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Title: **Demonstrating Shellfish Aquaculture Technology in Pilot and Commercial Scale Projects: Creating New Opportunities for Maine's Coastal Communities**

PI: **Brian Beal**

Organization: **Downeast Institute for Applied Marine Research & Education (Beals, Maine)**

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The project proposed to: 1) demonstrate marine aquaculture technologies in pilot and commercial scale projects designed to create jobs in coastal communities, produce healthful, local seafood, revitalize working waterfronts and support traditional fishing communities; and, 2) provide training for fishermen and others in coastal communities in aquaculture production methods.

The proposed project goals were to: To increase soft-shell clam harvests locally in the face of increasing threats due to invasive green crab predation, warming seawater temperatures, and ocean acidification, and to create a model shellfish management program for coastal Maine communities facing unprecedented declines in clam landings.

The proposed project objectives were to:

1) Determine spatial and temporal variability of green crabs, *Carcinus maenas*, in the Harraseeket River and intertidal areas adjacent to the river using specially designed and tested traps in an attempt to remove crabs from the ecosystem that, otherwise, would remain to prey on soft-shell clams of all age-classes;

2) Test the efficacy of "green crab fencing" of intertidal areas using methods similar to those used in the middle of the last century to deter green crabs from preying on soft-shell clam juveniles and adults;

3) Examine whether sediment buffering, under the lowest sediment pore pH conditions, will result in enhanced numbers of soft-shell clam settlers and recruits compared to control areas where no buffering occurs.

4) Examine the interactive effects of stocking density of cultured soft-shell clam juveniles (10-15 mm shell length, SL) in netted plots and crab trapping on clam survival and growth.

5) Determine whether the use of predator deterrent netting, in combination with various densities of adult soft-shell clams, will result in an enhancement of wild clam recruits; and,

6) Train clammers and other interested fishermen in the use of aquacultural techniques to improve local clam harvests.

All project objectives were met.

A) <u>Spatial and Temporal Variability in Green Crab Populations</u>

Results relating to the first objective were highlighted in Progress Report #1 and #3. Briefly, in 2014, green crab populations in the Harraseeket River varied significantly over: 1) time (May-September) (increasing significantly over that period); 2) section of the river (Upper vs. Lower Harraseeket) (with more individuals found in the lower portion of the river); and, 3) duration of time when traps were fished (significantly more crabs were caught when soak times were increased from 1 and 2 days to 4 days). Sex ratios were biased in favor of males by an average of 65:35 over the sampling period. Size-frequency distributions demonstrated that green crabs were smaller, on average, in 2014 than in the previous year when trapping began. A cold winter (December 2013 to February 2014) was associated with the loss of large green crabs in the Harraseeket River.

In 2015, similar results were observed, with more (18%) crabs caught in traps within the lower section of the Harraseeket River (i.e., towards the mouth of the river). Mean weights of the catch varied over the summer, with higher numbers occurring during periods of maximum seawater temperature (August-September). Different types of bait were used in 2015 vs. 2014. In 2015, both crushed soft-shell clams and herring were used on every other haul, whereas in 2014, soft-shell clams were used exclusively. Traps baited with herring produced approximately 10% higher catch rates than those baited with adult, crushed soft-shell clams. Again, sex ratios across most sampling dates were male-biased. Green crab size increased gradually over the summer reflecting at least one or two moltings (on average) over that period.

B) <u>Efficacy of Green Crab Fencing</u>

Results relating to the efficacy of installing fencing to prohibit green crabs from planted juvenile clams was discussed in Progress Report #1 and #2. Briefly, a total of fourteen 30-ft x 30-ft fences were installed at Staples Cove, near the mouth of the Harraseeket River, as well as fourteen similar size control plots (without fencing). Within each of the 28 plots, four 12-ft x 12-ft plots were established. Cultured juvenile clams were added to two plots (one was protected with mesh netting, the other was not), while the other

two plots contained no clams; however, one of those plots was protected with netting and the other was not. Results showed that protecting clams with netting was economically superior to installing fencing, as fencing did not result in significantly higher survival of cultured clam seed over-and-above the level of predator deterrence afforded by the netting.

C) <u>Sediment Buffering to Enhance Wild Clam Recruitment</u>

Field trials to examine the efficacy of placing crushed soft-shell clam shells in large plots to encourage buffering of low pH sediments that would provide suitable habitat for settling, wild, 0-year class soft-shell clams was conducted at a single site in 2014 and two sites in 2015. Those results were reported in Progress Report #1, #2, and #3. Briefly, the same experiment was deployed at all three sites with low pH (ca. 7.2-7.4) where thirty 10-ft x 10-ft plots were established near the mid intertidal. Five replicates of each of six treatments were randomly assigned to plots: 1) control; 2) control plus plot covered with mesh netting (4.2 mm aperture); 3) thirteen lbs of crushed clams spread into the plot; 4) thirteen lbs of crushed clams spread into the plot, and then covered with mesh netting (4.2 mm aperture); 5) twenty-six lbs of crushed clams spread into the plot; and, 6) twent-six lbs of crushed clams spread into the plot, and then covered with mesh netting (4.2 mm aperture). In both years, similar results occurred, and that was that netting generally enhanced numbers of soft-shell clam recruits relative to any effect due to the presence of shells. In 2014, the effect of netting was not observed on soft-shell clams, but on hard clams, *Mercenaria mercenaria*. However, at none of the three sites both in 2014 and 2015 did the presence of crushed shell result in a significant enhancement of wild soft-shell clam recruits.

In addition, a small-scale experiment was deployed adjacent to the large-scale experiment to examine a component of the large-scale experiment that was potentially logically flawed. That is, if crushed clam shells did not actually provide buffering capacity but did provide critical habitat that either attracted or provided spatial refuge for soft-shell clam recruits, then results from the large-scale study may have been misleading had significantly more 0-year class clams been associated with the crushed clam plots. To examine the potential for crushed clams acting as a habitat (spatial refuge) for settling soft-shell clam individuals, a matrix of 6-inch plant pots was established at each site in both years. Eight treatments were used that were replicated ten times: 1) control; 2) control with mesh netting (aperture as above); 3) crushed shell; 4) crushed shell with mesh netting; 5) crushed marble chips; 6) crushed marble chips with mesh netting; 7) crushed granite chips; and, 8) crushed granite chips with mesh netting. In each case, the addition of the substrate occurred on top of the sediments, as it did in the large-scale plots. Results were similar in both years. There was a significant enhancement of 0-year class individuals in the four treatments where netting was involved compared to treatments without netting. The addition of substrate (shell, marble chips, or granite chips) did not result in a significant enhancement of wild 0-year class soft-shell clams.

D) Interactive Effects of Clam Stocking Density and Green Crab Trapping

A field trial was deployed in 2014 at two mid-intertidal sites in the Harraseeket River that were approximately 2,000 feet apart. One site was on the western side of the river in Collins Cove. The other site was directly across the river from Collins Cove on the eastern side of the Harraseeket River. Nets (22-ft x 14-ft; 4.2 mm aperture) were deployed in ten blocks of four nets each at both sites in April 2014. Two netted plots in each block contained clams seeded at a density of 15 per square foot, while the other two plots were seeded at a density of 30 clams per square foot. Adjacent to five of the blocks of nets, a green crab trap (similar to those used to assess population dynamics of green crabs discussed in Part A – 36-inches long and 18-inches in diameter that were baited with crushed soft-shell clam adults) was deployed and fished/baite on a three-day rotating basis. Crabs caught in the trap were counted and a subset measured and these were removed from the system (composted). Plots were routinely inspected throughout the spring, summer, and fall, and in November two benthic cores were taken from each plot and washed through a 1 mm sieve. Results of this study are fully described in Progress Report #2. Below is a brief review of the methods and results.

At Collins Cove, less than 20% of the cultured clams survived. Most had been consumed by green crabs that had gained access to some of the netted plots because some of the corners of netted plots had become exposed. Other clams were consumed by milky ribbon worms, *Cerebratulus lacteus*. Green crab trapping did not enhance clam survival or growth at that site. Approximately 50% of clams that did survive reached commercial size (50.8 mm in length, or 2-inches). Young-of-the-year clams (0-year class individuals) occurred at a density of 3.1 individuals per square foot. At the other site on the eastern side of the river, survival rates exceeded 85%. There was no significant effect on growth or survival due to seeding density or the presence of green crab traps. Approximately 25% of the animals reached commercial size, and the number of 0-year class clams was 1,377 individuals per square foot. These disparate results from the same study set out on back-to-back low tides at sites only 2,000 feet apart indicate the difficulty with generalizing methods to enhance clam survival. While negative effects of green crabs and milky ribbon worms on clam survival at the site on the eastern side of the river, the effects were minimal compared to what occurred on the western side of the river. These results led to a series of field trials in 2015 that examined methods to exclude milky ribbon worms from plots seeded with cultured soft-shell clam seed. In addition, the immense settlement of wild, 0-year class clams on the east side of the river spurred additional research in 2015 about whether the particular site or an interaction between site and treatments could explain the wild clam results.

E) Predator Deterrent Netting and Adult Soft-Shell Clams to Encourage Wild Clam Settlement

In 2014, a field study was deployed at Spar Cove (near the mouth of the Harraseeket River) and Recompense Flat (outside the Harraseeket River, but in the northern part of Casco Bay) in late April to examine the interactive effects of predator deterrent netting and the presence of adult soft-shell clams in an attempt to encourage wild, 0-year class

clams to settle to discrete plots in the intertidal. Results of this study are described in full in Progress Report #2. Below is a brief description of methods and results.

The study was designed as a completely factorial test with two factors: 1) adult clam density (three levels: none; 1-bushel per plot; and, 2-bushels per plot); and 2) netting (two levels: none vs. netting). Treatments were assigned randomly to positions within a 6 x 5 matrix at both sites (with each plot within the matrix being 10-ft x 10-ft). Adult clams were locally sourced and each was pushed into the sediments with siphons extending towards the sediment/water interface.

Two benthic cores were taken from each plot at both sites in early November 2014. The contents of each core were washed through a 1 mm sieve and all live soft-shell clam adults and 0-year class individuals were enumerated and measured to the nearest 0.01 mm using digital calipers. At one site (Spar Cove), survival of adults was only about 35%, as milky ribbon worms preyed on the majority of those animals during the experimental period. Recruitment was not related to the adult clam treatment, and approximately 33x more wild, 0-year class clams occurred in plots protected with netting vs. plots without netting (2,372 ± 2399 ind. m^{-2} vs. 70.7 ± 77.1 ind. m^{-2}, n = 15). At Recompense Flat, less than 20% of adult clams survived during the experimental period for the same reason observed at Spar Cove: milky ribbon worm predation. Neither adult clam density nor netting showed statistically significant effects on wild clam recruitment, although there was an apparent increase in clam densities in netted vs. control plots (239 ± 451 ind. m^{-2} vs. 12.1 ± 12.4 ind. m^{-2}).

F) <u>Train Clammers and Others in Aquacultural Techniques to Improve Local Clam Harvests</u>

This has been a major effort over the grant period. Numerous informal trainings have occurred that have resulted in clammers and elected officials in Freeport to examine how farming clams (clam aquaculture) may be used as a management tool for enhancing clam production in that community. For example, in 2014 and 2015, juvenile clams reared at the Downeast Institute in the town of Beals were transferred to a floating upweller that clammers were responsible for maintaining and routinely cleaning and grading clams. The amount of time and effort that clammers put into growing, sorting, and culling clams resulted in discussions that ultimately resulted in the town's Shellfish Commission proposing to the Freeport Town Council that areas be set aside in the intertidal for clam farming. This discussion extended beyond the town of Freeport to the adjacent communities in Harpswell and Brunswick where a significant portion of clams in Casco Bay are harvested annually. In addition, clammers who assisted in the deployment and sampling from the field studies received hands-on experience in setting out aquacultural gear and learning about the importance of maintaining and inspecting that gear over the period of time when clams grow (April to November). One clammer has applied for his own intertidal lease and awaits a decision from the town of Freeport on this matter. (Not all clammers are enamored with the prospect of clam farming in their town and some are adamantly opposed to removing even an inch of intertidal flats

from the public domain for private farming.) The activities and results from the field trials have been reported at the Maine Fishermen's Forum during March 2015 and 2016. These presentations have led to a number of clammers outside Freeport and other communities (specifically the towns of Brunswick and Harpswell) becoming interested in clam farming and using aquacultural techniques to enhance clam numbers.

Collectively, the work presented here, and the work that continues past the grant period, are showing that it is not possible for communities in southern Maine to manage clam stocks using traditional approaches. As seawater temperatures continue to increase, predation by green crabs and other invasive species as well as a suite of local, endemic species such as the nemertean ribbon worm will become more problematic. As it is not possible for a community or a group of clammers to affect climate change and put a damper on increasing sea water temperatures, it is no longer possible for a community to have an effect on clam stocks on the scale of hundreds of acres as they did when seawater temperatures were cooler and fewer predators were present. Today, clammers and communities must adapt to changing conditions in the intertidal zone that are decimating clam stocks. It is not possible to fence or net hundreds of acres of the intertidal zone; however, it is possible to set aside 1-10 acres of the intertidal where an individual or a small group of hard-working individuals can work to increase clam numbers that would result in a commercial venture. Unlike Massachusetts, clam farming in Maine is a foreign idea and it will take time and continued projects such as this one to help train clammers and elected officials about the benefits of adding farming to the management toolbox to increase clam harvests.

Many articles have appeared in the local newspapers around Casco Bay about this project that have also served to put into the public realm that the marine ecosystem is a dynamic place and that if we do not adapt to conditions that individually we cannot change, then the clamming industry is in serious trouble due to predators.

Here is an incomplete list of articles that have appeared in newspapers and in other media sources in and around Casco Bay that have resulted in more public awareness of the realities that are occurring on the mudflats and that have a significant impact on the economic well-being of clammers and the coastal communities that they reside.

1) http://www.theforecaster.net/freeport-shellfish-group-tweaking-clam-farm-strategy/

2) http://www.theforecaster.net/clam-researcher-closing-flats-akin-to-doing-nothing/

3) http://www.pressherald.com/2016/05/01/mild-winter-heats-up-efforts-to-protect-clam/

4) http://news.keepmecurrent.com/beal-to-share-clam-research-at-public-session/

5) http://news.keepmecurrent.com/more-peril-for-clams-in-freeport/

6) http://vitalsignsme.org/blog/hot-topic-green-crabs

7) http://www.pressherald.com/2014/07/12/some-claws-for-alarm-green-crabs/

8) http://www.pressherald.com/2015/10/28/invasive-species-exploit-warming-gulf-maine-sometimes-destructive-results/

9) http://speakingofseafood.org/success-stories/a-collaboration-success-story-sea-pact-and-the-maine-soft-shell-clam-fishery/

10) https://www.instagram.com/p/BE9dfIImTDf/

11) http://news.keepmecurrent.com/researcher-studies-health-viability-of-soft-shell-clams-qa-with-dr-brian-beal/

12) https://www.facebook.com/MaineClammersAssociation/posts/1027487420658209?comment_tracking=%7B%22tn%22%3A%22O%22%7D

13) http://www.timesrecord.com/news/2016-08-18/Front_Page/Clam_restoration_discussion_is_tonight.html

14) http://maineclammers.org/what-we-do/freeport-leads-in-fight-to-stop-green-crab-invasion/

15) http://www.aquaculturemag.com/daily-news/2015/08/20/panel-floats-proposal-for-aquaculture

16) http://www.boothbayregister.com/article/clam-conservation-expert-speak-darling-marine-center/71024

17) http://usinsurequotes.com/insurance-news/32272-q-a-with-freeports-sara-randall-vigilant-about-marine-resour