Report to the Town of Freeport

Shellfish Habitat Resource Planning Study

Submitted by Resource Access International, LLC
February 5, 2014

Introduction

In the spring of 2013, the Town of Freeport was awarded a Shore and Harbor Planning Grant through the Maine Coastal Program, which is housed under the Maine Department of Agriculture, Conservation and Forestry, with a goal of determining what issues may be affecting the productivity of the local clam flats, and what, if any, actions may be taken to improve productivity. The town of Freeport provided a 50% in-kind match to the requested award of $20,000, creating a total project budget of $40,000. The town issued a Request for Proposals (RFP) to solicit bids for the work plan, and in March of 2013, Resource Access International (RAI) was notified that we had provided the winning bid for this project.

The initial project proposal consisted of a tiered approach to test various possible impacts on the shellfish harvest areas, including ocean acidification and pH levels in sediments; nutrient run-off or other related water quality; natural predation; and ongoing management of shellfish areas. The final outcome was to be a series of recommendations, based on the project data, that could potentially mitigate identified negative impacts in the shellfish harvest areas, as well as identify any potential to practice diversification in shellfish species that may be able to thrive in the Town of Freeport. All of these issues and concerns are driven by the overarching goal of increasing the value of shellfish landings in the Town of Freeport.

In April of 2013, shortly following the award of the grant to RAI, the Town of Freeport demonstrated an even deeper level of commitment to their shellfish resources, by responding positively to the request from their Shellfish Commission to make available $70,000 for additional work in the shellfish habitat areas within the town. Dr. Brian Beal from the Downeast Institute for Applied Marine Research and Education was hired to design and implement several projects in these areas to help determine what activities could potentially improve soft-shell clam survivability and recruitment in the Town of Freeport. Since several of the specific items included in Dr. Beal's project list were identical to those proposed by RAI, the Town of Freeport facilitated a series of meetings which resulted in a "hybrid" larger-scale project, with the work being performed jointly by RAI staff and the local volunteers that had been recruited by Dr. Beal. The integrity of key items in the original RAI proposal remained intact, while Dr. Beal was able to set up most of the larger-scale experiments that he wished to pursue as well. Although the newly formed larger-scale project was not without a series of sometimes serious logistical and management challenges, the resulting project could arguably be considered the largest focused piece of shellfish habitat work in the intertidal zone in one season within a municipality anywhere in the state of Maine. This report will discuss the specific outcomes from the original RAI proposed work scope, with occasional references to some of the items specific to Dr. Beal's project, the full outcome of which he has agreed to provide in a report to the Town of Freeport by the end of January 2014.

Study Areas

Although the original RAI proposal was to include only two specific study areas within the Town of Freeport, the shift to the hybrid project resulted in a much larger area of study, with varying degrees of sampling and activity in each area. Figure 1 shows the areas in the hybrid project included most of the Harraseeket River (currently higher shellfish productivity areas) as well as both Little River and Recompense Cove (currently lower shellfish productivity areas).

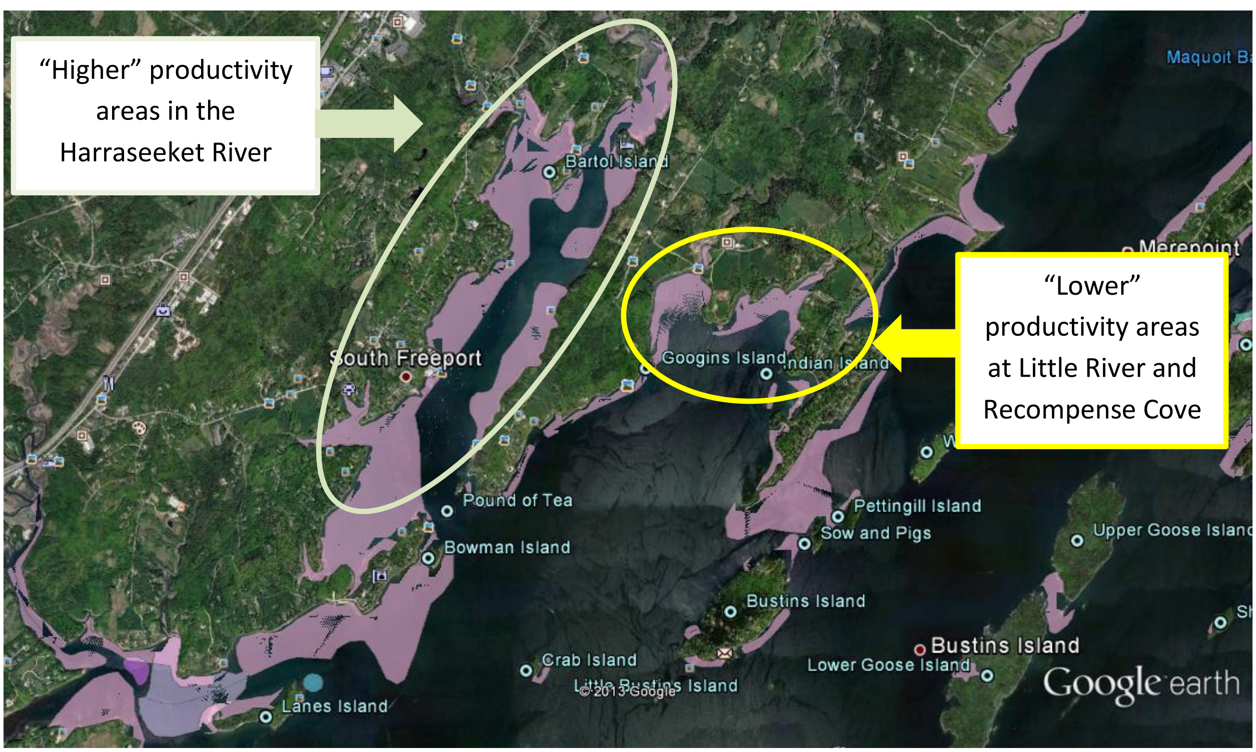

Figure 1. Purple areas indicate current or historical molluscan shellfish resource in the Freeport area. <http://www.maine.gov/dep/gis/datamaps>

Study Plan and Results

Introduction

The major working goals of the original RAI proposal were to design small scale projects and sampling that would assess the impacts of the two most likely causes for shellfish habitat degradation: ocean acidification as related to pH levels in sediment, and natural predation. Ocean acidification impacts would be measured through a series of pH measurements and sediment sampling throughout the season, in both "untreated" (natural) sites as well as "treated" sites (raked mud and/or the application of natural shell hash). Natural predation (specifically from European green crabs, *Carcinus maenus*) was to be measured using a small scale study of areas treated with "predator fencing", essentially a simple frame built of 2 x 4 lumber in 5' spans with mesh netting stretched across the open space of the frame, designed to stake into the mud and prevent predators from entering the protected area. The original RAI proposal consisted of two fenced "pens", each one approximately 5' x 15' in area. The use of crab traps would also be included in the study design, with 4 traps planned for use in the project.

The original small-scale study was dwarfed by the plans in the hybrid large-scale project, which was much grander in design, with a heavy focus on predator fencing and trapping large areas, as well as measuring clam survivability and recruitment. Ocean acidification and pH measurements were conducted as planned in the original proposal, but the fencing and trapping experiment in the hybrid project involved approximately 1,700 linear feet of predator fencing, built as 8', 10' and 12' spans, and installed across the entire mouth of Recompense Cove, and a series of six 30' x 30' fenced "pens" installed at the mouth of Little River, with various experiments conducted by Dr. Beal interspersed among the study areas, including buried clay pots with netting applied across the top, as well as large plots of netting applied to the mud both inside and outside the fenced areas. Trapping was also scaled up to include in excess of 60 traps in the study areas, both inside and outside the pens at Little River, as well as throughout the Harraseeket River. Dr. Beal planned for a small army of volunteer shellfish harvesters to build, deploy, and remove the fencing, as well as tend the traps bi-weekly throughout the project. RAI staff, in addition to performing our ocean acidification and pH sampling, agreed to inspect and maintain the predator fencing, as well as process all of the green crabs caught in the traps by the volunteer harvesters, as the budget permitted, which involved taking a total weight, and selecting sub-sample of each trap for carapace width, sex, and condition of the crabs.

Given the new design and scale of the project, the specific study goals for RAI were slightly shifted, although not diminished, from the original proposal, and could now be summarized as the following items:

- ⋆ Ocean Acidification Impacts: can measurement of sediment pH and sampling for saturation state adequately establish a baseline for natural sediment conditions, and can treatment of the sediment through roughing and/or addition of natural shell hash effectively modify these levels?

- ⋆ Natural Predation Impacts: can predator fencing be successfully installed and maintained over large areas, and can it effectively exclude green crabs, in conjunction with trapping, as a method for reducing or removing green crabs?

The methods, data, results and discussion to address these questions are written up in detail in the following pages, in a format that is designed to be both informative in nature and clear in language and style such that the Town of Freeport might take recommendations they so choose which are generated by these efforts and improve the quality of their intertidal habitat.

Ocean Acidification / pH levels and saturation state in sediments

Study design and data

Ocean acidification is rapidly becoming an issue at the forefront of global climate change, and a large amount of resources is currently being allocated to the study of this topic, especially on the west coast of the United States. Although serious impacts on the health and survival of larval shellfish due to ocean acidification have already been documented in the state of Washington, early indications suggest that the most serious effects in Washington are occurring at the open-ocean locations, where deep, highly acidic seawater is being upwelled into the area. Fortunately for Maine, the coast of New England is dominated by mostly downwelling occurrences, which spares our shellfish from the effects of the deep waters that are hitting Washington so hard. The effects of ocean acidification in our area, if they exist, are likely driven more by localized, sporadic events, such as run-off of nutrients from land-based sources and local release of the emissions resulting from the burning of fossil fuels (Feely et al., 2012).

The best methods for measuring the impacts of ocean acidification in a local environment are still being refined; we used two major approaches to estimating impacts of ocean acidification in our study areas: pH measurement in sediments, and measurement of sediment saturation state. All pH measurements were conducted in accordance with proprietary methodology developed by Mike Doan and the Friends of Casco Bay, including the same brand and style of pH meters and probes, and the same frequency of calibration between measurements. This is the same methodology used for pH sampling throughout Casco Bay, and our study has generated data that are both meaningful at a local level, as well as comparable to a larger data set, should other scientists wish to include the information in future studies in and around the area.

Measurement of saturation state is considered the gold standard in the study of ocean acidification, and is a much more robust indicator of "corrosivity" and the impact of ocean acidification than simple pH measurements, which is why we included these samples in the project. Samples collected from both sediment and overlying water were analyzed for both total alkalinity and dissolved inorganic carbon through a collaborative partnership with at Dr. Joe Salsbury's lab at the University of New Hampshire, and final saturation state calculations were conducted by Dr. Mark Green, from St. Joseph's College in Standish.

Methodology included collection of seawater samples during periods of high tide, using 100mL BOD bottles and standard methods to ensure no gas exchange between water and air. Water temperatures and salinity, measured with a hand-held refractometer were also measured at the same time. As the water retreated from the area, the surface 1-2 mm of sediment was collected over an 100cm^2 area using a spatula and transferred into a 50cc centrifuge tube. The mud was immediately centrifuged at 3500 rpm for 8 minutes, and pore water was removed using a syringe and transferred into a 20mL serum vial, pickled using $HgCl_2$, and sealed without head space using a rubber stopper.

In addition to merely tracking ongoing impacts in sediments, some scientists believe that it is possible to actually mitigate ocean acidification effects at a local level; Dr. Mark Green, as well as Dr. Brian Beal, at the Downeast Institute on Beals Island, have produced some promising results with mixing or layering shell hash and/or aragonite pellets in sediment, which may be buffering any acidification effects for the shellfish that settle there. Dr. Joe Salisbury from the University of New Hampshire has produced data that suggests that turning over the first few inches of mud may contribute to raising the surface pH, which may also have localized mitigation effects for acidification. We investigated these promising, "low-tech" ideas to see if they achieve any measurable results, and might therefore be good options to incorporate into mud flat management going forward. At the study area inside the fence line at Recompense Cove, we established a control site (no treatment); a "naturally hashed" site, where hydrography naturally deposited broken shell onto a small area; a "raked" site, where the mud was roughed over, or raked, on a regular basis, and a "hashed" site, where we added pulverized shell to an area that did not naturally contain any shell hash. There was no treatment required at the control site or the natural hash site. Roughing at the raked site was accomplished with a heavy-duty metal yard rake, turning over the first 2 – 3 inches of mud every other week. At the hashed site, local native shell hash was applied to the treatment area following methods established by Dr. Mark Green in his previous studies; 80 pounds of pulverized shell hash was layered to a depth that just covered the mud, then allowed to settle for two weeks. Another application of 80 pounds was applied after two weeks, leaving a layer of shell hash thick enough to cover the mud completely (Fig. 2).

The direct measurement of pH in marine sediments in the field is a process that is still being perfected, but the working procedure developed and employed by the Friends of Casco Bay group appears promising; we used this method for all measurements in the project. Since pH is measured on a log scale, there are some fairly large variations both within the site of ten discreet measurements (n=10, Average STD=0.37, CV=0.5), as well as between treatment sites; overall there was still a relative relationship that is helpful, although we would caution against assigning too much value to the specific pH number that is recorded with each measurement, until further studies increase the size of the data set, as well as the collection and analysis of the complimentary saturation state data.

Our small study determined that the relative pH levels at the control site, the natural hash site, and the raked site did not change much in relation to each other throughout the study, but we did notice a large increase in relative pH at the hashed site by the end of the project period (Fig. 3).

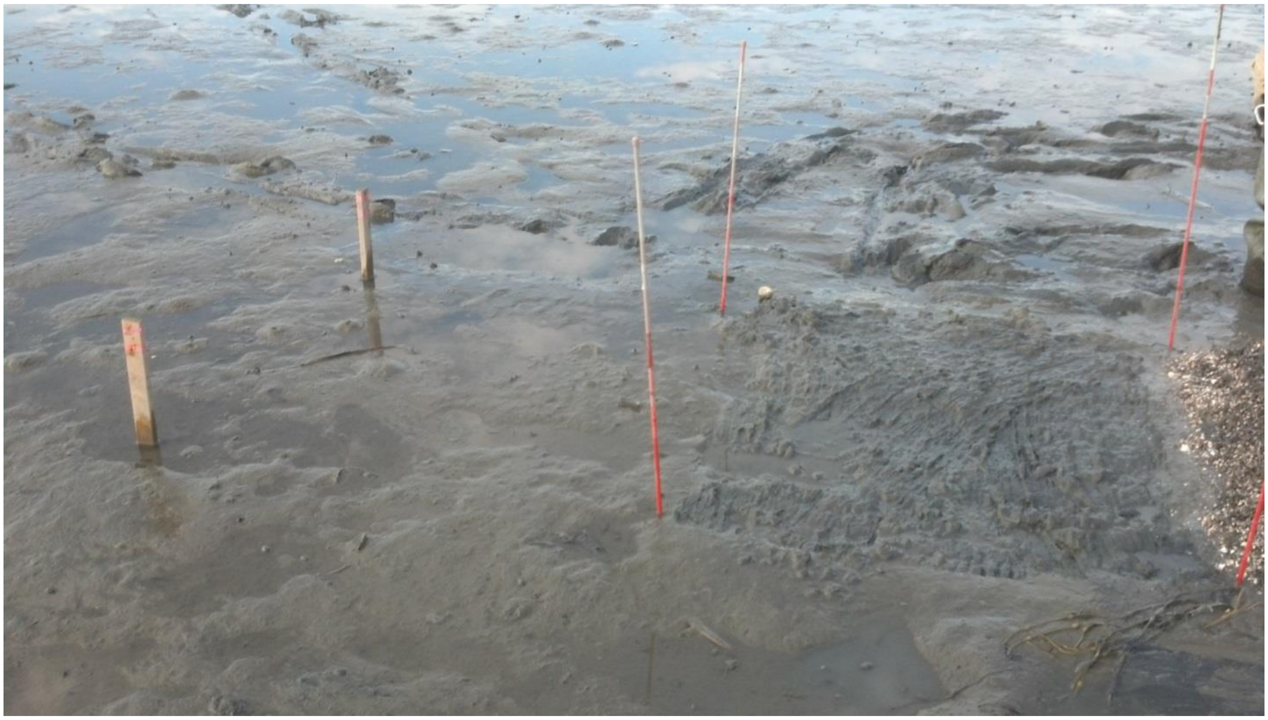

Figure 2. Top photo: Control site and "raked" site for pH measurements at Recompense Cove (the leading edge of the "hashed" site is just visible at the far right of the frame).

Bottom photo: Adding pulverized natural shell hash to the "hashed" treatment site.

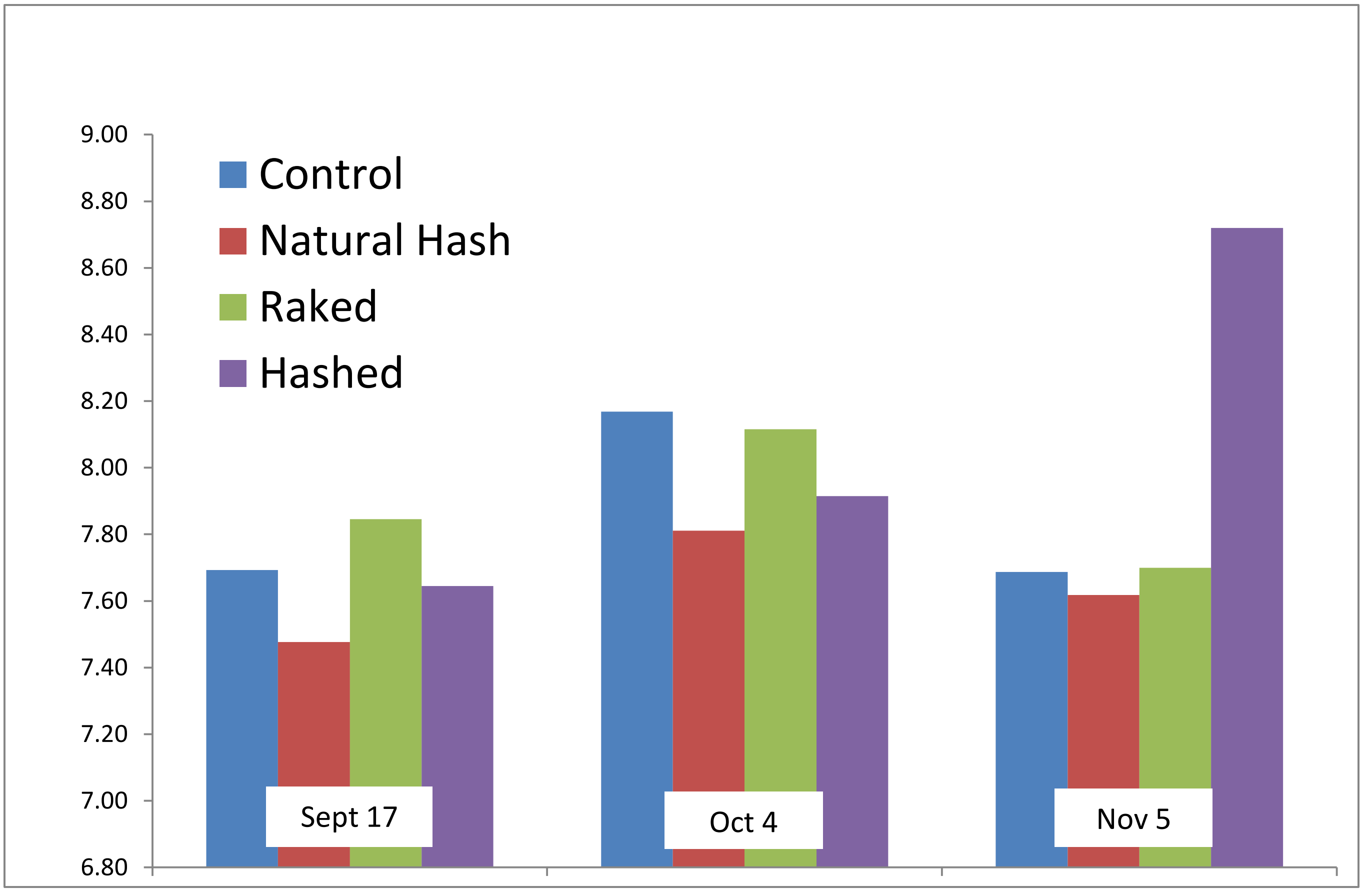

Figure 3. Relative pH measurements at all sites. Note the large increase in relative pH at the hashed site by the end of the study period.

Discussion and Conclusions

We investigated several low-tech, relatively inexpensive methods that a town might use to improve the quality of non-productive intertidal mud in their area which might be suffering from the local impacts of ocean acidification. Although the study period was brief, and a longer study might reveal more information regarding seasonal trends, we did observe a noticeable relative increase in marine sediment pH levels at the treatment site which was layered with pulverized shell hash. These data suggest that a town might easily improve the quality of otherwise non-productive, or "dead mud", by layering it with pulverized shell hash to improve pH levels. Improving pH levels in marine sediment is important because established research by Dr. Mark Green and others (Green et al., 2012) has demonstrated that buffered mud can effectively improve the settlement and survival of bivalve larvae (Fig. 4).

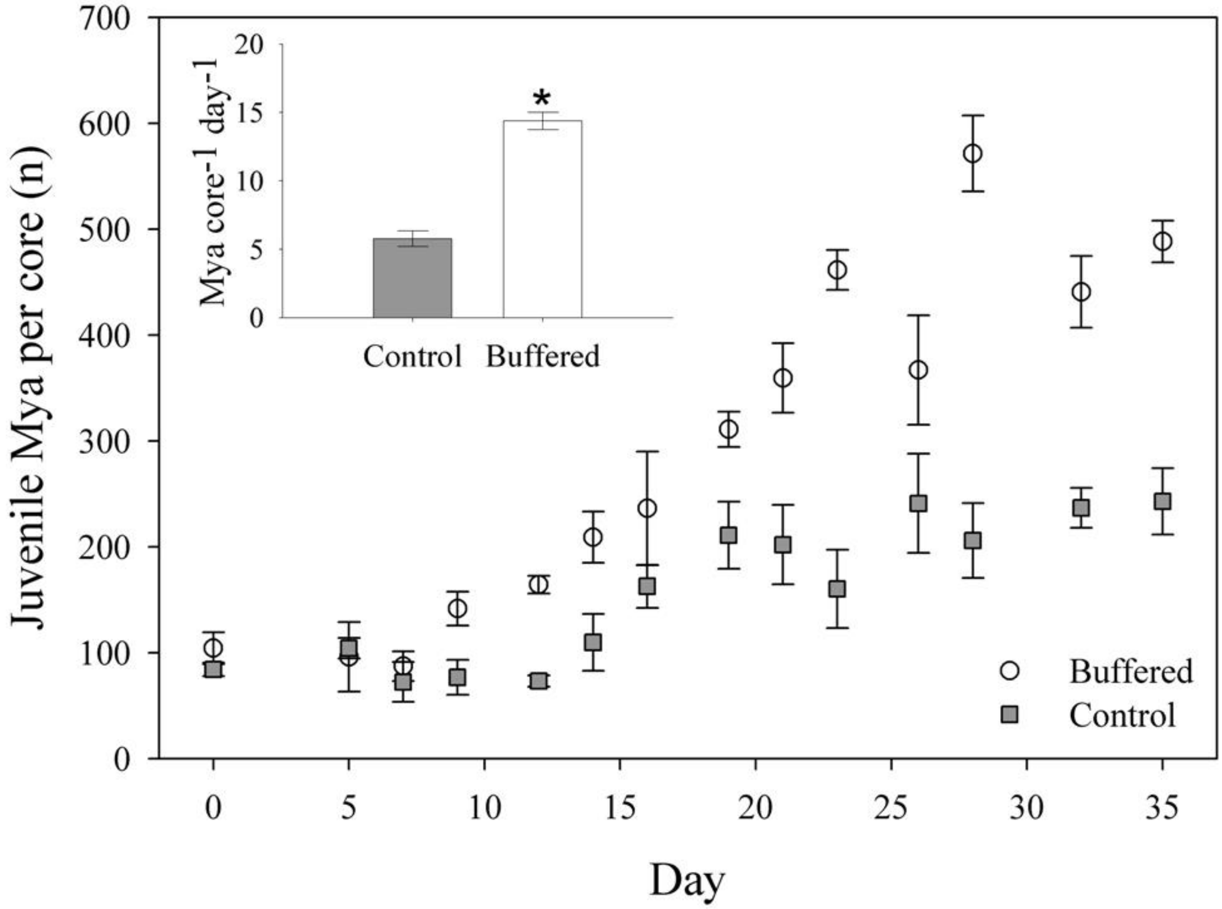

Figure 4. (from Green et al., 2012) Plots of total (live and dead) *Mya arenaria* as a function of time in both buffered and unbuffered sediment cores. Buffering significantly increased recruitment by just over a factor of two over the 30 day course of the experiment.

Complimentary saturation state samples for these sites remain in process at Dr. Salsbury's lab at the time of this publication, and will be provided as a data addendum as soon as they become available. At this time, there is enough pH data to support these conclusions without the saturation state data.

Natural Predation / Predator Fencing and Trapping

Study design and data

Natural predation on bivalve shellfish in the intertidal zone has been well documented for decades. Major predators include seabirds, marine worms, carnivorous snails, and crabs, all of which may inhabit the intertidal zone at various population combinations or densities (Flimlin and Beal, NRAC Bulletin No. 180-1993). There are obviously limited options in controlling migrating seabird predation, and there have been studies conducted on controlling marine worm (*Cerebratulus lacteus*) predation through predator/prey competition with other marine worm species, and through trapping or collection studies, and to date there are no methods documented which seem to be effective at remediating the impacts of this predator (Borque et al., 1999). Carnivorous snails have devastated clam flats in the recent past, hitting areas in eastern Maine particularly hard in 2010, when clam diggers in that area were collecting thousands of moon snails (*Euspira heros*) and their egg collars from flats on a daily basis, where clam mortality was in excess of 80 percent (Mack, BDN 2010).

We planned to focus our natural predator work on experiments controlling predation by European green crabs (*Carcinus maenas*), an invasive species which appears to be growing in numbers in the Casco Bay region. There have been multiple studies in Maine as well as across the U.S. that have documented the impressive biological and economic damages caused by green crab predation (National Center of Environmental Economics/US EPA, 2008), as well as many studies on techniques to protect shellfish from green crab predation. Dr. Brian Beal has had excellent results and very high survival rates for clams in studies he has conducted using predator netting placed directly over the shellfish flats (Beal, 2006); however, the cost associated with the use of the prescribed netting is cost-prohibitive at a large scale, at ~$5,000 per acre of flats, and may not be affordable to scale-up for large-scale operational status, which is why RAI selected to use predator fencing and trapping as potential methods to effectively combat green crab predation.

As part of the hybrid project, predator fencing design was based on a prototype that was used successfully in the Cape Cod Co-Operative Extension project cited above; final design was selected and executed by volunteer shellfish harvesters, and was made into a series of 8’, 10’ and 12’ spans, with a strip of aluminum flashing across the top rail (Fig. 5).

The scale of the hybrid project, as discussed earlier, was massive in comparison to the original RAI proposal. The areas that were subject to predator fencing included all of Recompense Cove, at a total span in excess of 1,700 linear feet, and six large (30’ x 30’) pen areas established at the mouth of Little River in Freeport. The location of these areas is noted in the map in Figure 6.

Figure 5. Construction of green crab predator fencing by local volunteer shellfish harvesters.

Figure 6. Location of predator fencing in Freeport, indicated by the red line. Red dots indicate 30' x 30' pens.

Installation of such a large amount of fencing was accomplished by dozens of local volunteer shellfish harvesters and a contracted airboat captain from a nearby town. A large majority of the installation was achieved in one day, with residual placement of panels across the mouth of Recompense Cove happening over the course of several days. Fence panels were loaded onto a flatbed truck, belonging to one of the local volunteers, then transported to the Little River Bridge. Multiple days were required to complete the installation due to the limited time available during low-tide. Volunteers moved the panels from the road, down over the bank onto the mudflat, where they were then loaded onto the airboat and transported to the appropriate locations for installation. Volunteers were stationed at the various installation locations to receive the fence panels and install them in the mud with sledge hammers. Figures 7-11 document all of the steps of the installation.

Figure 7. Transporting fence panels from the flatbed truck at Little River Bridge, down the bank and onto the mudflat.

Figure 8. Walking fence panels from the mudflat onto the airboat for transportation to the installation sites.

Figure 9. Installation of fence panels at Recompense Cove.

Figure 10. A "spotter" stands at a point to keep the installation moving in a relatively straight line across the mouth of the cove.

Figure 11. Fence line showing one of the "fish gate" openings located every 150' to allow safe passage for any fish trapped in the cove as the tide changes .

After the installation of the fence, a single crab trap was placed inside three of the pens at Little River, and three crab traps were placed immediately outside three of the pens. Traps were baited with approximately 2 pounds of smashed soft-shell clams (*Mya arenaria*) in mesh bait bags hung inside each trap. The traps were hauled after approximately one week (on July 31), and all crabs were weighed, counted, sexed, and measured. Traps were reset with fresh bait, and hauled again on August 27, and the same data were collected. The next haul was in early October, with the same data collected; unfortunately, there was a serious degradation in the integrity of the pens sometime in September, following a series of powerful weather conditions and extreme tides, calling the effectiveness of any data collection for the traps after that point into question. The data are summarized in Figures 12 and 13.

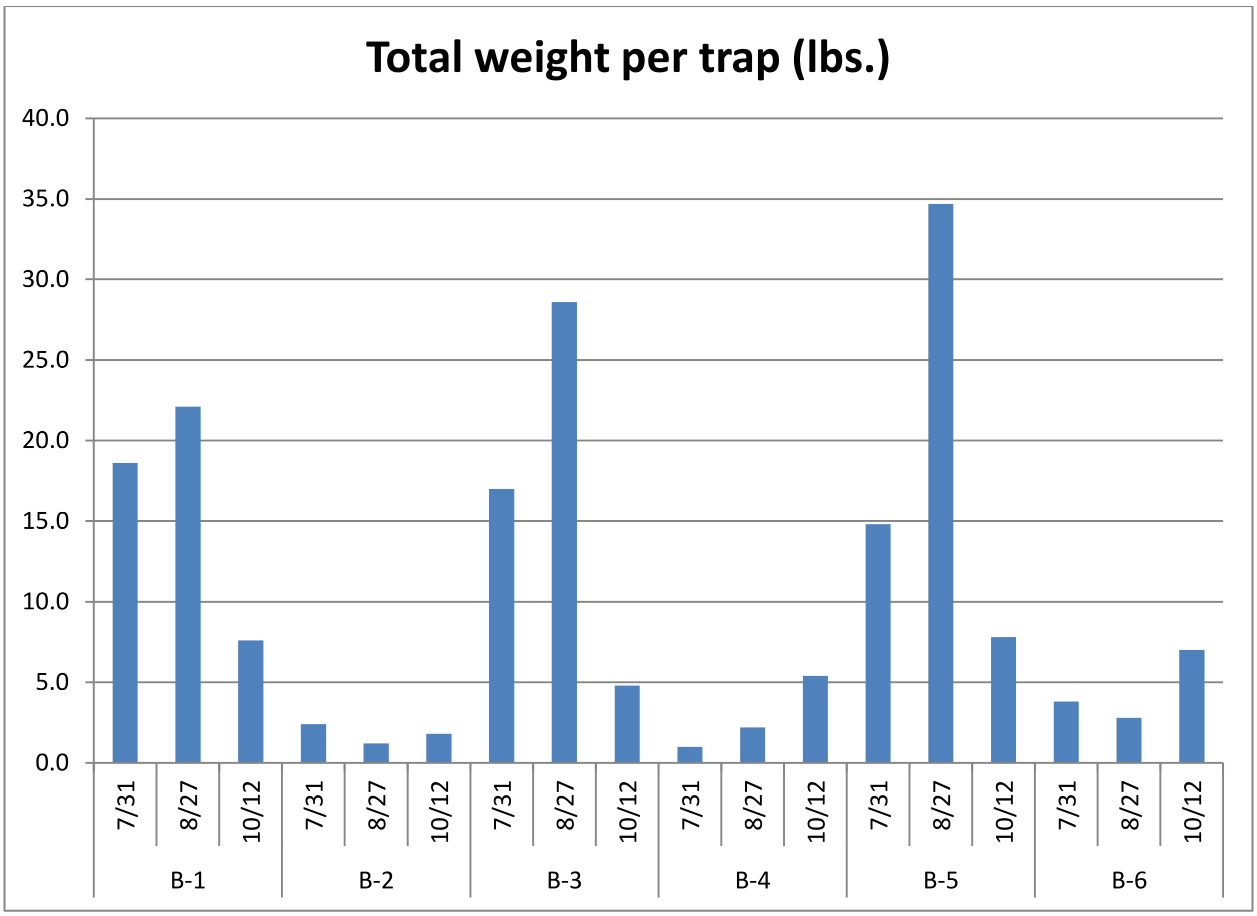

Figure 12. Total weight per crab trap on each haul. Odd numbered traps (B-1, B-3, B-5) were located outside the pens; even numbered traps (B-2, B-4, B-6) were located inside the pens.

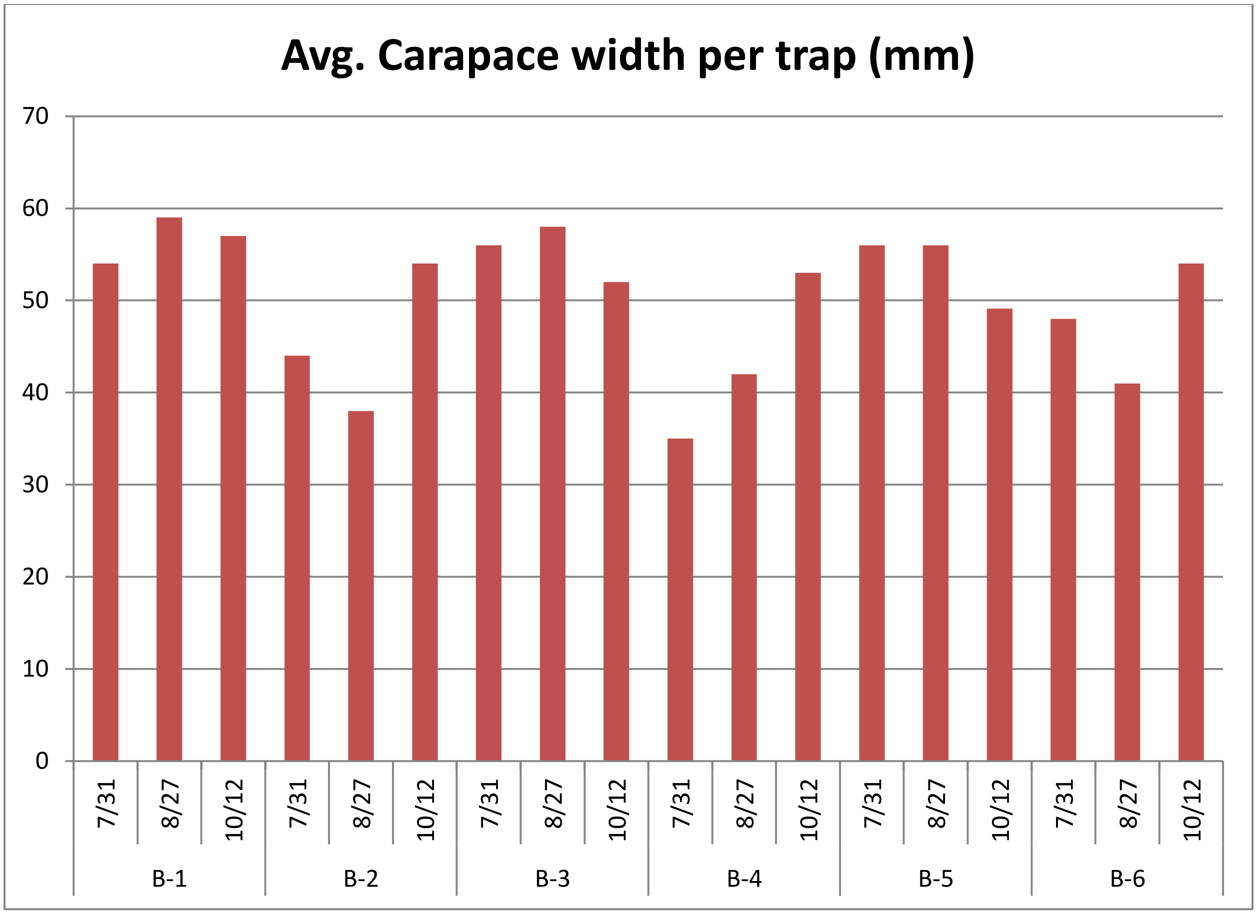

Figure 13. Average carapace width per crab trap on each haul. Odd numbered traps (B-1, B-3, B-5) were located outside the pens; even numbered traps (B-2, B-4, B-6) were located inside the pens.

Although our sample size is fairly small, we can still run a Student's t-test to see if the results from the groups of traps outside the pens versus inside the pens are statistically similar or different from each other; in other words, does predator fencing have a measureable effect on the presence and size of green crabs? The results in Table 1 demonstrate that there is a statistically significant difference between the average weights for the catch in the traps inside the pens compared to outside the pens at the July and August sampling periods (there are more crabs trapped outside the pens in July and August), but this relationship is not significant at the October sampling (there is no statistical difference between the two groups in October). Likewise, we see that the average carapace width for crabs trapped inside the pens was smaller than that for crabs trapped outside the pens for the July and August sampling periods (the crabs inside the pens are smaller than the crabs outside the pens in July and August), but this relationship does not exist in October (there is no significant difference between the two groups in October).

Table 1. *Mean Weight (lbs.) of catch per trap and Carapace width (mm) for traps located inside predator fencing and traps located outside predator fencing.*

	Trap location			
	Outside pens	Inside pens	*t*	*df*
Weight of catch - July	16.8 (1.91)	2.40 (1.40)	10.5	4
Weight of catch - August	28.5 (6.30)	2.07 (0.808)	7.2	4
Weight of catch - October	6.73 (1.68)	4.73 (2.66)	1.10	4
Carapace width - July	55.3 (1.15)	42.3 (6.66)	3.33	4
Carapace width - August	57.7 (1.53)	40.3 (2.08)	11.6	4
Carapace width - October	52.5 (3.94)	53.9 (0.723)	0.634	4

Discussion and Conclusions

Although a larger sample size would provide more confidence, these data could reasonably suggest that since we know that the integrity of the pens was seriously compromised sometime in September, after the July and August sampling periods, then predator fencing can be an effective deterrent to green crabs, and those crabs that breach the fence are of a smaller (and we assume less damaging) size than the outside population, if the predator fence is maintained properly. This is an important caveat, and it cannot be stressed enough that there is no benefit to using predator fencing if the fencing is not regularly and properly maintained. The discussion that follows will provide a detailed history of the challenges experienced with the construction, deployment, maintenance, and removal of predator fencing in Freeport.

Permitting process: The Army Corps of Engineers (ACOE) requires the application for a Section 10 permit to place predator fencing in the intertidal zone. This process can be lengthy, and the time that elapsed waiting for permit approval resulted in the deployment of fencing in July, rather than in the late spring, as was planned in the original proposal. The scale and scope of the hybrid project was daunting, and there were a series of challenges in the Freeport project that may result in much more scrutiny and review by the ACOE prior to issuing a permit for similar activity. Groups aspiring to any future predator fencing projects should plan for ample time (at least 90 days) for ACOE review, and be prepared for modification requests or special additional requirements on the part of that agency.

Fence construction: Construction of such a large amount of predator fencing, nearly 2500 linear feet total for the hybrid project, is a challenge in itself. Shellfish harvesters volunteered to acquire materials that were paid for by the Town of Freeport, construct the panels, and transport them to the installation site. This task represented many hundreds of hours of labor, the use of a large portion of private property for the building and storage of the panels until they were ready for deployment, the use of a commercial flatbed truck for transportation from the build site to the deployment area, and many more man hours of labor to hoist the panels on and off the flatbed truck prior to deployment. The cost for materials and labor should be considered by any group or municipality that wishes to use predator fencing as a strategy to protect their shellfish resource. In addition to the initial labor and material investments in the construction of the fencing, we learned throughout the season that there were some critical design flaws in the fence construction that should be addressed before any future use of predator fencing:

- Corner posts need to be reinforced from the original design; the end posts tended to split and crack upon installation with a sledge hammer (Figure 14).
- Individual panel spans should not be greater than 8 feet. Many panels that were 10 feet and greater were not able to sustain stability during the entire field season, and would crack at the midpoint.
- Addition of wire mesh "hardware cloth" or similar material is needed to extend at least 12 inches below the sediment. Tidal action and crab activity resulted in many spots of "under-burrowing" at the fence line, allowing crabs to move freely under the fence and gain access to the protected area (Figure 15).
- Flashing along the top rail needs to be tacked down underneath furring strips or other similar material. The screws and washers that were used to attach the flashing were not adequate to hold it in place for more than one or two tidal cycles (Figure 16).
- Longer screws (at least 3"), as well as additional screws (more than two per section) should be used to connect corner posts and rails; many of the shorter screws backed out as a result of tidal action throughout the season (Figure 17).

Figure 14. Corner posts of fence panel s that were split upon installation. Note the complete collapse of the top rail in the right picture, as the split extended throughout the entire post.

Figure 15. Underwash below the bottom rail, caused by tidal action, allowing free movement of green crabs underneath the fenceline.

Figure 16. Flashing along top rail, designed to keep crabs from climbing up and over the fence while it is submerged, has pulled away completely from screws and washers after installation.

Figure 17. Longer screws (at least 3 inches), and more than two per section, are needed to prevent "backing out" after tidal action.

Fence Maintenance: One of the requirements of the ACOE permit was to have someone inspect all of the predator fencing twice a week, to ensure that the integrity of the fence is maintained and to make sure there is no unintended by-catch caught up in or behind the fence. The original RAI proposal involved less than 100 linear feet of predator fencing, but the hybrid project scaled up by Dr. Beal involved nearly 2,500 linear feet of predator fencing. RAI staff agreed to take on the responsibility of maintaining the fence for as long as the budget would support staff time to do so; this effort turned out to be the most labor intensive portion of the project. RAI staff performed this function from the date of installation in late July through early October, when the budget for this portion of the project was completely exhausted. From October through December, there was little to no maintenance performed, and the fence line rapidly deteriorated.

Fence maintenance was performed 3 – 4 days per week by RAI staff, for the entire period from July through October. We did not expect to need to spend this much labor time on the fence, but the design flaws discussed in the previous section began to cause deterioration almost immediately. Typical repairs included replacing missing aluminum flashing and securing with new screws and furring strips; reinforcement of longer panel spans that had cracked at the center point where they flexed in the tidal cycle; repairing rails that had pulled away from end posts; re-attaching netting that had pulled away from an edge of the frame; cutting and applying wire mesh hardware cloth to the bottom rail in areas experiencing underwash. Keeping up with repairs was a challenge due the fact that all work had to be completed at the low tide period, in order to be able to access the fence. RAI expended a total of 808 man hours on this portion of the project, often dedicating as many as four staff at a time to fence maintenance, but the Town of Freeport was only billed for 462 labor hours, since this was the estimate for the project that we planned in the budget for this portion of the project. As we approached nearly 350 hours of unbilled labor time for fence maintenance by early October, with other project commitments still pending, we met with the Town of Freeport to inform them that our participation in the additional labor requirements spawned by Dr. Beal's larger hybrid project would need to be curtailed. Since it was never clearly outlined in Dr. Beal's larger project who was responsible for carrying out to completion all of the various components in the larger hybrid project, the remaining work for fence maintenance now fell unexpectedly to the Town of Freeport to organize, which was an unplanned burden for Town staff and resources.

In addition to the ongoing maintenance, RAI staff also experienced one by-catch emergency during the season; RAI staff was just arriving at the Recompense Cove site to perform several hours of repairs, when campers at the campground which overlooks the site approached them to inform them that a large fish was trapped behind the fence. RAI staff immediately approached the large fish, which was a species of local shark, approximately 4 feet long, and attempted to guide it through the nearest fish gate in the fence line. The tide was quickly receding, so RAI staff called Marine Resource Officer Dan Devereaux from the neighboring town of Brunswick, who was out in the area with an airboat doing survey work. Dan responded within a few minutes, and everyone worked together to maneuver the shark onto a large piece of netting so that the airboat could safely tow it to the deeper water beyond the fence (Fig. 18). The shark was successfully and safely freed from the area.

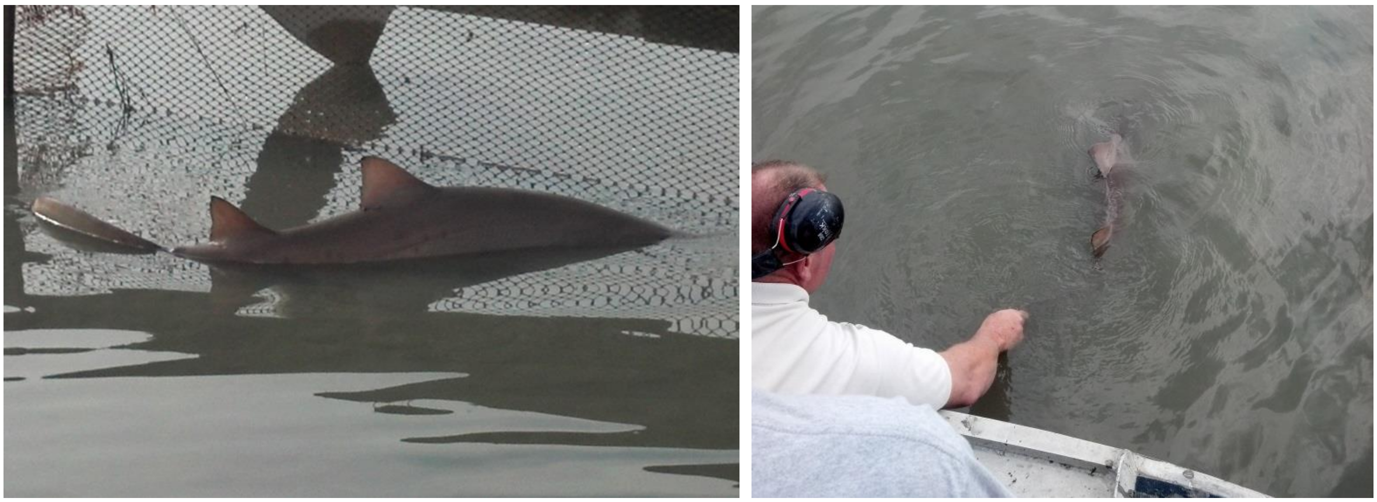

Figure 18. A small shark trapped behind the fence as the tide was receding is successfully freed by RAI staff and Brunswick Marine Resource Officer Dan Devereaux.

Lessons learned from the fence maintenance experience include:

- A small team (2-3 people) cannot reasonably maintain more than ~500 linear feet of fencing during a season.
- The party responsible for fence maintenance should be reachable at any time of day or night to handle unforeseen emergencies at the fence line, and should have access to an airboat and qualified operator as needed.

Fence Removal: The final component in predator fencing is the removal of the fence by the end of the year, required by the ACOE permit, prior to the onset of winter and ice. Although a large team of local shellfish harvesters (approximately 20) volunteered to set out the fence in July, with the assistance of a hired local airboat and captain, there was no specific plan in Dr. Beal's large hybrid project for who would handle fence removal at the end of the season. Once again, the Town of Freeport staff was left with a large task and no allocated labor or resources with which to perform the task. Based on discussions with the Town

Planner and Town Manager, town staff used marine-grade rope to weave through approximately 20 fence sections per run, then tied a buoy at each end of the run to mark the sections as the high tide level returned to the area. Fence sections were pulled, and left on the mud during a low tide period; the fence floated to the surface during high tide, and a town boat and staff were dispatched to haul the buoy line from the fence sections on board, then slowly and carefully tow the tethered fence sections to a small beach area that has easy access to a road. Once the fence sections were at the beach area, the buoy line for each section was tied to a town maintenance vehicle and the entire section was pulled up onto the beach, out of the water, and stacked in an alternating pattern like dominoes. Stacked sections were loaded onto town trucks, and delivered to a winter storage site provided by the town. The Town of Freeport successfully performed a very large task that was dropped in their lap at the last minute, resulting in yet another important lesson:

- A full plan for fence removal needs to be in place at the beginning of any predator fence project.

Recommendations

There were definitely some unexpected challenges in this project that were generated by the design and management of the larger, scaled-up study that was tied to this one, so our first recommendation would be to consider these potential issues carefully before moving ahead with future projects; sometimes, a smaller, well-planned, easily managed project with clear oversight and professional staff designated for all tasks will be able to produce a cleaner, albeit smaller, but potentially more useful data set, than a project that is much grander in scale and scope, but that relies on remote planning and management and a volunteer workforce.

Local ocean acidification impacts may be present in the area, and the topic is becoming a larger priority area of study at the national, regional, and state level. We expect that more information will be generated on this issue by the larger groups associated at those levels, and do not recommend that the Town of Freeport allocate any great amount of resources to further study this issue, but rather stay engaged and informed about the research that is being done at a larger scale in the region. If the Town wished to take steps to improve the quality of non-productive intertidal mud, the application of pulverized shell hash appears to be an effective and inexpensive option to buffer the mud and improve the recruitment potential of an area.

Natural predation by European green crabs on bivalve shellfish is a clear and overwhelming issue in many areas of coastal Maine, including Freeport. Although we have demonstrated that predator fencing can reduce the presence and size of green crabs in a small area, we have also learned from the larger project that predator fencing is problematic to deploy and maintain in large areas, or in high-energy tidal areas. We would not recommend the use of predator fencing except in very prescriptive, appropriate locations, where the design of the fence to be deployed has been modified to address the flaws discussed in this paper, the span of the fencing is not greater than 500 feet, and there are enough resources (staff) specifically allocated for the deployment, maintenance, and removal of the fencing. These staff should also be available on a 24/7 basis to handle emergencies and potential non-target species entrapments, and have access to an airboat with a qualified operator.

There are not enough data to determine if trapping efforts alone have a measurable impact on green crab numbers in an area; although preliminary reports from the larger study indicate that catch per unit effort in traps did not decrease over the course of the study, there was not enough consistency in trap location, baiting, or hauling frequency to reach a definitive conclusion. Mark-recapture studies on green crab populations, coupled with well-managed and consistent trapping efforts, could provide more critical information on this topic. At this time, we are not recommending that Freeport allocate resources for this particular type of study, since the neighboring town of Brunswick is already underway with a series of mark-recapture green crab population studies coupled with trapping in 2014, and we recommend that Freeport stay informed on the results and outcome of these studies in order to take advantage of those data and then consider how to apply them in the Town of Freeport.

It was very clear during the study period that the shellfish harvesters in the Town of Freeport are extremely passionate and dedicated to fighting to save the remaining wild shellfish resource in the area. There is at least a small core group of harvesters, in addition to a larger, perhaps less-consistent group of harvesters, that could be directed in future efforts to try to control natural predation. Based on the experiences learned during this season, the direction of that labor force would likely not succeed under a remotely managed or strictly volunteer organizational structure. If Freeport wishes to tap into the labor of local shellfish harvesters or any similar ancillary group in order to perform specific projects, it would require allocated resources for a full-time, on-site manager to handle all aspects of the organization and direction of this group, as well as management of the materials and tools used by the group.

One final observation worth mentioning is that there appears to be an improved natural set of hard clams (*Mercenaria mercenaria*) in northern Casco Bay in recent years. As efforts to protect natural shellfish population of *Mya arenaria* continue, it is worth considering the place that hard clams might have in the future of Freeport; they are easily seeded into areas, their harder shells might provide slightly more protection from natural predators (although an army of green crabs will eventually crack into any shell), and the market value is slightly higher for this species. Like the *Mya*, Hard clams would still require some level of predator protection to survive, either removal of green crabs from the area or direct protection like netting or cages, but they might provide an alternative species to help fill the gap left behind by the shrinking wild populations of *Mya arenaria*.

References

Beal, B.F., December 2006. Large-scale, manipulative field tests using cultured and wild juveniles of the soft-shell clam, *Mya arenaria* L.: Interactive effects of intertidal location, predator exclusion netting, netting aperture size, and planting area on clam growth and survival within the Hampton-Seabrook estuary. New Hampshire Estuaries Project. 97 pp.

Borque, D., Miron, G., Landry, T., and N.G. MacNair, 1999. Endobenthic predation by the nemertean *Cerebratulus lacteus* in soft-shell clam (*Mya arenaria*) populations in Prince Edward Island. Canadian Tech. Report of Fisheries and Aquatic Sciences 2288: vii + 19 p.

Feely, R.A., Klinger, T., Newton, J.A., and M. Chadsey, November 2012. Scientific Summary of Ocean Acidification in Washington State Marine Waters. NOAA OAR Special Report; Contribution No. 3934 from NOAA/Pacific Marine Environmental Laboratory, Washington.

Flimlin, G. and B.F. Beal, 1993. Major Predators of Cultured Shellfish. Northeast Regional Aquaculture Center, Bulletin No, 180-1993.

Green, M., Waldbusser, G., Hubazc, L., Cathcart, E., and J. Hall, 2012. Carbonate Mineral Saturation State as the Recruitment Cue for Settling Bivalves in Marine Muds. Esuaries and Coasts, Coastal and Estuarine Research Federation, August 2012.

Mack, S.K., 2010. Clammers seek relief from predatory moon snails. Bangor Daily News, March 6, 2010. <http://bangordailynews.com/2010/03/06/news/clammers-seek-relief-from-predatory-moon-snails>

National Center of Environmental Economics/US EPA, June 2008. Ecological and Economic Impacts and Invasion Management Strategies for the European Green Crab. 73 pp.