Final Report

2003 Dissolved Oxygen Monitoring Project

Prepared for the

CASCO BAY ESTUARY PARTNERSHIP

by

FRIENDS OF CASCO BAY

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Abstract

Friends of Casco Bay and the Casco Bay Estuary Partnership (CBEP) have monitored for low dissolved oxygen in Casco Bay annually since 1999. This project was originally a statewide effort initiated in the mid 1990's by the Maine Department of Environmental Protection and the Wells National Estuarine Research Reserve. Since 1999, the project has evolved from a Casco Bay-wide search for regions experiencing low dissolved oxygen to a more focused and intensive study of two embayments that demonstrate reduced water quality. Quahog Bay and the New Meadows River appear to be more eutrophic than the rest of Casco Bay. Both are poorly flushed and have no obvious sources of excess nutrients, but they seem to have different mechanisms establishing the low dissolved oxygen conditions. This paper discusses the 2003 Dissolved Oxygen Monitoring Project, which took place in Quahog Bay. Since previous projects determined that the dissolved oxygen levels in Quahog Bay are generally lowest at the bottom, we surmise that high organic matter concentrations in the sediment result in elevated sediment oxygen demand. Stratification in the water column may be exacerbating the situation. In addition to a series of late summer water column profiles of dissolved oxygen and other parameters, the 2003 project measured the amount of total organic carbon in sediment samples.

1.0 Introduction

Coastal nutrient enrichment and eutrophication are growing concerns worldwide. Excess nitrogen and phosphorous loads from point and non-point sources stimulate phytoplankton and macroalgal populations. These increases in algal biomass can become detrimental as low dissolved oxygen (DO) conditions occur as a result of elevations in ecosystem metabolism. Low DO is therefore a valuable indicator of water quality degradation from nutrient pollution. Almost all marine organisms require DO for respiration, so it is vital to identify areas with low (hypoxia) or no (anoxia) DO.

In 1995 and 1996, the Maine Department of Environmental Protection (DEP), with assistance from Friends of Casco Bay (FOCB) and the Wells National Estuarine Research Reserve (WNERR), set out to field test a matrix for predicting coastal water hypoxia susceptibility. The matrix was a grid of flushing rates versus nutrient loading. The regions with the highest nutrient loading and lowest flushing rates were expected to exhibit the lowest levels of DO. Data was collected along the entire coast of Maine and created a valuable baseline of DO conditions. Both the 1995 and 1996 field seasons involved water column profile monitoring on three and four dates through late summer and early fall. The 1996 field season included chlorophyll, organic nutrient, and inorganic nutrient analysis. Monitoring was conducted when DO concentrations were most likely to be at their lowest: in the late summer and early fall, during early morning, and at low tide. Higher water temperatures found in late summer lower the capacity of water to hold DO. The loss of DO resulting from overnight respiration is reflected in early morning sampling results. Water at low tide theoretically holds less DO than water at high tide, since incoming tides bring in colder, more oxygenated water from offshore.

Even under these conditions, the coast of Maine proved to have good water quality, with only a handful of waterbodies exhibiting low DO. One notable finding from the 1996 study was that sites with fresh water inputs had higher nutrient concentrations.

In 1999, FOCB and CBEP decided to monitor a subset of the Casco Bay sites that had been monitored during the 1995-1996 statewide project. The intent was to look for changes in water quality since 1995-1996, and to look for hypoxic conditions in regions of Casco Bay that might warrant closer attention. Water column profile monitoring was conducted during late summer and under early morning and low tide "worst case" conditions.

The study became an annual monitoring event, with the parameters and sites changing to reflect what had been learned the previous year. In 2000, the number of sites within each embayment was reduced and early morning sampling was conducted during both high and low tides. Results indicated a pronounced difference in DO levels between waterbodies in eastern Casco Bay and those in western Casco Bay, with no significant differences in DO levels between high and low tides. Two embayments in eastern Casco Bay, Quahog Bay and the New Meadows River, exhibited hypoxia, while all of those in western Casco Bay exhibited remarkably healthy conditions even under the theoretically "worst case" monitoring conditions combining late summer, early morning, and low tide. These findings mirrored what had been seen in 1995,1996, and 1999.

As a result, monitoring efforts shifted in 2001 to focus on eastern Casco Bay. Analysis of dissolved inorganic nutrients and chlorophyll were added to the standard profile suite of temperature, salinity, DO, and pH. At the conclusion of each profile an unattended Yellow Springs Instruments 6000 series datasonde, set to record data every hour for 24 hours for monitoring diurnal conditions, was left at the surface of the most inshore site in both embayments. The results provided more evidence that both Quahog Bay and the New Meadows River experienced hypoxic and, in some cases, anoxic conditions during the monitoring period.

This information reinforced the decision to monitor just the eastern Casco Bay region. The 2002 fieldwork would focus on the New Meadows River, and Quahog Bay would be studied in 2003.

Most of the hypoxic conditions in the New Meadows River were found above and below the causeway in the upper reaches of the embayment. In 2002, four sampling sites were established going from upriver to downriver. Four datasondes were placed unattended at each site to record surface data every hour for four weeks. Once each week, a water column profile was conducted at each site, and surface water samples were collected for dissolved inorganic nutrient analysis.

Nutrient concentrations were very high, and while upriver these concentrations were dominated by ammonium, there were no other discernable trends from site to site. DO conditions improved from site to site downriver. The site above the causeway was anoxic in the bottom third of the water column, below severe temperature and salinity stratification. The diurnal range of the DO concentrations at the upriver sites fluctuated wildly, with very low levels detected in early morning and very high levels by early evening. A significant phytoplankton biomass caused supersaturation of DO during the day and undersaturation at night. When photosynthesis was peaking, pH was high owing to massive reductions in bicarbonate. Chlorophyll concentrations and pH levels exhibited diurnal fluctuations, following the same trend as DO.

The local sediments are known to have very high total organic carbon concentrations and high sediment oxygen demand (EPA, 2003), and these conditions certainly contribute to the hypoxia. However, the swing in DO suggests that much of the hypoxia is caused by the elevated nutrient concentrations driving the exceedingly high primary productivity. This situation seems to be recurrent and persistent throughout the summer, occurring not just during the warmer, late summer period. Unattended sonde data collected through another FOCB project in this area showed that the high primary productivity gets underway as early as late June. This is a condition that defines the upper New Meadows. Speculation about the possible causes of the high nutrient and carbon levels include contributions coming down from the anoxic region found in the New Meadows Lake area above the causeway, and recycled carbon and nitrogen from historic fish kills.

During the summer of 2003, the study shifted, as planned, to investigating the poor water quality detected in Quahog Bay. The intent was to identify the conditions that bring about the poor water quality. A six-site transect was designed, running from the mouth of Quahog Bay to the upper reaches. At each of the six sites on four different days during late summer, a water quality profile of the water column was completed both in early morning at low tide and again in the afternoon at high tide. In addition, sediments were collected for total organic carbon analysis. A review of the previous dissolved oxygen monitoring projects (Heinig, 2002) suggested that the low DO found in Quahog Bay was a product of high sediment oxygen demand. The goal of the 2003 project was to confirm that the lowest DO concentrations were found at the bottom, and to measure the sediment organic carbon concentrations. We also tried to determine how the water quality conditions change as Quahog Bay becomes well mixed in the early fall. We sampled during the period that water in Quahog Bay was likely to be stratified and during the period when the water was likely to be well mixed.

2.0 Methods/Materials

The primary component of the 2003 Dissolved Oxygen Monitoring Project involved a series of water column profiles, conducted on four different days, first in the early morning at low tide, and again in the afternoon at high tide. There were six profile sites running in a transect from the mouth of Quahog Bay north toward Tondreau’s Point at the upper end of the bay (see Figure 1, sites QB1a, QB2, QB3, QB4, QB4a, and QB5, respectively). QB1a and QB2 were the deepest sites, almost 20 meters at high tide, and QB5 was the shallowest. See Table 1 for site descriptions and water depths at low tide.

Table 1

Site	Site Description	Water Depth (feet)
QB1a	Just west of southern tip of South Ledge, mouth of Quahog Bay	64
QB2	Between Pinkham Point and south end of Pole Island	66
QB3	Just west of North Ledge	30
QB4	South of Snow Island	19
QB4a	Northwest of Center Island	19
QB5	Mouth of Orr's Cove – off Tondreau's Point	15

Each water column profile consisted of measurements taken at the surface, at a depth of one meter, at two meters, and then every two meters down to the bottom. In addition to the profiles, a sediment sample was collected once from each site for analysis of total organic carbon.

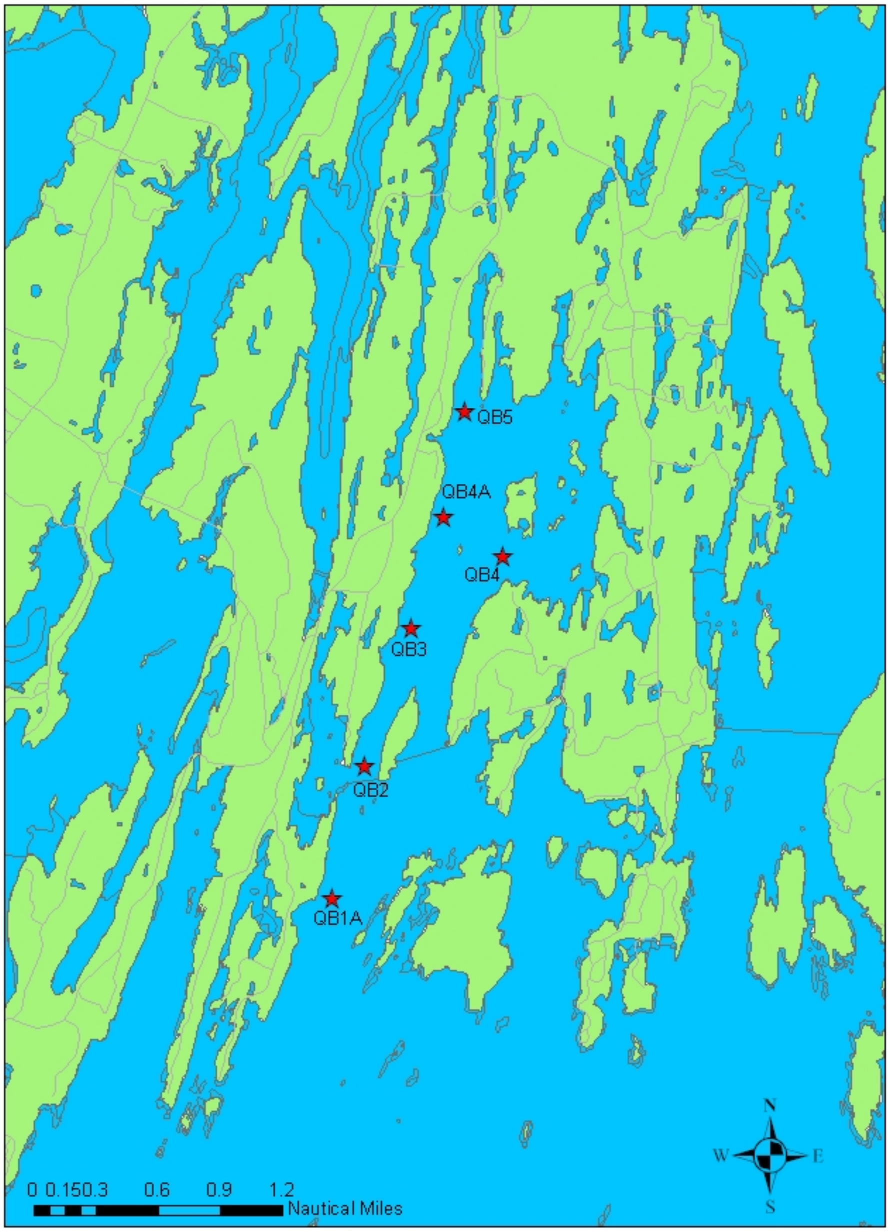
All six sites were sampled within one hour using two boat crews. The crews started one half hour prior to low or high tide and finished within one half hour after the tide. In this way, sampling at all of the sites was done as simultaneously as possible. Sampling dates were August 13 and 29, and September 11 and 29, (referred to as events, below). Each crew used a Yellow Springs Instruments 6000 series datasonde to record depth, temperature, salinity, Dissolved Oxygen (mg/l and percent saturation), pH, and chlorophyll. Water clarity was determined using a Secchi Disk. Air temperature and weather conditions were recorded at the start of the early morning run and again before the afternoon run. Prior to the early morning profile, both sondes were calibrated against known standards and then compared side by side in a bucket of seawater. At the conclusion of the afternoon run, the calibration of each sonde was checked against the standards, and then both sondes were returned to the seawater bucket for comparison. Both sondes passed all calibration checks and were in agreement throughout the 2003 study. Additional quality assurance information may be found in the Friends of Casco Bay QAPP, RFA No. ME01230, "The Friends of Casco Bay Citizens Water Quality Monitoring Program, Revision 2".

A single boat crew was responsible for sediment collection, which was completed on September 26. Using a Petersen grab, 3 replicate samples were taken from each site and shipped to Linda Schick at the Darling Marine Center in Walpole, Maine, for analysis of percent total organic carbon (TOC). The sediment TOC samples were collected and analyzed pursuant to EPA method # 9060, SW-846 chapter 5.

Density was derived through an equation using temperature and salinity. Statistical analyses were performed using SAS JMP software.

Figure 1

2003 Dissolved Oxygen Monitoring Project



Quahog Bay, Harpswell, Maine

3.0 Results

The summary statistics for all data collected can be found in Table 2. See Appendix A for all of the water column profile data.

Table 2

	Temperature (C)	**Salinity (ppt)**	**DO (mg/l)**	**DO (%Sat)**	**pH**	**Chlorophyll Fluoresence (ug/l)**
Mean	15.4	31.4	7.6	92.9	7.9	6.9
Standard Deviation	2.4	0.4	1.2	17.7	0.2	5.9
Maximum	21.6	32.0	10.6	138.2	8.2	70.7
Minumum	10.8	28.2	5.5	62.6	7.2	0.1

3.1 Spatial Trends

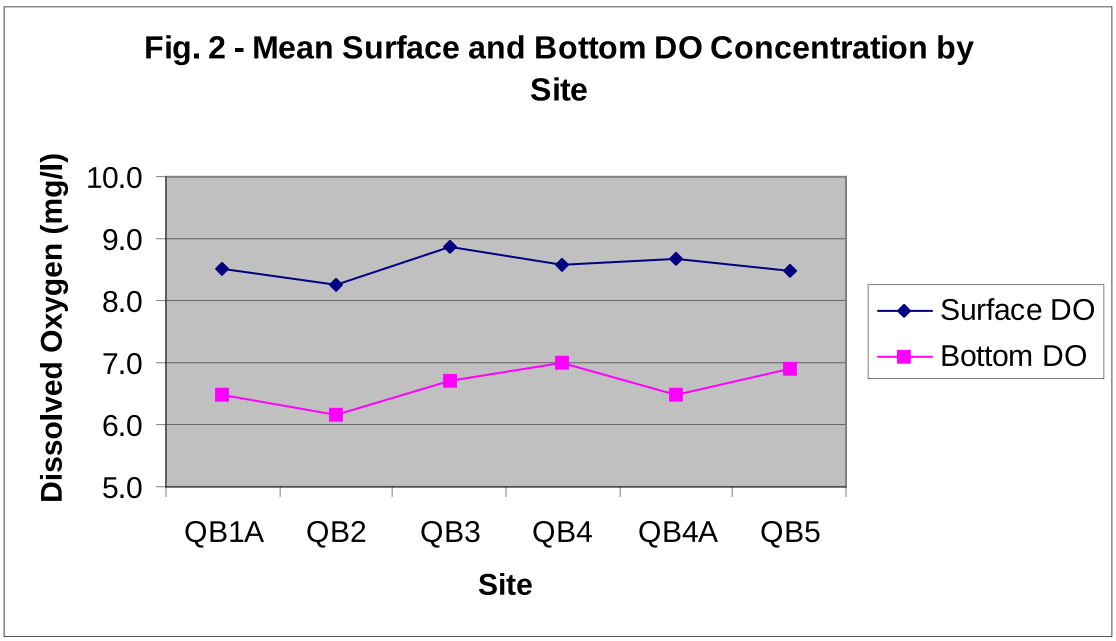
Water temperatures generally increased from the mouth of the bay to the upper end. Temperature means from site to site were: QB1a, 14.5 degrees C; QB2, 14.8 degrees C; QB3, 15.7 degrees C; QB4, 16.3 degrees C; QB4a, 16.2 degrees C; and QB5, 17.0 degrees C. Sites 1a and 2 were significantly different than the rest of the sites. Site 5 was also significantly different from the others. Although the means were higher moving up the bay from site to site, the maximum and minimum values were roughly the same throughout the transect. Pearson correlations showed a strong negative relationship between water temperature and depth (-0.655), the result of the marked stratification found at all sites during the first three sampling events.

Salinity was very consistent along the transect, and throughout the entire 2003 project, with 97.5% of the values falling between 30.5 ppt and 32.0 ppt. Most of the other 2.5% was due to a severe rain event just before the final sampling date, lowering the surface salinity at site QB5 on September 29 to 28.2 ppt at low tide. By the afternoon high tide the salinity had returned to close to 30 ppt. With the absence of a distinct halocline, most of the water column stratification was due to the differences in temperature.

A significant finding correlates DO with depth. Pearson correlation values of –0.692 for DO concentration and depth, and –0.722 for DO percent saturation and depth, are indicative of this very strong and consistent phenomenon. Throughout the project, the DO levels were always lower at depth. ANOVA results revealed that this was a significant trend ($P<.0001$).

Grouped by site, DO concentrations generally were similar with regard to the lowest values. Although the lowest individual DO value was 5.5 mg/l at QB5 on the morning of August 29, every site experienced at some time DO values between 5.5 and 6.0 mg/l, and percent saturations in the mid to high 60's. The low of 5.5 mg/l corresponded with the lowest overall percent saturation of 62.6 percent. The real difference from site to site was found in the maximum values. DO values for QB1a and QB2 were tightly grouped and did not show as much variability as the other four sites. An analysis of DO by site revealed that sites QB1a and QB2 fell below the mean of all DO data, while the mean for each of the other four sites were found above the mean for all DO data. This was a significant difference (P<.0001). The DO means for each site were, in mg/l: QB1a, 7.4; QB2, the lowest mean at 7.2; QB3, 8.0; QB4, 8.1; QB4a, 8.0, and QB5, 8.1.

Mean bottom water DO was similar from site to site, from a low of 6.2 mg/l at QB2 to a high of 7.0 mg/l at QB4. The range of bottom water DO, however, was much narrower at sites QB1a and QB2, and the other four sites showed much greater variability. Figure 2 illustrates the difference between mean surface water DO and mean bottom water DO from site to site.



pH was strongly correlated with depth (-0.667), as well as DO concentration (0.695), and percent saturation (0.743). pH also exhibited a wider than expected range, from a maximum value of 8.2 to a minimum value of 7.2. The lower values were always found at the bottom, and were associated with the low DO. The relationship between DO and pH was further illustrated through ANOVA (P<.0001).

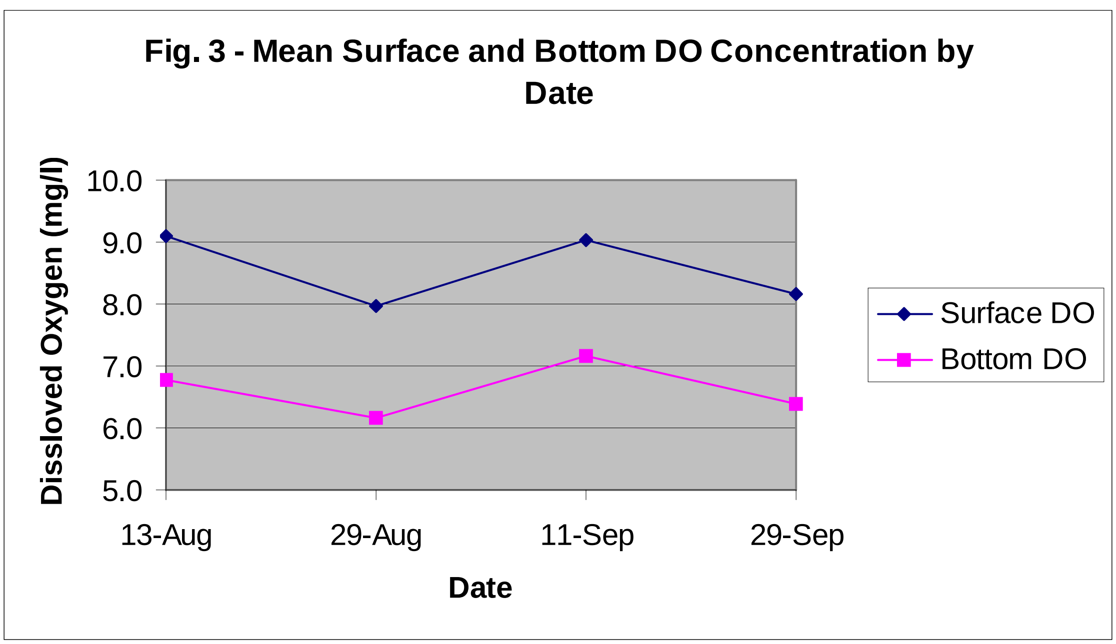
Density, as sigma-t, was calculated to determine the extent of the stratification in Quahog Bay. A bivariate fit of DO by sigma-t was significant (P<.0001), although this was not unexpected as we knew that DO was always lower during this study at the bottom, and higher sigma-t resulted in lower DO.

3.2 Temporal Trends

Water temperatures were highest on the first sampling date, August 13, reaching 21.6 degrees C at site QB5 at the surface in the early morning. All four sites recorded temperatures at or around 20 degrees C during that first event, all in the morning and all dropping a degree or two by the afternoon event. The lower afternoon temperatures were most likely due to the incoming tide. The coldest individual temperature was also recorded on August 29, 10.8 degrees C at site QB1a at the bottom.

The mean temperature was also highest on August 13, at 16.5 degrees C. The final sampling date, September 29, had a very similar mean, 16.4 degrees C, but the range was much narrower. The temperature range was widest on the first date and became progressively tighter from event to event. That very narrow range on the final date represented a lack of stratification, with temperatures consistent throughout the water column. Surface temperatures tended to get lower from event to event, while bottom water temperatures tended to increase. Therefore the stratification became less and less and the mean increased from the second event to the third (September 11, 15.6 degrees C) to the final mean of 16.4 degrees C on September 29.

The mean DO value was highest at 8.23 mg/l on September 11. Bottom water DO values were not significantly different between sampling dates, but values on September 11 tended to be higher than on the other dates. Overall, bottom water DO values were close to what is generally considered hypoxic, with a mean bottom DO concentration for all sites and dates of 6.6 mg/l. As evidenced by a standard deviation of only 0.8 mg/l, this condition was fairly consistent. The lowest bottom water DO concentration was 5.5 mg/l at QB5 during the morning of August 29. The mean surface water DO and mean bottom water DO concentrations by date are compared in Figure 3.



Analysis of sediment samples for total organic carbon (TOC), expressed as percent carbon, showed relatively consistent results from site to site. The lowest mean (4.3%) was found at QB2, the deepest site, while the more shallow sites, QB5 and QB4a, had the highest mean percent carbon (4.6%). Table 3 shows the mean TOC values for each site, along with the mean bottom DO concentrations.

Table 3

Site	Mean Sediment TOC (%)	Mean Bottom DO Concentrations (mg/l)
QB1a	4.4	6.5
QB2	4.3	6.2
QB3	4.5	6.7
QB4	4.5	7.0
QB4a	4.6	6.5
QB5	4.6	6.9

3.3 Tidal Trends

There were no significant differences in water temperature, salinity, DO, pH, or density when comparing low tide to high tide.

4.0 Discussion

A principal finding from the 2003 Dissolved Oxygen Monitoring Project was that low DO is present at the bottom of Quahog Bay. This finding is consistent with previous projects. Near hypoxic conditions persisted at the bottom throughout the entire project period, regardless of date, site, tidal stage, or extent of water column stratification.

The low DO conditions found in Quahog Bay are fairly stable and consistent at the bottom, and the temperature stratification present during the first three sampling events produced only a more pronounced difference between the bottom DO and the surface DO, and did not result in significantly lower DO. Stratification was not present during the final date, September 29, allowing for a comparison of conditions before and after the water column became well mixed. The final sampling date was also notable for having the biggest swing in DO from the morning profile to the afternoon profile. Most obvious at the surface, DO concentrations increased by about 1.0 to 1.5 mg/l diurnally during the first three events. These swings suggest moderately healthy levels of phytoplankton biomass. The more pronounced change on September 29 might be a result of the lack of stratification in the water column or is perhaps due to the heavy rains prior to sampling, both of which may introduce nitrogen into the system and fuel a small phytoplankton bloom. The difference in DO from the morning sampling period to the afternoon sampling period should give some indication of the level of primary productivity. High phytoplankton biomass would result in an increase in DO by the late afternoon, after a full day of photosynthesis, and then a full night of respiration would reduce DO levels by early morning. These diurnal swings provide some measure of the system metabolism. Since we experienced low to moderate swings, it is possible that this project was conducted after the conclusion of a substantial spring bloom, and the organic matter at depth is the result of that bloom.

The relatively low pH values at depth suggest that benthic respiration was fairly pronounced. The very strong correlation between pH and DO, while not unexpected, associates this high benthic respiration with the hypoxic conditions. Very high photosynthetic activity will raise pH in the water column due to the high concentrations of bicarbonate being assimilated. High rates of respiration have the opposite effect, lowering pH as carbon dioxide is produced. The persistent occurrence of both low DO and low pH at depth may be indicative of elevated bacterial respiration in the sediment, the result of the breakdown, or mineralisation, of high concentrations of organic matter.

Further evidence of elevated concentrations of organic matter in the sediment was found in the total organic carbon analysis. The mean values of 4.3% to 4.6% TOC found in Quahog Bay are considered very high for the coast of Maine. Results from the EPA 2002 National Coastal Assessment (NCA) study in Casco Bay revealed concentrations ranging from 0.4% to 3.6% in sites outside Quahog Bay. The 3.6% was found at the mouth of the Presumpscot River, the greatest direct source of freshwater to Casco Bay. Other high values were found in Back Cove (3.3%) and the New Meadows River (2.8%). The NCA values for Quahog Bay were 3.9% at QB2 and 4.6% at QB3. Linda Schick at the Darling Marine Center, who performed the analysis for the 2003 Hypoxia project, commented that the concentrations in Quahog Bay were higher than what has been found at almost any site along the coast of Maine. Only Linekin Bay in mid-coast Maine experiences similarly elevated levels. Although TOC comparisons between regions are risky due to potential differences in sediment type (Mayer 1993, 1994, and 1999), these results suggest that Quahog Bay has excessive amounts of organic matter.

There is also a remarkable consistency in the TOC values between different projects. See Table 4 for a comparison of data from three different studies: the EPA National Coastal Assessment, an EPA Sediment Oxygen Demand project, and this project.

Table 4 – Comparison of mean TOC percentages between projects

Project	**NCA**	**EPA SOD**	**Dissolved Oxygen Monitoring Project**
Year	**2002**	**2003**	**2003**
QB1a	-	-	4.4 %
QB2	3.9 %	3.8 %	4.3 %
QB3	4.6 %	4.2 %	4.5 %
QB4	-	-	4.5 %
QB4a	-	-	4.6 %
QB5	-	3.8 %	4.6 %

4.0 Conclusions

Quahog Bay appears to be a net heterotrophic system at depth, subsidized by the ample supply of labile organic carbon in the sediments. These conditions drive the persistently low DO concentrations in the bottom water. This phenomenon exists regardless of stratification. The obvious next question is: Where does all of the organic matter come from?

There is the possibility that fish kills during the early 1990's introduced elevated carbon and nutrient levels that are still cycling within the bay. Sediment carbon to nitrogen ratios are relatively low, around 7:1, indicating that the carbon is labile and easily recycled. Other possibilities include submarine groundwater discharge, of which there is evidence in Quahog Bay (Laine 2003, Lim 2003). These discharges may contribute to elevated concentrations of nutrients.

The suspected poor flushing rates in Quahog Bay must play a role in the accumulation of organic carbon. Future studies should include some measurement of flow into and out of Quahog Bay. Building an awareness of the flushing rates in Quahog Bay may help us develop a clearer picture of why these hypoxic events occur.

Acknowledgements

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