Investigating the effects of marine biogeochemistry on soft-shell clam (*Mya arenaria)* shell thickness in Georgetown, Maine

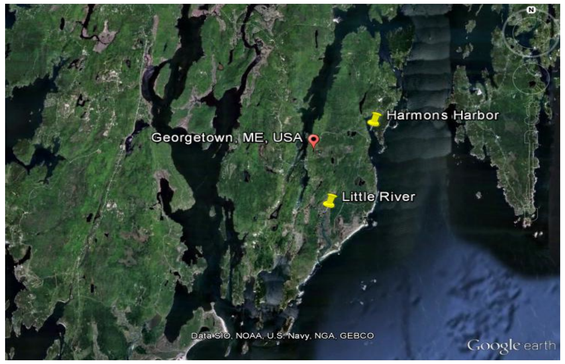
Alden Drake, Anna Hall, Liza LePage, Dan Lesser, Arhea Marshall, Gabi Serrato Marks, Alana Menendez, Jasmine Terry-Shindelman, Nate Schwehm, Tricia Thibodeau, Jessie Turner, Dominique Wein, Dana White, Michèle LaVigne, Ruth Indrick

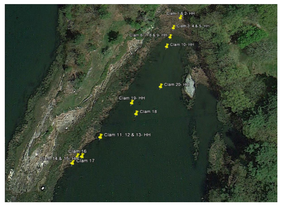
Bowdoin College, Department of Earth and Oceanographic Science

Introduction

The soft-shell clamming industry represents the second largest seafood industry in Maine, yielding $12 million dollars annually. It provides nearly 1700 commercial harvesting jobs, as well as occupations for dealers, food services, and management (Beal, 2001). Within the Kennebec Estuary, some clam flats are known for thin shells, resulting in economic loss for fishermen because the shells break during transport. Those flats with thick shells are more economically viable for clamming. Our study aims to assess how differences in marine biogeochemical properties influence clam shell thickness in Georgetown, ME. We chose two clam flats with known differences in clam shell thickness: Harmon's Harbor (HH), a clam flat with historically thicker shells and Little River (LR), a clam flat with historically thinner shells. We hypothesized that Little River would have more acidic conditions than Harmon's Harbor, as prior research indicates that clam shell thickness is negatively affected by ocean acidification (Salisbury *et al.* 2009). Field experiments were conducted at each flat to measure nutrients, water properties, alkalinity, and sediment characteristics, as well as clam size and shell thickness at each site.

Locations





Harmon's Harbor (HH) Clam Sampling Locations

Little River (LR) Clam Sampling Locations

Clam Physical Properties

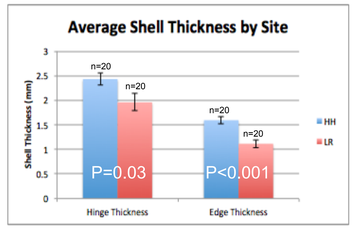


Figure 2. Shell Thickness
Mean shell thickness at HH and LR. Error bars show ±1 SE.

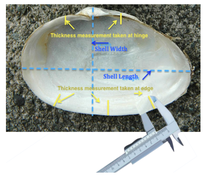


Figure 1. Shell diagram
Yellow lines denote the location of shell thickness measurements taken along the hinge and edge of each clam. Blue lines denote the location of length and width measurements of each clam, taken at the longest and widest point of the shell.

Methods

- 20 clams were collected from each site, where indicated on the maps.
- Each full clam was weighed.
- The soft tissue was separated from the clam shell, then weighed. The tissue was then dried and reweighed.
- Shell properties were measured using a caliper, as indicated in Figure 1.

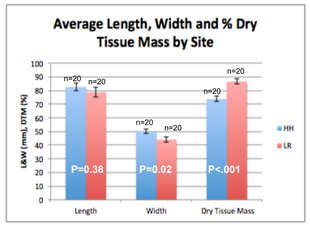


Figure 3. Physical Characteristics
Mean length, width and % dry tissue mass at HH and LR. Error bars show ±1 Standard Error.

Results

- Shells were thicker at HH than LR, as measured both at the hinge and at the edge of the shell (Figure 2).
- Clam length was not significantly different between sites, indicating that length was not indicative of clam thickness (Figure 3).
- % Dry tissue mass was significantly higher at LR than HH, indicating that energy is being allocated to soft tissue mass growth, not shell thickness (Figure 3).

Water Properties

Table 1. Average water parameters at each of the clam flats. A total of 8 samples were taken at each site.

	Salinity (PSU)	POC (g/L)	[DO] (mg/L)	pH	DO%	Temp (°C)
Little River	25.73	.004 (g/L)	12.5275	7.8675	132.86	10.93
Harmon's	29.74	.017 (g/L)	15.031	8.31	151.52	7.425
Statistically Significant Difference?	YES (.0086)	NO (.29)	YES (.0001)	YES (1.32E-05)	YES (.002)	Yes (8.714E-10)

Results: Salinity and dissolved oxygen varied between the two sites and on a gradient moving out to sea where both generally increased. The sites were statistically significant from each other with LR having consistently lower values in every variable compared to HH. This included fresher water at LR than at HH. Both sites were characterized by tolerable temperature and salinity conditions for soft-shell clams (Berquist *et al.* 2009).

Sediments and Organic Matter

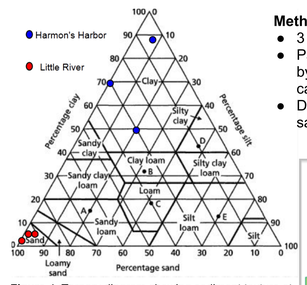


Figure 4. Ternary diagram showing sediment texture at each site. Little River sediment is categorized as sand and Harmon's Harbor sediment is categorized as clay.

Methods:

- 3 samples from each site
- Particulate organic matter was measured by combusting dried sediment and calculating the weight lost.
- Determined sediment texture by separating sand, clay, and silt using Calgon solution.

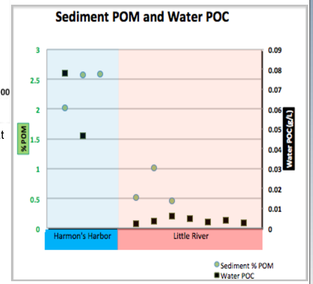


Figure 5. Comparison of water particulate organic carbon POC) and sediment particulate organic matter (POM) at each site determined by combustion analysis.

Results:

- Previous research has shown that fine-grained sediments are richer in OM than sandy sediments, providing a larger food source for clams.
- Harmon's Harbor has more fine-grained sediment and less organic matter (in water and sediment) than Little River.

Nutrients

Methods: HH and LR data represent averages of 5-6 samples, with 2-3 replicates of each. Kennebec Estuary data were used as a baseline comparison for nutrient data, and represent averages from 0-5 meters from 4 sites along the estuary. Error bars for each site show the data range.

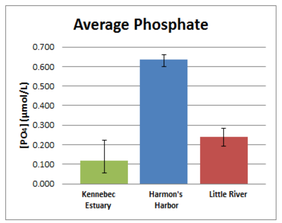


Figure 6: Average phosphate concentrations at LR and HH were significantly higher than the Kennebec Estuary ($p < 0.05$).

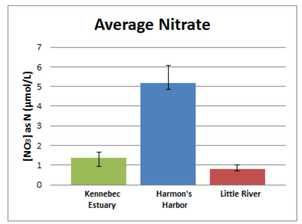


Figure 7: Average nitrate concentration was significantly higher at HH than at the Kennebec Estuary ($p < 0.05$), while average concentration was significantly lower at LR ($p < 0.05$).

Results:

- Overall lower nutrient levels at LR compared to HH correspond to lower POM in the sediment and lower POC in water (see figure 5), suggesting lower phytoplankton growth (clam food source).
- The phosphorus to nitrogen ratio at LR (3.3) was lower than at HH (8.2) or the Kennebec Estuary (11.6), and much lower than the expected Redfield ratio (16), indicating that primary productivity is nitrogen limited at LR.

Alkalinity, pH, and Saturation State

Methods:

- 3 water samples were collected per site.
- 2 replicate titrations per water sample measured total alkalinity (TA).
- Using pH measured on site with YSI, the saturation state of aragonite was calculated for both sites.

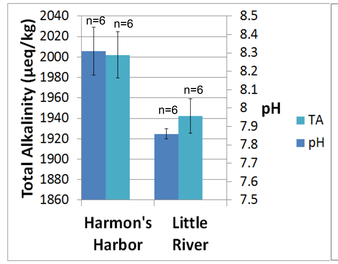


Figure 8. Total Alkalinity and pH at both sites. All differences were statistically significant ($p<0.05$).

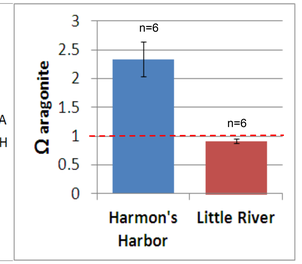


Figure 9. Saturation state of seawater at both sites. Difference was statistically significant ($p<0.05$). Dotted line indicates **Ω aragonite < 1**, the point at which calcifiers cannot extract CaCO3 from seawater.

Results:

- Alkalinity and pH were significantly lower at LR, meaning that the water there had less buffering capacity and was more acidic than HH. This indicates a positive correlation between alkalinity & pH and clam shell thickness.
- Saturation state ($\Omega_{aragonite}$) was higher and more variable at HH, and lower and less variable at LR, at which $\Omega_{aragonite}$ was < 1.

Conclusions

- **Lower nitrogen at Little River correlates with lower sediment POM, water POC, and thinner clam shells than at Harmon's Harbor. These factors suggest that lower primary productivity may be causing clams at Little River to allocate more energy toward soft tissue growth than shell development.**
- **Freshwater input at Little River contributed to lower alkalinity and pH resulting in a lower saturation state. Therefore, there were less carbonate ions available for the clams to build thicker shells.**
- **Little River is a naturally acidic environment due to freshwater input, which demonstrates how Maine clam flats might be impacted by ocean acidification in the future.**

Bibliography

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