)
Model number of meter			
Serial number of meter			
Depth (m): 0	.	.	.
1	.	.	.
2	.	.	.
4	.	.	.
6	.	.	.
8	.	.	.
10	.	.	.
12	.	.	.
14	.	.	.
16	.	.	.
18	.	.	.
20	.	.	.
22	.	.	.
24	.	.	.
26	.	.	.
28	.	.	.
30	.	.	.
32	.	.	.
34	.	.	.
36	.	.	.
38	.	.	.

REMARKS:

Staff use ONLY	Date	Initials
Sheet rec'd		
Data ck'd		
Data entered into database		
Entry ck'd vs sheet		

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APPENDIX B: FOCB CWQM Program Data Quality Objectives

Parameter	Method/Range	Units	Sensitivity (a)	Precision	Accuracy	Calibration Method
Temperature	Thermometer -5.0 to +45.0 C	degrees Celsius (C)	0.5 C	±1.0 C (b)	±0.5 C (b)	NIST Certified Thermometer
	YSI DO Meter -5.0 to +45.0 C	degrees Celsius (C)	0.1 C	±0.23 C (g)	±0.5 C (d)	NIST Certified Thermometer
	YSI 6600 Sonde -5.0 to +45.0 C	degrees Celsius (C)	0.01 C	NA	±0.15 C (h)	NIST Certified Thermometer
pH	pH Octet Comparator (Wide-Range) 3.0 to 10.0 units	standard pH units	0.5 units	±0.6 units (b)	±0.4 units (b)	pH Meter
	pH Octet Comparator (Narrow-Range) 7.2 to 8.6 units	standard pH units	0.1 units	±0.3 units (c)	±0.2 units (b)	pH Meter
	Oakton Waterproof pHTestr 2 -1.0 to 15.0 units	standard pH units	0.1 units	±0.1 units (g)	±0.2 units (g)	pH Buffer Reference Standards
	YSI 6600 Sonde 0.0 to 14.0 units	standard pH units	0.01 units	NA	±0.2 units (h)	pH Buffer Reference Standards
Dissolved Oxygen	Micro Winkler Titration 0 to 20 mg/l	milligrams per liter (mg/l)	0.1 mg/l	±0.9 mg/l (b)	±0.3 mg/l (b)	Standard Winkler
	YSI DO Meter 0 to 20 mg/l	milligrams per liter (mg/l)	0.1 mg/l	±4% of reading (g)	±11% of rdg at 0 C; ±7% of rdg at 25 C (d)	Standard Winkler
	YSI 6600 Sonde 0 to 50 mg/l	milligrams per liter (mg/l)	0.01 mg/l	NA	±2% or 0.2mg/l of rdg(whichever is greater)up to 20mg/l; ±6% of rdg from 20-50mg/l (h)	Standard Winkler
Dissolved Oxygen (pre- & post-measurement checks)	YSI DO Meter 0% to 200% saturation	percent air saturation (% sat)	0.1% sat	±3% sat (g)	±5% sat (d)	
	YSI 6600 Sonde 0% to 500% saturation	percent air saturation (% sat)	0.1% sat	NA	±2% or 0.2% of rdg(whichever is greater)up to 200%; ±6% of rdg from 200-500% (h)	Barometric Pressure

Parameter	Method/Range	Units	Sensitivity (a)	Precision	Accuracy	Calibration Method
Salinity	Hydrometer 0 to 42 ppt (1.0000 to 1.0700 specific gravity)	parts per thousand (ppt)	0.1 ppt (0.0005 specific gravity)	±1.0 ppt (b)	±0.82 ppt (b)	Orion 140 S-C-T Meter (vs. NIST Certified Conductivity Standards)
	YSI S-C-T Meter 0 to 40 ppt	parts per thousand (ppt)	0.1 ppt	±0.5 ppt (g)	±1.6 ppt at 33 ppt; ±0.7 ppt at 10 ppt (e)	NIST Certified Conductivity Standards
	YSI 6600 Sonde 0 to 70 ppt	parts per thousand (ppt)	0.01 ppt	NA	±1.0% of reading or 0.1 ppt, whichever is greater (h)	Orion 140 S-C-T Meter (vs. NIST Certified Conductivity Standards)
Conductivity (pre- & post-measurement checks)	YSI S-C-T Meter 0 to 50,000 mhos/cm	micromhos per centimeter (mhos/cm)	100 mhos/cm	±112 mhos/cm (g)	Pre-meas: ±250 mhos/cm; Post-meas: ±600 mhos/cm (f)	NIST Certified Conductivity Standards
	YSI 6600 Sonde 0 to 100 mS/cm	milliSiemens per centimeter (mS/cm)	0.001 mS/cm to 0.1 mS/cm (range dependent)	NA	±0.5% of reading +0.001 mS/cm (h)	NIST Certified Conductivity Standards
Limit of Visibility	Secchi Disk Depth 0 to 20 m	meters (m)	0.1 m	NA	NA	NA
Sample Depth	Marked Line 0 to 36 m	meters (m)	1 m	NA	NA	NA
	YSI 6600 Sonde 0 to 200 m	meters (m)	0.001 m	NA	±0.12 m (h)	barometric pressure

NA = not available

(a) Determined by the increments measurable with the stated method reflecting estimation where allowed.

(b) Data taken from EPA Volunteer Water Monitoring: A Guide for State Managers, 1990, EPA 440/4-90-010, p. 39; based on data provided by the Chesapeake Bay Citizen Monitoring Program.

(c) Data taken from the Quality Assurance Project Plan for the Chesapeake Bay Citizen Monitoring Program, Section 5, p. 2.

(d) Data taken from the manufacturer's instruction manuals and 1995 Water Column Profile Data Report, 1996, Friends of Casco Bay Citizens Water Quality Monitoring Program, Volume I, pp. 28-29.

(e) Data taken from the manufacturer's instruction manuals and 1995 Water Column Profile Data Report, 1996, FOCB CWQM Program, Volume I, pp. 28-29. The salinity accuracy figures are for +4 to +45 C. For -2 to +4 C, the meter should be accurate to ±1.9 ppt at 33 ppt and ±0.7 ppt at 10 ppt.

(f) Data taken from the manufacturer's instruction manuals and 1995 Water Column Profile Data Report, 1996, FOCB CWQM Program, Volume I, pp. 28-29. The post-calibration errors actually errors actually observed in 1995 ranged from -296 to +320 mhos/cm (after correction to 25 C).

(g) Data taken from 1995 Water Column Profile Data Report, 1996, FOCB CWQM Program, Volume I, pp. 28-29.

(h) Data taken from YSI 6-Series Environmental Monitoring Systems technical manual, Appendix J, pp. 262-264.

APPENDIX C: Suspect nutrient data not used in analyses.

Station	Day	Time	Depth(m)	NO_3+NO_2 (µM)
P3SMP	06/20/02	13:12	2.0	500.00
P3SMP	06/20/02	13:10	4.0	500.00
P2HWR	07/17/02	9:32	41.0	500.00
P11QB	06/20/02	14:36	0.0	500.00
SMTC	06/20/02	9:55	0.0	500.00
P11QB	06/20/02	14:44	6.0	500.00
SMTC	02/13/02	9:40	0.0	455.68
P7CBI	02/25/02	11:24	12.9	353.17
P6FGG	02/25/02	11:47	15.3	308.69
SMTC	02/25/02	9:55	0.0	274.46
SMTC	02/05/02	16:30	0.0	243.62
P2HWR	06/20/02	11:44	29.3	232.71
SMTC	03/01/02	9:20	0.0	136.96
SMTC	11/07/02	11:55	0.0	114.60
P2HWR	04/21/04	9:15	8.0	55.66
P1RIL	06/20/03	9:42	14.2	52.61
SMTC	02/15/02	10:45	0.0	44.88
P6FGG	11/20/02	13:25	19.2	43.90
P2HWR	06/20/02	12:06	8.0	41.65
P1RIL	06/20/03	9:37	0.0	40.64
P9LFP	04/21/04	13:55	9.4	39.29
SMTC	11/06/02	12:33	0.0	37.92
P5BSD	04/21/04	12:45	12.0	36.06
P2HWR	06/20/02	12:14	0.0	31.64
P3SMP	06/20/02	13:18	0.0	31.59
P5BSD	06/20/02	15:47	27.0	29.91
P2HWR	06/20/02	12:01	14.0	27.99
P4BRI	04/21/04	11:15	0.0	27.71
SMTC	03/08/02	9:25	0.0	24.30
SMTC	01/06/03	14:15	0.0	23.36
P2HWR	07/17/02	9:38	26.0	22.05
P5BSD	02/25/02	10:55	30.0	21.58
P3SMP	07/17/02	10:29	14.0	20.54
P9LFP	06/20/02	17:25	8.0	20.22

Station	Day	Time	Depth(m)	PO_4 (µM)
P5BSD	12/31/02	12:01	30.7	6.91
P6FGG	11/20/02	13:25	19.2	5.60
SMTC	06/05/02	10:11	0.0	4.51
P11QB	07/17/02	11:50	19.0	3.23

Station	Day	Time	Depth(m)	NH_4 (µM)
SMTC	11/07/02	11:55	0.0	337.50
SMTC	02/25/02	9:55	0.0	311.43
SMTC	02/05/02	16:30	0.0	205.33
P3SMP	06/20/02	13:12	2.0	120.00
P3SMP	06/20/02	13:18	0.0	120.00
P3SMP	06/20/02	13:10	4.0	120.00
P2HWR	06/20/02	11:44	29.3	120.00
P2HWR	07/17/02	9:32	41.0	120.00
P11QB	06/20/02	14:36	0.0	120.00
SMTC	06/20/02	9:55	0.0	120.00
P6FGG	05/30/02	15:48	0.0	120.00
P4BRI	06/20/02	13:58	19.0	120.00
P11QB	06/20/02	14:44	6.0	120.00
SMTC	02/13/02	9:40	0.0	101.24
P7CBI	02/25/02	11:24	12.9	100.00
P6FGG	02/25/02	11:47	15.3	99.09
SMTC	03/01/02	9:20	0.0	98.85
P2HWR	06/20/02	12:14	0.0	78.18
P2HWR	06/20/02	12:06	8.0	65.07
P5BSD	06/20/02	15:47	27.0	62.35
P2HWR	06/20/02	12:01	14.0	52.90
SMTC	07/12/02	9:55	0.0	49.99
P2HWR	07/17/02	9:38	26.0	48.77
P2HWR	04/21/04	9:15	8.0	48.01
P9LFP	06/20/02	17:25	8.0	44.60
SMTC	07/11/02	15:50	0.0	44.19
P6FGG	11/20/02	13:25	19.2	44.10
SMTC	07/10/02	11:47	0.0	42.38
P2HWR	07/10/03	11:48	37.9	36.80
P9LFP	04/21/04	13:55	9.4	34.96
P4BRI	04/21/04	11:15	0.0	34.03
P6FGG	03/30/04	11:50	0.0	33.70
P5BSD	06/20/03	14:43	14.1	29.09
SMTC	03/31/04	10:26	0.0	28.00
SMTC	01/06/03	14:15	0.0	27.66
P3SMP	07/17/02	10:29	14.0	27.34
SMTC	04/05/04	13:15	0.0	26.90
P6FGG	03/31/04	11:50	16.7	26.70
P5BSD	02/25/02	10:55	30.0	26.01

Station	Day	Time	Depth(m)	SiO_4 (µM)
SMTC	04/16/04	11:30	0.0	146.67
P1RIL	04/21/04	8:25	0.0	144.65
P1RIL	06/20/03	9:42	14.2	39.07
P1RIL	06/20/03	9:37	0.0	30.59