The Effect of Tidal Flow Restoration on the Center Transect of the Intertidal Mudflats at Dingley Island

(Bowdoin College students)
Department of Geology
Bowdoin College, Brunswick, Maine

Abstract

This study characterizes the effect of a construction project that restored tidal flow to an intertidal mudflat in a coastal embayment in mid-coast Maine. Prior to the summer of 2003, a causeway built in the early 1950s impeded tidal flow through this mudflat. As a result of this unnatural obstacle to tidal flow, the economically important soft-shell clam yield has diminished in recent years. The objective of this study (part of a long term investigation of these mudflats) is to determine the effect of this tidal flow restoration on sediment characteristics such as shear strength, organic carbon content, and grain size distribution. Measurements were taken and samples collected along a transect running down the center of the mudflats on both north and south sides of the newly installed bridge. Because the bridge construction was only recently completed, the mudflats have not yet had time to fully adjust to the restored tidal flow, nor have they recovered from the impact of demolition and construction. However, some initial trends are clear. Shear strength has increased dramatically, indicating more cohesive sediment and a better environment for the sensitive clams. Organic carbon content has increased substantially immediately south of the causeway, indicating organisms have started to return to the flats. Lastly, redox potential discontinuity depth has increased dramatically, indicating a more oxygenated sediment, which is essential for soft-shell clam growth. Other parameters provided only inconclusive results; further study of these flats is crucial for a complete understanding of the effects of this bridge construction.

Introduction

This study characterizes the effect of tidal flow on the intertidal mudflats found at Dingley Island, located in the New Meadows River, Harpswell, Maine. From about 1950 until 2003, Dingley Island was connected to mainland Harpswell by a 200 ft. causeway. The causeway formed a solid barrier blocking the tidal flow west of the island. The blockage caused massive sediment deposit, which has been suggested to be behind the steady decline in productivity of the nearby clam flats. This past summer, construction began on a 24 ft. bridge that would restore tidal flow. The bridge was completed in late July 2003. The purpose of this study is to determine the success of the bridge construction by analyzing whether the physical properties and sediment characteristics of the flats have changed to create an environment more conducive to soft-shell clams (Heinig, 2003).

Several studies have already been performed that will be essential in evaluating the effect of the bridge construction. At least four studies published on topics like sediment flux and intertidal erosion will be relevant to our study. However, our study is not an experiment per se; rather, its purpose is to determine whether the overall quality of the sediment has improved as a habitat for soft shell clams. We will use data from as far back as Fall 2001 to compare the changes in redox potential discontinuity depth, organic carbon, grain size distribution, sediment depth, sediment density, shear strength, and water content since the construction was completed in July 2003. Our study is being performed in conjunction with two others simultaneously. This report will focus on the effects of the tidal restoration on a transect running through the center of the flats in the main tidal channel (Figure 1). The other mudflat studies will consider effects on transects running to the east and west of the central transect.

Intertidal mudflats are a low energy exposed environment with the deposition of sediments providing habitats and food resources for intertidal organisms (Maine DEP, 2002). Sediment characteristics can indicate the quality of mudflat environment and the effect of tidal flow restoration. Sediments, a form of soft substrate, are classified by size. The largest sediments considered here are sand and mud (500µm - >1000µm), while the smallest (less than 63 µm) are silts and clays (Rumohr, 1999). In this study, grain size measurements are performed to characterize sediment types. The intertidal mudflats are considered to be depositional environments; nevertheless, there is some erosion by the movement of water through the channel (Anderson, 1981). By analyzing sediment grain size distributions, we can quantify the effect of increased tidal flow through the channel. The higher the velocity, the larger the sediment sizes we would predict would be found, as the smaller sizes would be transported away, unless they were suitably cohesive (Garrison, 2003). Since we focused on the central transect, through which the tidal channel flows, we would expect to find larger sediment grain size than would be found at other transects. In addition, we expect that the largest sediments would be found near the bridge, due to the increased velocity relative to other parts of the channel.

Another indicative measurement is the shear strength of the surface sediment. Shear strength, measured using a specialized cohesion indicator (which measures torque), will tell us how easy it is to break away particles and re-suspend them in the water column. The more cohesive the sediment, the less erosion will occur during tidal changes. Furthermore, cohesive sediments are more suitable for soft-shell clam growth

(Abraham, 1986). For this reason, any changes in shear strength will help determine whether the bridge construction will have a positive impact on the clam yields on these flats.

The redox potential describes the reduction/oxidation regime, which is related to the concentration of oxygen dissolved in the water occupying the space between the grains of sediment (porewater). In this study, redox potential discontinuity (RPD) depth, which is the depth at which a rapid change in the redox potential occurs, is indicated by the change in color from the near-surface gray oxic layer of the sediment to the anoxic black layer below. The redox potential is affected by the following factors: sediment grain size, sediment organic content, and tidal water oxygen concentration. Larger grain sizes have more water circulation and greater RPD depth. Higher levels of organic content lead to more decomposition by bacteria, consumption of oxygen, and therefore shallower RPD depth. The greater the dissolved oxygen in the sea water above the sediment, the more oxygen supply to interstitial water, and therefore the greater the RPD depth (Rumohr, 1999). Since we expect to have increased grain sizes and low organic carbon in response to restored tidal flow, we expect increased RPD depth.

Sediment density and water content are inversely related, and we expect that as tidal flow is restored, water content will fall (increased tidal flow will result in less standing water). As water content falls, sediment density will increase because of the inverse relationship between the two parameters. Another important parameter measured was sediment depth. We expected that the increased tidal flow would move sediments deposited immediately adjacent to the causeway and distribute them more evenly throughout the flats. We also expect that deeper sediments will be better for the clam population because it will ease die-offs due to overcrowding and generally increase the carrying capacity of the flats.

As mentioned previously, soft-shell clams, the economically beneficial organism at Dingley Island, are the intertidal mudflat organisms on which this study is focused. Still, there are other organisms and plants that inhabit the mudflat environment and impact mudflat ecology. The abundance of organisms could imply a high quality intertidal mudflat. In this study, organic carbon content is measured to obtain quantity of organisms in the central transect of mudflat. Normally, the low organic content sediments are aerobic with the gray to blue gray color and the high organic content sediments are anaerobic with the black color (Dyer, 1998). In this study, the loss of sediment weight through combustion indicates the organic content (see *Methods* section for details). Dyer (1998) states a rough division between aerobic and anaerobic organic content of sediments with a loss on combustion of over 5 % suggesting a high organic content. We expect that organic content at the central transect would be less compared to the east and west transects because the stronger tidal flow makes it harder for organisms to inhabit this area. It is possible there will be a north-south correlation with organic carbon content as well, depending on the strength and direction of the tidal flow.

The overall object of our study is to evaluate the quality of sediments at Dingley Island. Furthermore, we will compare the results with past studies to quantify any changes or differences caused by the newly created bridge. Finally, we hope to analyze the data and determine the overall trend in mudflat quality since the installation of the bridge. As noted above, the qualitative answers to these questions should help us determine whether the health of the ecosystem has improved since the bridge was installed. Further study will solidly establish the extent to which the bridge installation has enhanced the health of the clam flats.

Methods

On September 24, 2003, substrate samples were collected (in triplicate) to measure sediment density, water content, organic carbon content, and grain size (though the latter two were not *processed* in triplicate). Each sample was put into a pre-massed vial to be brought back for laboratory analysis. Sediment density samples were collected by taking a constant volume core of 5 mL. Sediment depth measurements were taken by injecting a probe into the sediment until the underlying hard surface was reached. The measurement was reported in centimeters. On October 8, 2003, triplicate measurements of redox potential discontinuity (RPD) depth and shear strength were taken. All samples and measurements were taken along the center transect between Dingley Island and mainland Harpswell (Figures 1 and 2).

In order to determine density, water content, grain size distribution, and organic carbon content of the samples, each sample was brought to the lab for testing. The 5-mL density samples were massed and density was calculated in g/mL.

In order to determine grain size and organic carbon content, the samples were strained through sieves of sizes 1 mm, 500 µm, 243 µm, and 63 µm. Filtrate from the 63µm sieve was collected and allowed to settle for a week. The remaining water was siphoned off until only the silt and clay remained. The sediment remaining in each sieve was slurried and collected into pre-massed tins. These tins were dried for at least twenty-four hours using a standard dryer at 105°C. They were then massed and percentages of each grain size in each sample were calculated.

After the grain size percentages were recorded, the samples were burned in an oven at 450°C for two hours to eliminate the carbon content. The remaining matter was massed and compared to the mass before the burn. Thus we calculated percent organic carbon both in absolute terms and as distributed by grain size.

The water content samples were massed and then dried for two hours using a standard dryer at 105°C. We calculated water content by comparing the masses of the dry and wet samples (though water content is reported here as a percentage of the dry mass, not the total sample mass).

RPD depth was simply measured in centimeters by using a ruler (Figure 3). Thin layers of sediment were peeled back until the underlying anoxic layer was reached. Shear strength was measured using a Torvane tool manufactured by Durham Geo-Enterprises. Due to the lack of relative cohesiveness, the 0.2 vane was used as the default setting (Figure 4). Measurements were taken and converted into kg/cm^3.

Data collected during this study was not the only data used during the analysis. To complement our results and help quantify changes, data collected during the month of May 2003 as well as the fall semester of 2001 were used as baseline data for these parameters.

Sampling Stations, Center Transect, Dingley Island

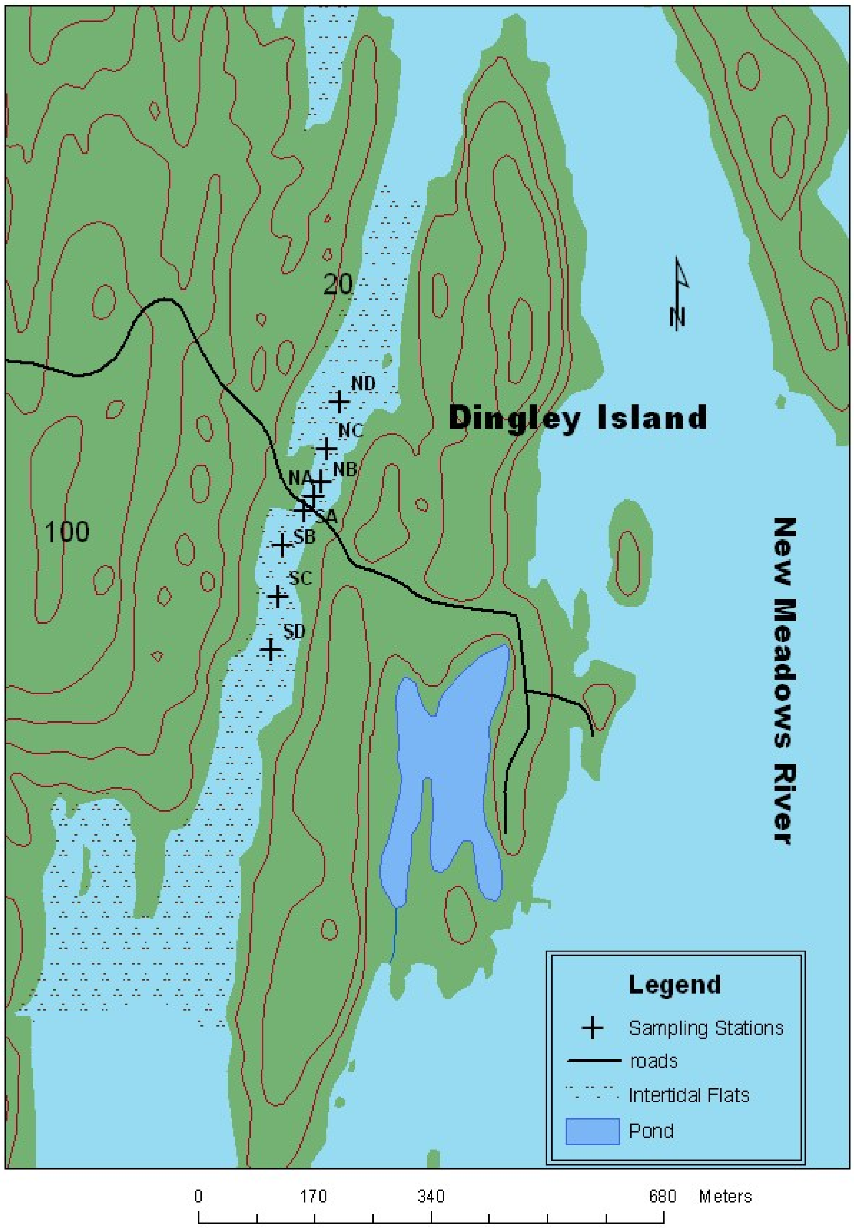

Figure 1. Overhead view of site. Dingley Island is on the right (east), mainland Harpswell on the left (west).

Figure 2. South side of the site. The middle group of students are collecting samples along the center transect.

Figure 3. Measuring RPD depth.

Figure 4. Measuring sediment shear strength.

Results

Sediment Depth

Sediment depth data from fall 2001 showed an increasing trend of sediment depth, moving closer to the bridge on both sides (Figure 5). The sediment was deeper on the north side than on the south side, on average. However, the deepest sediment was found on either side of the causeway (sampling sites NA and SA). The deepest sediment overall was found at site SA.

Average sediment depth in the fall of 2003 (40.9 cm) was similar to sediment depth at each station compared to the depth in 2001 (40.1 cm). Figure 5 shows that average sediment depth in the autumn of 2003 was relatively uniform on the north side of the causeway, while the average sediment depth on the south side had an increasing trend from sampling site SD to site SA (i.e. moving toward the causeway). As in 2001, in 2003 the sediment depth on the north side was deeper than on the south side, on average. Only two sampling sites showed a net decrease in sediment depth between 2001 and 2003: NA and SC.

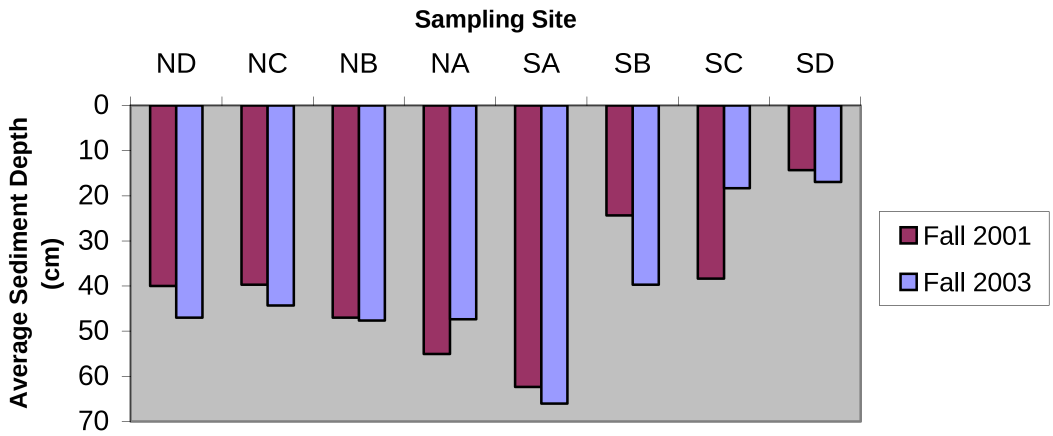

Figure 5. Average Sediment Depth in centimeters, before and after bridge construction, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Shear strength

Shear strengths increased considerably from 2001 to 2003 (Figure 6). In 2001, shear strength was negligible at more than one-third of all sampling sites. The highest average shear strength was at the SD station, which was the highest average shear strength in the 2003 as well. Moreover, the average shear strength of the south side of the causeway was greater than the north side in 2001.

In fall 2003, shear strength was highest both close to the causeway and far away from the causeway, i.e. the lowest shear strength was found at an intermediate distance. The highest average shear strengths in 2003 were found on the south side, farthest from the causeway, similar to 2001.

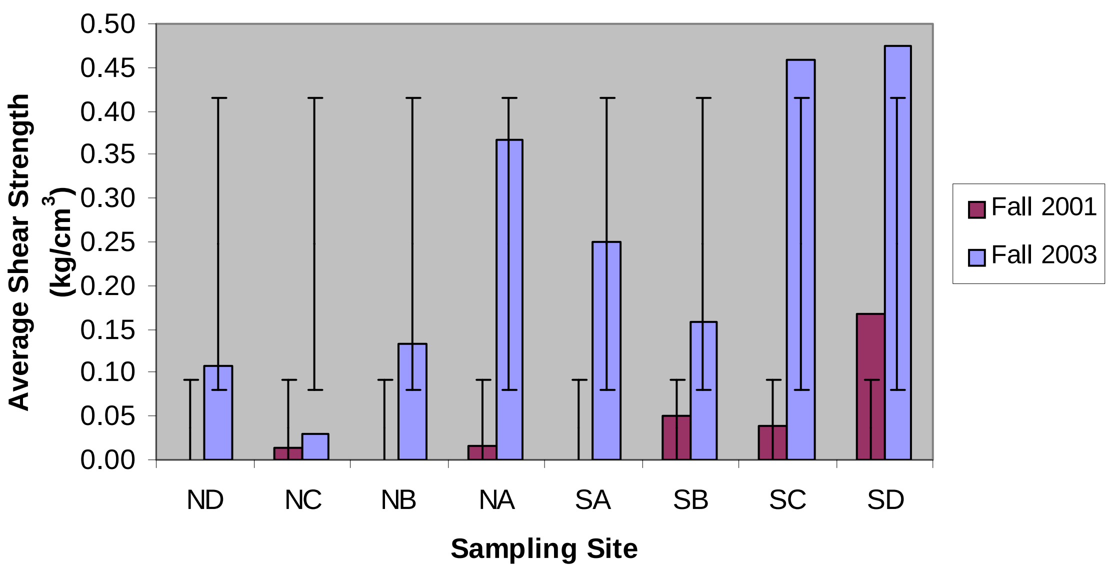

Figure 6. Average shear strength of sediment (kg/cm^3), before and after bridge construction, center transect, Dingley Island. (Shear strength negligible in 2001 at sites ND, NB, and SA.) Error bars reflect one standard deviation from mean.

Water content

Figure 7 shows that in fall 2001 water content was substantially greater than in 2003. Water content in 2001 was always over 100% of the dry sample mass (except for site SD), in some cases double the percent water content in 2003. There was a decreasing trend in water content from the north to the south in 2001. By 2003, water content averaged just under 100% along the transect from north to south. As in 2001, the percent water content was lowest at the sites farthest south of the causeway: to about 75% at site SC and to about 60% at site SD.

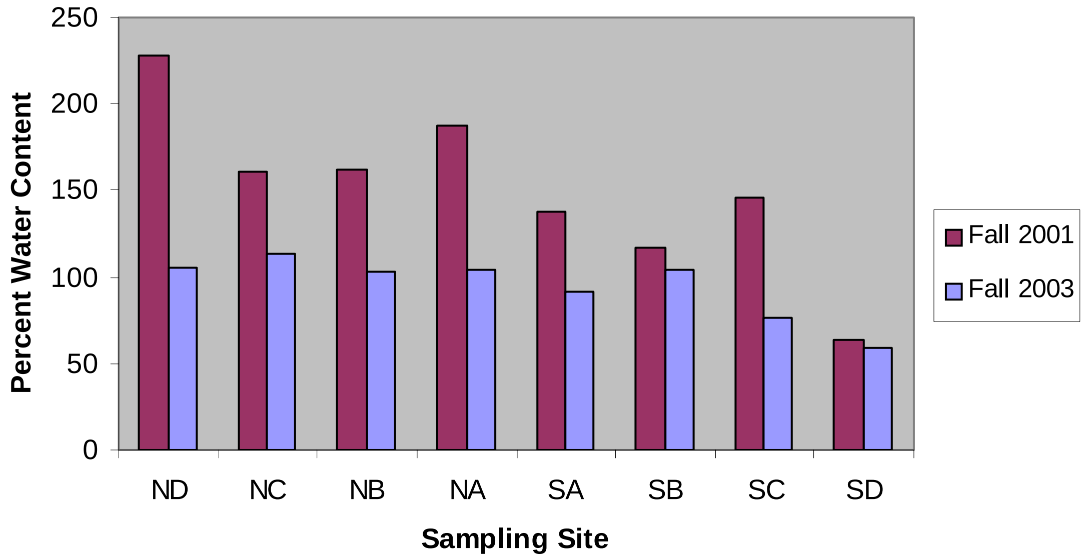

Figure 7. Water content as a percentage of dry sample mass, before and after bridge construction, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Sediment density

Figure 8 shows that density of sediment of all but one of the sampling stations in both fall 2003 and fall 2001 were nearly equal within a density range between 1.3 – 1.7 g/mL. Comparing density of sediment between fall 2001 and fall 2003 data and between the north and the south sides of the causeway, there was no clear difference or trend. However, there was a striking density measurement that was about twice the average density (approximate 3.7 g/mL) at the NA station in the fall 2001. The data point from the fall 2001 data set at site NA is an outlier.

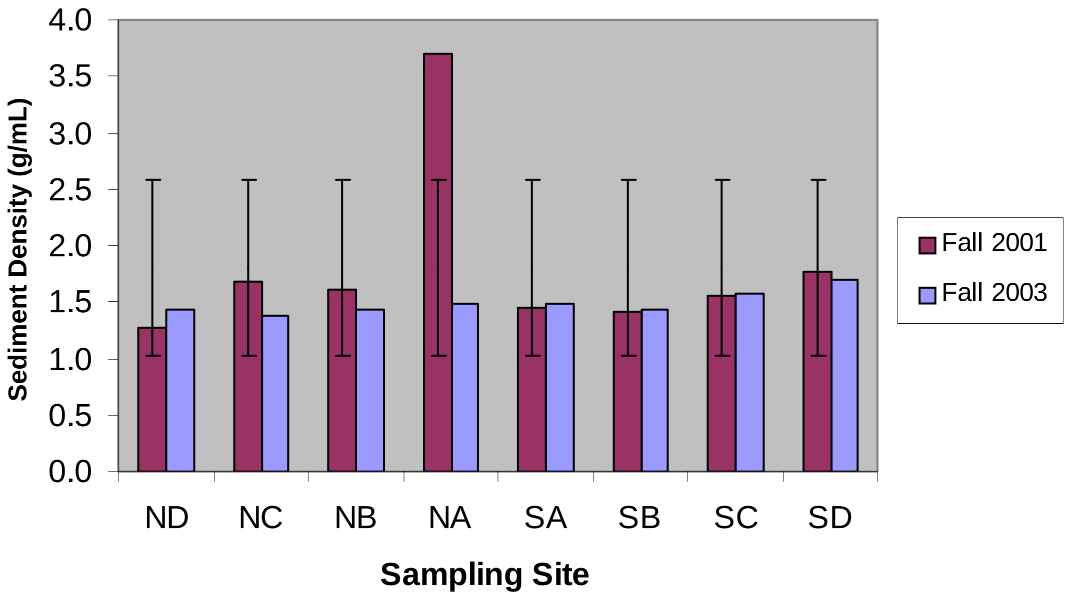

Figure 8. Sediment density in g/mL, before and after bridge construction, center transect, Dingley Island. Sample locations ND-NA are north of the causeway, SA-SD are south. Error bars reflect one standard deviation from the mean.

Grain size distribution

In both spring 2003 and fall 2003, sediments less than 63 µm in size formed the greatest percentage of the sample mass, at every sampling site (Figures 9 and 10, respectively). Sediments sized between 63 µm and 243 µm, as well as sediments between 243 µm and 500 µm were less abundant, and sediments 500 µm - 1000 µm and >1000 µm were least abundant in almost all sampling stations. The May 2003 samples showed an interesting trend: on the north side, the percentage of sediments less than 63µm in size *increased* moving away from the causeway, while on the south side, the percentage of sediments in this size *decreased* moving away from the causeway (Figure 9). The decreasing trend moving away from the causeway appeared on the south and north sides of the causeway in the fall of 2003 as well. The lowest percentage of <63 µm sized sediments was at the SD station (Figure 10). At both times, the greatest percentages of the largest (500+ µm) sediments were found farthest from the causeway on the south side. After bridge construction, percentage of the largest (500+ µm) sediments more than doubled to about 40%. Importantly, the proportion of finest (<63µm) sediment sizes diminished after bridge construction immediately on either side of the causeway. Most notably, on the north side, the percentage of sediment sized between 63 and 243µm more than doubled. At these same locations, the percentages of the largest (500+ µm) sediments increased.

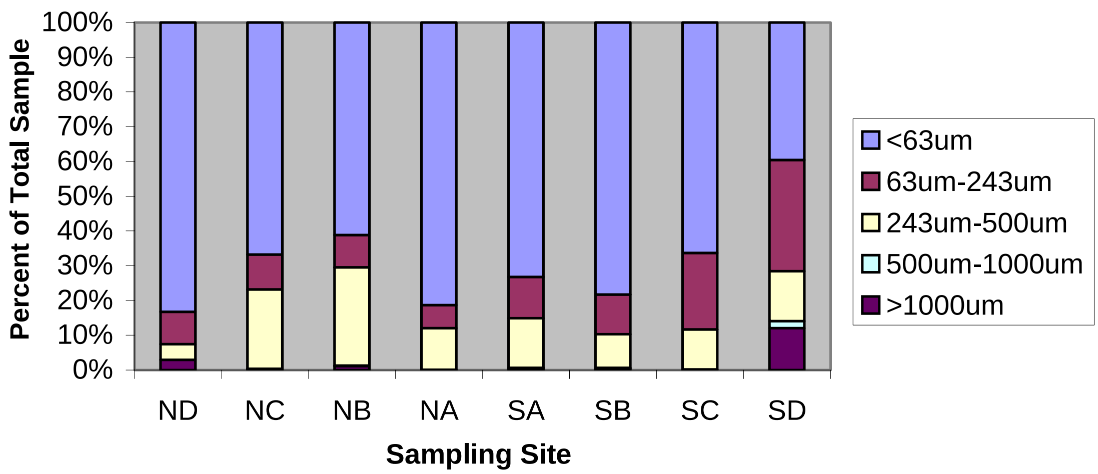

Figure 9: Grain size distribution as a percentage of total sample mass, May 2003, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

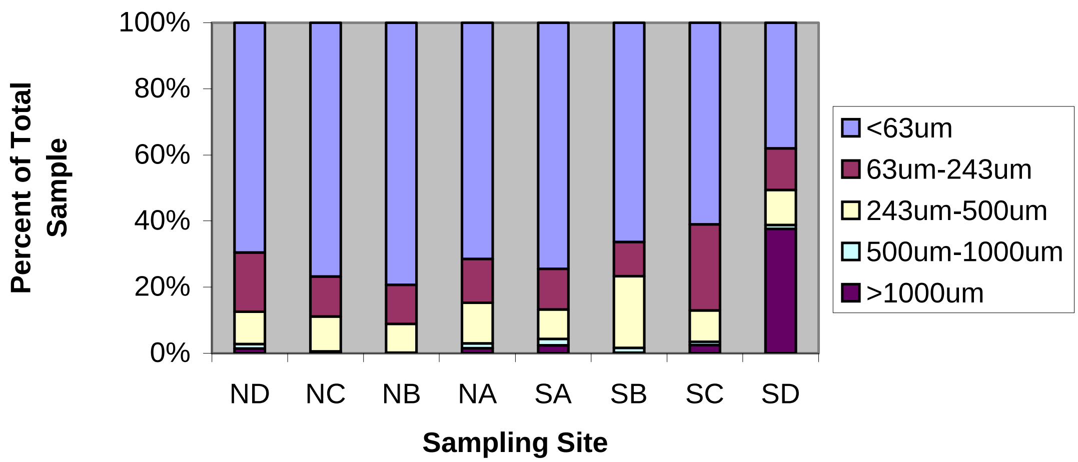

Figure 10: Grain size distribution as a percentage of total sample mass, Fall 2003, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Organic carbon content

As Figure 11 shows, percent organic carbon decreased steadily from north to south in May 2003. The highest organic carbon content was found at the ND station (13.6%), the station furthest north of the causeway, and the lowest percent organic carbon content at the SD station (3.9%), the station furthest south of the causeway.

The percent organic carbon content on the north side showed no discernable trend from May to September; however, there was a striking increase in organic carbon (more than quadrupling to about 40 %) at the NB station. Looking back at organic carbon distributed by grain size, we notice that the at the NB station, the percentage of sediments sized 243-500 µm made up about 9% of the total sample. However, that grain size was about 83% organic carbon (1975% of the next largest amount of organic carbon, found in sediments sized below 63 µm). This leads us to conclude that the 243-500 µm fraction is responsible for this outlier. On the south side of the causeway, organic carbon content steadily decreased as one moves away from the causeway (site SD showed about 4.6% organic carbon). Importantly, organic carbon content nearly doubled immediately south of the installed bridge after construction, but showed no change immediately north of the causeway.

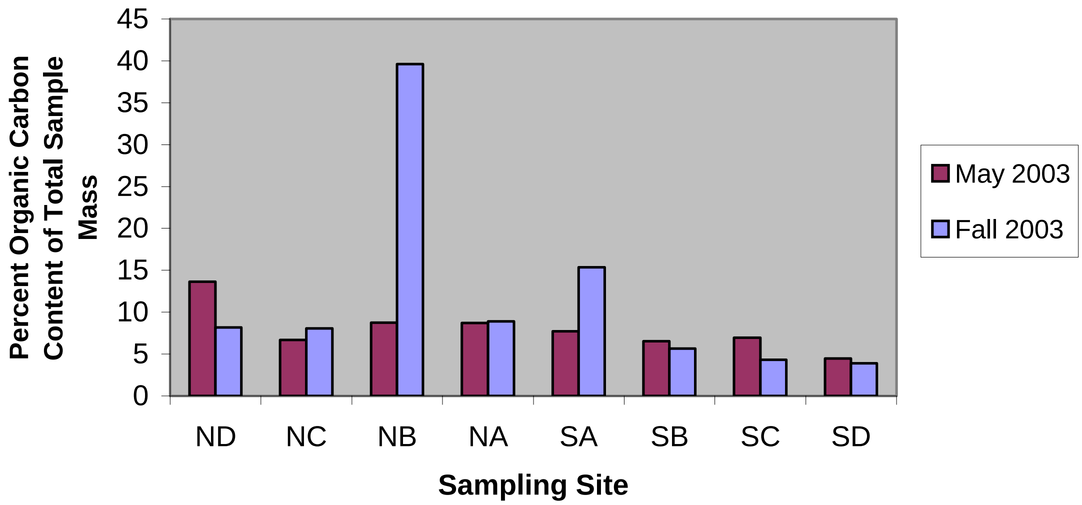

Figure 11. Organic carbon content as a percentage of total sample mass, before and after bridge construction, center transect, Dingley Island. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Figures 12 and 13 show that organic carbon content as distributed by grain size fell categorically from May to September 2003. The May 2003 samples had higher organic carbon content in almost all grain sizes at every sampling site (Figure 12). In some cases, organic carbon made up 100% of the sediment in that particular grain size. In contrast, samples taken in September 2003 show organic carbon as low as 5% of the total sample mass, in most cases (Figure 13). However, the September 2003 data show a relatively high percentage of organic carbon content for sizes of 243 µm – 500 µm and <63 µm at the NB station and the SA station (about 85 % and 20% respectively). Though we may safely consider the surprising data at site NB to be merely an outlier, 20%

organic carbon in the silt/clay sized sediments, immediately south of the causeway, may indeed be significant.

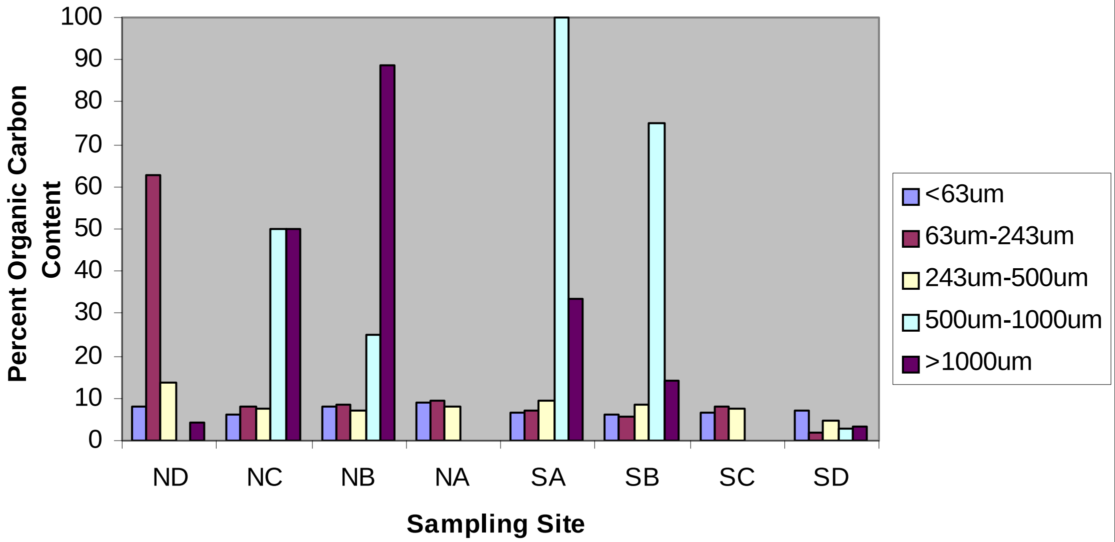

Figure 12. Percent organic carbon content distribution by grain size, May 2003, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

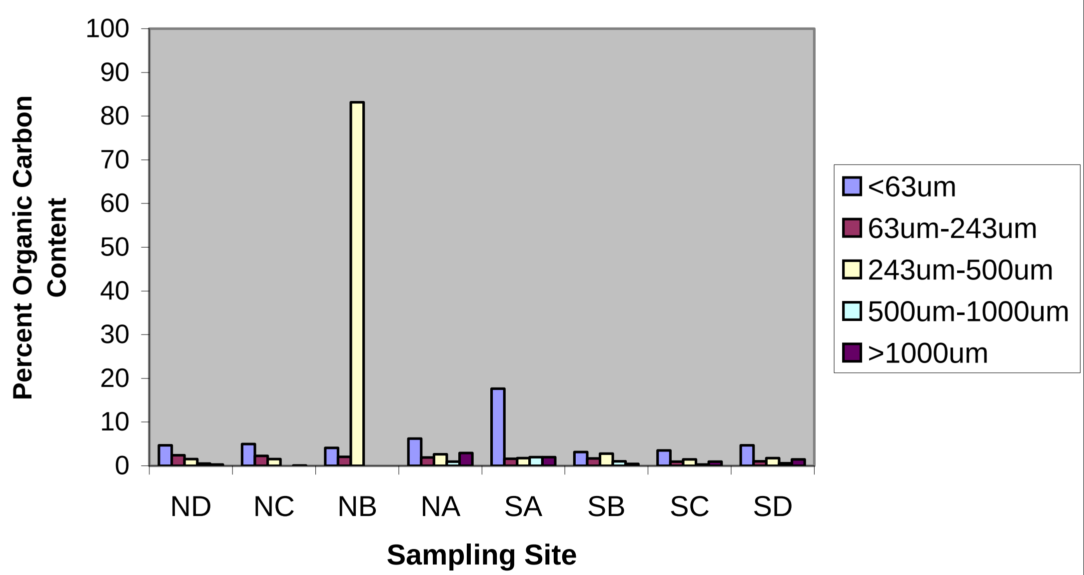

Figure 13. Percent organic carbon content distribution by grain size, Fall 2003, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Redox Potential Discontinuity (RPD)

The average RPD depth in 2003 (1.79 cm) was substantially higher than in 2001 (.50 cm) at every sampling station (Figure 14). In both years, the average RPD depth at the north sampling sites was less than the south sampling sites' average depth. In 2001, there was a decreasing trend of average RPD depth moving toward the causeway on the north side. This trend changes slightly in 2003. RPD depth starts shallow, then increases dramatically at site NC, then decreases as one moves toward the causeway, much like in 2001. There was no pattern apparent south of the causeway in 2001; however, RPD depth clearly increases as one moves toward the causeway in 2003. Over both years, the ND station had the least change in RPD depth. Most obvious from Figure 14 is that RPD depth increased immensely next to the causeway on the south side between 2001 and 2003.

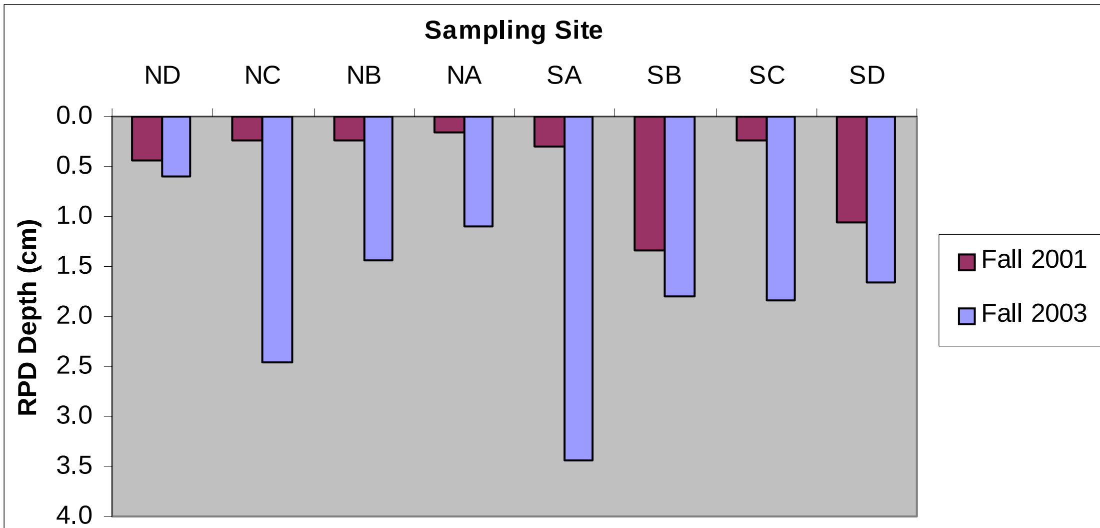

Figure 14. Redox potential discontinuity depth in centimeters, before and after bridge construction, center transect, Dingley Island, Harpswell, ME. Sample locations ND-NA are north of the causeway, SA-SD are south. D is farthest from the causeway.

Discussion

The effect of tidal flow and tidal restoration on sediment depth, water content, grain size, and shear strength should help to predict the effect of the bridge construction on the soft-shell clam community. A previous study indicated that juveniles of bivalves that settled on impenetrable hard clay substrates did not survive and most settled in sand sediment (MacKenzie, 1997). Furthermore, these clams prefer cohesive sediment that will not collapse around their sensitive filters (Abraham 1986). The strong tidal flow would carry small, suspended sediments along with the flow and leave the larger sediments on the mudflat. Since soft-shell clams are generally more abundant in sandy areas (areas of medium sediment sizes), we would predict more soft-shell clams along the central transect. Restored tidal flow has begun to transport the finest sediments over the flat while depositing coarser sediments in the channel. Abraham (1986) showed reported that soft-shell clams prefer coarser sediments to silty substrates, and that higher populations are correlated with lower organic carbon content. Hertweck (1995) also found that the shallowest part of the channel systems together form an intertidal watershed, with channel troughs functioning as sediment traps for muddy sediment. Thus, soft-shell clam populations should be healthier in deep, cohesive tidal flats.

Though there was no overwhelming trend in sediment depth before and after the bridge construction, it is clear that sediment depths have increased overall. Though we expect that the restoration of tidal flow to the channel between the island and the mainland will move sediments away from the causeway and even out sediment depths, this has not yet occurred. We hypothesize that since bridge construction was completed very recently, the full effect of this restoration has not taken place. Future study will yield more definitive results; however, from our initial results, we can predict that the strongest tidal flow is on the north side (due to the progress of the transport mechanism). Interestingly, sediment depth actually *increased* on the south side of the causeway, close to the bridge. Perhaps this indicates that the tide flows under the bridge from the north and deposits sediments on the south side, before retreating, or that the sediment gets backed up at the bridge where sediments are deposited. Strong tidal flow should transport sediment out of the area and deposit it at the area with weaker relative flow (Garrison, 2002). We would expect that because these data are taken from the central transect, we would notice some scouring of the sediment due to the striking change in tidal flow; however, when compared to results from the east and west transects, our data are quite similar, indicating that the construction has not affected the channel in any way different from the mudflat as a whole. Overall, sediment depth results show no impact of tidal restoration: before meaningful discussion can occur, more study is required.

Shear strength, a measure of the cohesion of the surface sediment, is a good indicator of the quality of the flats for soft-shell clams (Abraham 1986). Shear strength increased substantially at every sampling station along the center transect. More cohesive sediments tell us that water content is low, sediment density is high, and grain sizes are predominately fine. It may also indicate that organic carbon content is higher because the high surface area may encourage bacterial growth. These relationships fit somewhat well with our data. The restoration of tidal flow should lead to less water content since the flow would decrease the effects of stagnating water on the sediment. The open causeway between the north and south sides of the causeway created a flow that was relatively strong at the central transect. Due to the strong tidal flow, the time which water spent at one point on the mud decreased. Thus, there was less absorption of water into sediment indicated by higher shear strength of the sediment along the central transect.

Even though the water content clearly decreased along the central transect, the sediment density was still similar from the stage before the bridge construction. We expected to see higher sediment density because as water moves out of the interstitial spaces between sediments (due to decreased water content), the sediments will become more compacted. However, the sediment density before and after the bridge construction was relatively similar. Therefore, we assume that after the bridge construction, as water content decreased, less dense, lighter particles took the place of the water than before the bridge construction.

Sediment grain size has clearly been sorted by the tidal flow: the larger sediment grain size concentrations and sediment scouring appeared with the stronger tidal flow, while the smaller grain size and deposition occurred with the weaker tidal flow, as expected (Anderson, 1981). Also, the erosion and deposition on the mudflat were dynamic; they changed over the period from spring to fall by the effect of environment (Anderson, 1981). The influence of tidal flow restoration caused a decrease in finest sediment in almost all sampling stations and an increase in the largest sediments especially at the sampling sites immediately next to the bridge. Although the largest sediments increased, the major component of the samples was still the finest sediments (<63 μm), which indicated that the study site was still a tidal mudflat, not a sandy flat.

The decrease in finest sediment due to the tidal flow may affect the food resources for the soft-shell clams. Because finer sediments contain more nutrients than coarser sediments, we expected that the clams would be more abundant in the area with finest sediment because the finest sediment contained more nutrients than the large sediment (Tyler-Waters, 2003). *Mya arenaria* are filter feeders, and can filter up to 4 liters of water per hour (Bertness, 1999). Filtered particles are sorted by size in the enlarged gill surface of the soft-shell clam. Larger particles do not enter into the digestive system because they are not good sources of nutrients (Bertness, 1999). Thus, soft-shell clams are likely to live in areas with an abundance of fine sediments in order to effectively consume nutrients. This assumption corresponded with our study since the fine grain size were the major component in the sediment samples.

We also assumed that seasonal changes influenced the organic carbon content in the mudflat. In spring, the temperature began to increase and most organisms reproduced during spring and summer depending on their natural history. In fall, organisms would save some energy in order to survive through the winter. Organisms that could not adjust to the change of temperature and physical factors like the stronger tidal flow would die. Thus, we expected to see more organic carbon content during spring and summer than during fall and winter. This conclusion could be complicated by the fact that organic carbon content is not a perfect measure of life in the flats. Organic carbon can also reflect dead organisms that haven't completely decomposed.

Overall, the enhancement of the soft-shell clam harvest would be predicted due to the increasing of dissolved oxygen in the mudflat: redox potential discontinuity depths increased after the bridge construction. The apparent increase of RPD depth is strongly correlated with the bridge construction. It is affected by the tidal flow as well as other physical properties and sediment characteristics. The stronger the flow, the more oxygen-laden water would flush the sediment layer. The oxygen dissolved in sediment increased because oxygen that was dissolved in water contacted with the surface of the mudflat and was dissolved into the sediment more.

Since soft-shell clam harvesting is an important economic resource at Dingley Island, our comparative study on the tidal flow restoration before and after the bridge construction should predict the condition of soft-shell clam resource in the future. Though these results are preliminary, there are several indications that the health of the flats for the clams is improving. The most cogent arguments can be made using results for shear strength and RPD depth. A deeper oxygenated layer allows more clams to live on the flats, and more cohesive sediments indicate flats more conducive to the biology of the clams. Further study of this estuary is absolutely required before a definitive answer can be presented; however, preliminary indications found through this study suggest that the bridge construction is starting to improve the health of the intertidal mudflats at Dingley Island.

Future studies of this estuary are clearly necessary. Most likely, the environment simply has not had enough time to adjust to the impact of bridge construction, in at least two ways. First, these flats probably are still feeling the negative impacts of construction and demolition. Second, the beneficial effects of tidal flow restoration probably have not yet been fully realized. There are other reasons why further study would be ideal. It would be interesting to be able to control for the seasonal variations in mudflat characteristics. Most obviously, organic carbon content and RPD depth are likely to fluctuate substantially over the year due to several factors such as leaf litter, organism growth and death rates, etc. Lastly, a more detailed sampling regime could yield more meaningful and interesting results. By sampling certain areas with high levels of specificity, more accurate results could be found. In addition, it is clear that the clams on these flats do not live anywhere near the causeway. Taking more samples from areas where the clams are actually found could increase the usefulness of future studies.

Literature Cited:

Abraham, B., P. Dillon. 1986. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) -- Softshell Clam*. U.S. Fish and Wildlife Service Biol. Rep. 1986(11.68) pp 18.

Anderson, Franz E. Luther Black. Les E. Watling. William Mook. Lawrence M. Mayer. 1981. *A temporal and spatial study of mudflat erosion and deposition. Society of Economic Paleontologists and Mineralogists*. Journal of Sedimentary Petrology. Tusa, OK, United States. Vol. 51, Issue 3, pp. 729-736.

Bertness, Mark D. 1999. The Ecology of Atlantic Shorelines. Sinauer Associates, Inc. Publishers Sunderland, Massachusetts. pp 259.

Dyer, K. R. 1998. *The typology of intertidal mudflats*. K. S. Black, D. M. Paterson, and A. Cramp eds. Sedimentary Processes in the Intertidal Zone. The Geological Society, a Geological Society Special Publication. No. 139 p. 21.

Garrison, Tom. Oceanography: An Invitation to Marine Science. 4th edition. Brooks/Cole: January 2002. p.124.

Heinig, Christopher S. Last update 23 June 2003. *Project Description, New Meadows River Watershed Project*. MER Assessment Corporation. Internet. Available at http://academic.bowdoin.edu/courses/f03/geo103/dissemination/Dingley_projdescr.pdf. Accessed 7 October 2003.

Hertweck, G. 1995. *Distribution patterns ff characteristic sediment bodies and benthos populations in the Spiekeroog backbarrier tidal flat area, southern North Sea*. Senckenbergiana maritima. Frankfurt/Main, vol. 26, no.1-2, pp. 81-94.

MacKenzie, CL Jr. 1997. *The natural history and habitat characteristics of softshells (Mya arenaria) in northern New Jersey*. Journal of Shellfish Research. vol. 16, no. 1 Jun, p. 310.

Maine DEP. Last update: 23 April 2002. Maine Coastal Habitat, Maine's Coastal Wetland. Volume.1, part 2 p.29. Internet. Available at http://www.maine.gov/dep/blwq/doccoast/coastal3.htm. Accessed 7 October 2003.

Rumohr, Heye. *ONEDIN Marine Environment Online Course*. 1999. Available at http://www.aqualex.org/html/onedin/marine_environment/chap2/chap2-4.html. Accessed 7 October 2003.

Tyler-Waters, H., 2003. *Mya arenaria.* Sand gaper. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [online]. Plymouth: Marine Biological Association of the United Kingdom. [cited 12 February 2003]. Available from http://www.marlin.ac.uk/species/Myaare.htm. Accessed 19 December 2003.