Final Report

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Title: Hard clam farming in eastern Maine: field experiments to evaluate biological and economic efficacy of field-based nursery and growout

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Abstract:

We have discovered the easternmost commercial population of hard clams, *Mercenaria mercenaria* (L.), in the U.S., in the waters of Eastern Maine. In 2007, we received permission from the State of Maine to lease a 6-acre tract in the shallow subtidal of Goose Cove (Trenton; Hancock County) to farm cultured hard clams. This is the first-ever lease of this type in eastern Maine. Working with our research partners from the Downeast Institute for Applied Marine Research & Education (DEI) in the town of Beals, we received Phase I USDA SBIR funding to examine seasonal growth and survival of cultured seed (6-12 mm shell length, SL) at multiple sites in eastern Maine from Trenton east to Cobscook Bay. That effort demonstrated unambiguously that the waters of far eastern Maine (Washington County) are too cold, and predators such as moon snails and green crabs too numerous to undertake farming operations in that region. Survival and growth of cultured seed in Goose Cove, however, was excellent in small plots where seed was planted in mid-Spring and protected with flexible netting. We observed > 85% survival through December, with animals attaining SL > 20 mm. We propose to extend our experimental approach to larger, pre-commercial scales to test hypotheses concerning both spatial and temporal variation in cultured hard clam growth and survival during the nursery, overwintering, and grow-out phases at Goose Cove and sites west of there in Hancock County. Specifically, we wish to determine what configuration of a field-based nursery system, and which nursery locations, will allow us to produce the largest transplantable hard clam seed; what the most efficient method is to store pre-planting size seed over the winter to optimize survival and growth; what field grow-out methods will produce market size animals in the most effective and efficient manner; and, to what degree interannual variability plays in hard clam growth and survival, both in the field nursery and grow-out phases. Answers to these questions will affect plans to commercialize our rearing methods and procedures.

Field-based nursery experiments

Three different field-based nursery methods were used to grow hard clams, *Mercenaria mercenaria*, to pre-commercial/pre-growout size. Each method required the use of hatchery-reared (cultured) individuals produced at the Downeast Institute for Applied Marine Research and Education (Beals, ME: www.downeastinstitute.org). Hard clam broodstock used throughout the project was collected from wild and cultured individuals at Goose Cove (Trenton, ME). One nursery method required juveniles at 1 mm shell lengths (SL) - the upweller method; another used juveniles that were ca. 2.5 mm SL, and used floating wooden trays lined with window screening; and, the third method used soft bags placed on top of the mudflat surface to grow ca. 3 mm SL individuals.

Upweller

A floating bivalve upweller (sensu Rivara et al. 1999; Leavitt 2002) was constructed and placed at two locations in eastern Maine: Upper Bagaduce River in Hancock County (44^{o} 24' 27" N, 68^{o} 43' 27" W), and Upper Somes Sound in Hancock County (44^{o} 19' 59" N, 68^{o} 18' 37" W). The upweller (Figs. 1), 22-ft wide and 20-ft long, held twenty silos (55-gallon plastic drums). This system was designed to grow 750,000 hard clams (37,500/silo) to 12-15 mm SL. Although clams reached sizes between 8-12 mm SL, the Bagaduce River location was abandoned after the first year (2011) due to proximity to other shellfish nurseries for oysters (*Crassostrea virginica*) grown by other commercial entities. In addition, the site was difficult to access (boat only) that made routine maintenance difficult. The Somes Sound site (a marina) had colder seawater than the Bagaduce River, but accessibility was not a problem and hard clams grew to sizes ca. 10 mm from June to October in 2012 and 2013. Some problems with mortality (ca. 30%) immediately after clams were transferred from the hatchery to the upweller were observed in 2012 and 2013. After the initial mortality, both growth and survival were excellent. If the mortality agent can be identified, the upweller system will work very well.

A problem occurred with the timing of hatchery seed in two of the three years. That is, we expected to receive seed clams in late May/early June, and this only occurred once. In two years, cultured seed arrived later (mid July/early August) because of production problems at the hatchery unrelated to the USDA grant. Because there is a narrow window for clam growth that occurs from June to October, missing one or more months of growth in the upweller (or in the intertidal) is critical. For example, when clams are placed into the upweller at Somes Sound prior to June, growth of animals by November exceeds 12 mm SL. In 2011 and 2012, seed (averaging 1.82 ± 0.04 mm, n = 148) arrived late (early August) and by November, seed had only attained an average size of 5.81 ± 0.22 mm, n = 149). These clams were overwintered (see below), and were placed into soft benthic bags (see below) the following spring.

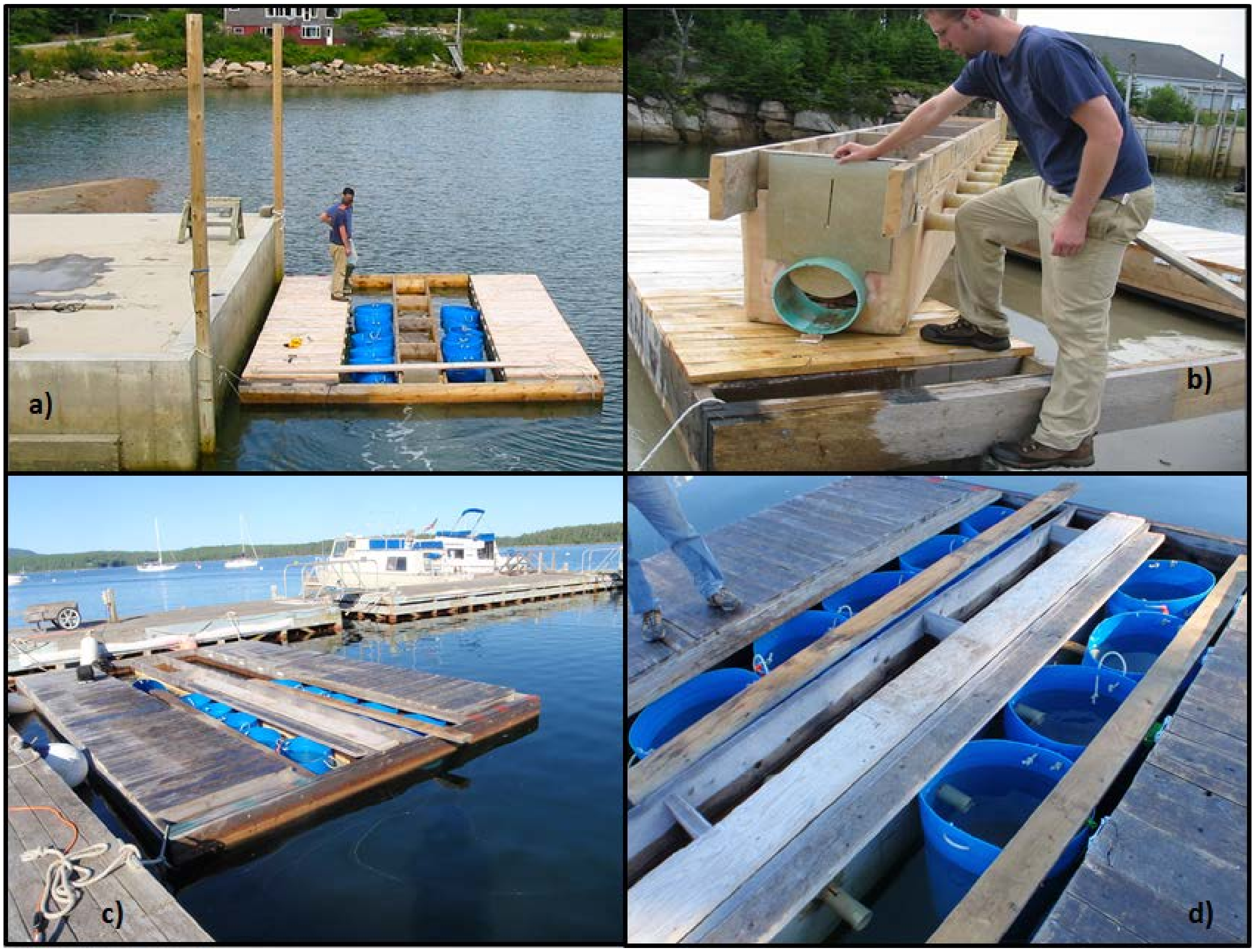

Figure 1. a) 22-ft x 20-ft floating bivalve upweller; b) internal fiberglass tank that connects flowing seawater to silo units; c) upweller deployed in Somes Sound, near Southwest Harbor, ME; d) 55-gallon silo units.

Floating wooden trays

Wooden trays (4-ft x 3-ft) lined with nylon window screening material were used to grow hard clam seed to overwinter sizes of only 6-8 mm during 2011 and 2012 at a site in eastern Maine adjacent to the Downeast Institute (DEI) at Mud Hole Cove, Beals, ME (44^{o} 29’ 08” N; 67^{o} 35’ 11” W; Fig. 2). The site has been used since 2005 as a nursery for hard clams; however, clam growth is not as fast as in the Somes Sound upweller. Survival varied between 90-97%. We extended results from previous investigations at this site by examining densities of 2,500 to

Figure 2. a) 4-ft x 3-ft wooden tray lined with window screening and covered with a piece of black plastic (3 mil thickness) to protect clams from bird predators at Mud Hole Cove, Beals, ME; b) close-up of tray; c) handful of cultured hard clam juveniles 6-8 mm shell length that were held from June to October 2012 at a density of 2,500 per tray; d) hard clams on window screening inside a wooden tray that were at a density of 7,500 per tray from June to October 2012.

12,500 per tray and found a negative linear relationship between intraspecific density and growth similar to that observed by Beal et al. (2009).

Although relatively inexpensive to construct (ca. $25.00 each) and maintain, wooden floating trays are not practical for nursery culture because they require a surface lease that is difficult to obtain in Maine under the current regulatory climate (see below). Trays were used in this project only at Mud Hole Cove because it was not possible to deploy them in the other areas that we had proposed due to our inability to obtain permits from the state of Maine to do so.

Benthic soft bags

A third strategy for growing clam seed in large numbers to an overwintering size (> 12 mm SL) was the use of benthic soft bags. Several designs were employed over time, and the evolution of this technique and results observed is, perhaps, the most significant discovery during the three year project. The bags now allow us to take seed from 3 mm to ca. 20 mm SL on the intertidal flats that removes a significantly large step (upweller and/or floating trays) in the nursery phase.

The first bags (5-ft x 14-ft) were constructed of fiberglass window screening on the bottom, and 4.2 mm flexible netting (polypropylene) on top (N = 30). Three Styrofoam floats were attached to the underside of the top net so that it would not interfere with feeding during tidal inundation. The top and bottom nets were stapled together, and then duct tape was placed around the periphery to ensure a secure seal. Each bag was anchored by walking the periphery into the soft sediments, and then back-filling the resulting furrow with mud pushed in by foot. The clams grew fast; however, a species of native amphipod (*Ampelisca abdita*) known to produce mats of tubes and fecal pellets (sensu Mackenzie et al. 2006) fouled each bag so densely that bags became too heavy to move and sample quantitatively. Of the 30 bags deployed in Spring 2011, only three were sampled to give any credible information. The remaining bags weighed between 300-400 pounds due to the amphipod altering the sedimentary habitat and had to remain on the flat over the winter (seven of these bags survived the winter, the rest were carried off by ice). The bags were designed to produce cultured clams that would not remain on the flat over the winter, but be placed into a controlled, overwintering scenario (see Beal et al. 2009 for a description of a lost-cost overwintering technique with cultured hard clam seed that results in greater than 95% survival from November through April of the following year). Because small clams (< 20 mm SL) burrow so shallowly, ice is a problem in some winters (rafting portions of the sediment away), and they are susceptible to low winter air temperatures during exposure at low tide. The soft bags, then, are nursery grow-out containers to grow juvenile clams to an overwinter size. Approximately 20,000 clams were placed in each of the thirty soft bags, and we estimate that 90% (n = 3) survived the period between May and November 2011, and these were overwintered with survival rates exceeding 90%.

A second iteration of the soft bag technique used fiberglass window screening sewn along one long side and heavy-duty Velcro® to seal the remaining three sides. Besides amphipods, the second try posed other problems as well. The fiberglass screening used on the bottom of each bag proved too weak (it would tear easily with time; deteriorated with prolonged exposure to sun, weather, and tides; it did not support the weight of animals grown; and, it did not pose an effective barrier to invasive green crabs). This design was abandoned, but the information gleaned from it allowed us to settle upon a design that works well.

In the most recent design, the bottom screen constructed using fiberglass window screening in the first two iterations was replaced with a more resilient, durable, and heavy-duty screening called Pet Screening (http://www.homedepot.com/p/Phifer-48-in-x-84-in-Black-Pet-Screen-3004153/100565927; Fig. 3).

After two years, no tears have occurred in any of the bags, screening has not deteriorated, and it is an effective barrier to green crabs and other predators. In addition, instead of trenching by pushing the periphery of each net into the sediments, the corners of each bag are anchored with weights (rocks, metal anchors, etc.). Because the bags are not in direct contact with the bottom except at each corner, amphipods are unable to construct tubes as efficiently and this resulted in less additional sediments fouling the bags. Enough natural sediment entered each soft bag to allow excellent growth of the cultured juveniles, and during the past two years (November), all mud was easily sieved from each bag and juvenile clams were then poured into containers for transport to the overwintering sites. Data taken from soft bags during the fall of 2013 show that these are excellent units for growing hard clams to overwintering sizes. For example, clams averaged 11.3 ± 0.4 mm (n = 65) in May and 19.3 ± 0.7 mm (n = 65) in October, an absolute increase in shell length of 8 mm, or a 70% increase in SL.

Figure 3. a) Five benthic soft bags (5-ft x 14-ft) rolled up; b and d) an open bag with 20,000 3-4 mm SL hard clam seed on an intertidal flat; c) a seeded soft bag that will be used to grow clams from April through November to sizes ca. 20 mm SL. The corners are weighed down (secured to the flat), and that prevents amphipods (*Ampelisca abdita*) from colonizing bags.

Overwintering trials

A low-cost technique for overwintering hard clam seed that is similar to one used for overwintering cultured soft-shell clam, *Mya arenaria*, seed (Beal et al. 1995) was used in each year of the project with excellent results. This technique places 2-4 kg of seed varying in size from 6-20 mm SL into window screen bags (ca. 45 cm x 45 cm). Bags are then placed on shelves in cages constructed from vinyl-coated lobster trap wire (38 mm aperture; Fig. 4). Cages were kept over the winter at the Downeast Institute in a large cement tank (35,000 L – 15 m long

Figure 4. a) 45 cm x 45 cm bag constructed of nylon window screening holding 3.5 kg of hard clam seed; b) overwintering cage (14-gauge wire; 0.96 m x 0.45 m x 0.45 m) holding 8 bags of hard clam seed.

seed up to 4 kg/bag (ca. 30,000 individuals) resulted in excellent (> 95%) survival. In addition, we investigated another overwintering technique that does not require taking seed clams to the hatchery and the associated costs (electrical pumps). During the winter of 2013-2014, clams were placed in soft bags that were placed in the rocky intertidal near Goose Cove and covered with blue tarp material that was weighed down with rocks. The tarp kept the clams protected from freezing air temperatures while also deterring diving ducks from accessing the small clams. Survival rates using this technique ranged from 60-70% and bags were fouled with small mussels (*Mytilus edulis*) that were not observed at the DEI hatchery. Given the large disparity in survival rates between the two techniques, the intertidal method will be used only during times when space is unavailable at the DEI hatchery.

Field grow-out trials

We had anticipated conducting field grow-out trials at Goose Cove (Trenton – Eastern Frenchman's Bay, Hancock County) and Morgan Bay (Surry – Upper Blue Hill Bay, Hancock County; 44^o 27' 04" N, 68^o 28' 51" W). Grow-out trials occurred at Goose Cove exclusively because attempts to use the Morgan Bay site were frustrated by legal wrangling over environmental, social, and political concerns expressed at public hearings overseen by Maine's Department of Marine Resources (https://penobscotbaypress.com/news/2013/mar/14/public-hearing-set-for-morgan-bay-aquaculture-leas/#.U4NmOii9Zhs). The process to obtain an experimental lease site to conduct quahog grow-out trials began in 2010. As of this date, the Department of Marine Resources has not made a decision on the application.

Hard clams were planted during the spring of 2012 and 2013 under flexible netting (4.2 mm aperture) at a density of 150 to 250 individuals m^{-2}. Netted plots (14-ft x 22-ft) were arrayed in the intertidal zone below the mean low water mark at Goose Cove (Fig. 5). Core samples (0.01842 m^2) taken showed how growth rates vary as a function of planting date (Fig. 6). In addition, density varied significantly with planting date as animals planted earlier in the season had higher survival rates at the end of the growing season. For example, survival in netted plots seeded in May returned a density of 219 ± 124 ind. m^{-2} (survival rate > 90%), but those seeded in July returned a density of only 157 ± 88 ind, m^{-2} (survival rate ca. 70%). Differences are likely due to green crabs (whose population exploded during the summers of 2012 and 2013) that are able to crush some of the smaller seed clams through the netting (pers. obs.).

Growth rates of cultured vs. wild hard clams were measured by collecting clams on 25 July 2013 from areas at Goose Cove where no cultured clams were ever planted vs. areas planted in 2011. Annual growth lines from clams from both origins were measured and then Ford-Walford plots (Walford 1946; Kaufman 1981; McCuaig and Green 1983) used to derive von Bertlanaffy growth equations (Fig. 7).

Figure 5. Protective (predator) netting (14-ft wide x 22-ft long) used at Goose Cove (Trenton, Maine). Three to five Styrofoam floats are attached on the underside of each predator net to provide lift during periods of tidal inundation that keeps the netting off the surface of the mud an keeps the net from interfering with feeding. a) nets looking southeast; b and d) looking east toward Cadillac Mountain in Bar Harbor; c) looking north toward the town of Trenton.

The growth equation for wild clams was: $L_t = 166.1(1-e^{-0.0824(t)})$, where L_t = Length at time t (in years), 166.1 = asymptotic length (L_∞), and -0.0824 is the von Bertalanffy growth parameter. The equation yields the results in Table 1.

Table 1. Results of length at age for wild clams at Goose Cove using values for the von Bertalanffy parameters calculated from a Fort-Walford regression (see Fig. 7).

Age (in years)	Length (mm)
1	13.13
2	25.23
3	36.38
4	46.64
5	56.08

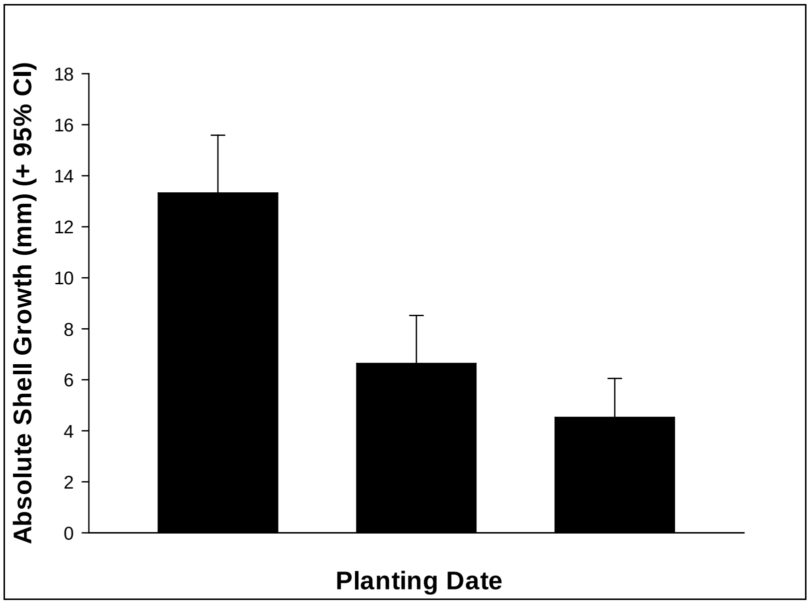

Figure 6. Growth rate of cultured hard clam seed by planting date in 2012 and 2013 at Goose Cove, Trenton, Maine. Core samples taken in October. (n = 4)

These results suggest that a clam takes between four and five years to reach a shell length of 50.8 mm, or 2-inches.

The von Bertalanffy growth equation could not be used to assess growth rates of cultured clams because none of the clams exhibited asymptotic growth over the range of sizes used (27.6 - 50.2 mm). Nonetheless, the Ford-Walford plot can be used to show that cultured clams attain a shell length of 50.8 mm in approximately three growing seasons.

The reason for the difference in growth is due to several years (five) of selecting broodstock that showed wide annual growth lines. Initially, the selection used wild clams, then cultured clams that exhibited fast growth were selected after the third year.

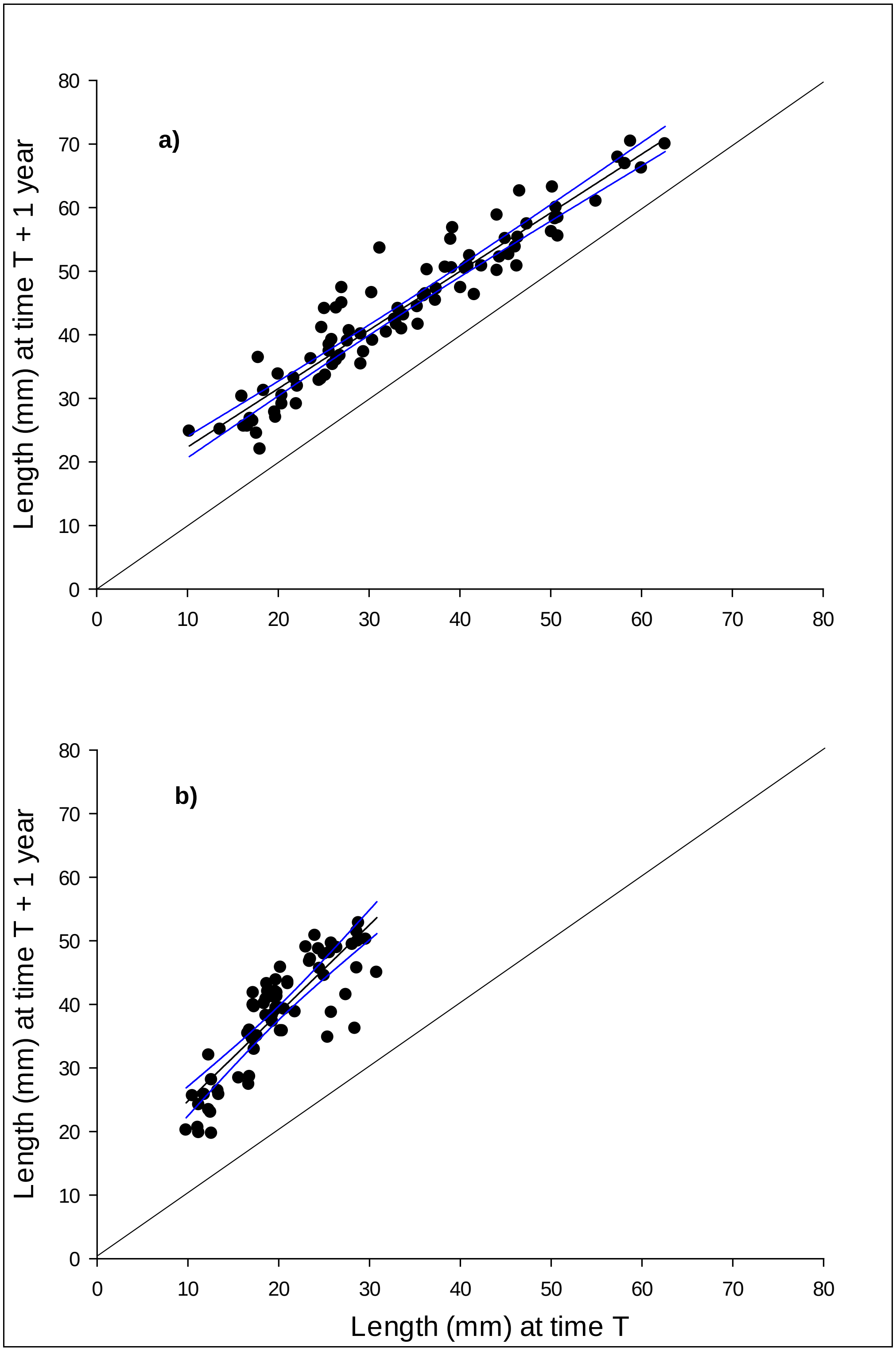

Figure 7. Ford-Walford plots for wild hard clams (a; n = 87) and cultured hard clams (b; n = 72) collected from Goose Cove, Trenton, ME on 25 July 2013. Cultured clams were planted in 2011. The line Y = X is shown (line of zero growth), along with the least squares regression line and 95% confidence intervals, for each plot.

Summary

Several issues over the grant cycle affected the project in a variety of ways – some positive and some negative. ***First***, a management decision early on in the project to support financially staff at the hatchery (Downeast Institute) to produce seed rather than to support field staff resulted in too much field work for the PI to undertake. The correct decision should have been to increase field staff so that important field work could be completed in a timely fashion. Most field work that was proposed was completed, but the time it took to complete the work was too long for just one person. ***Second***, ice posed a major setback in years I and II. Soft benthic bags containing seed clams that require careful overwintering off site cannot be left in the field past mid-November due to possible icing events (e.g., scraping = light ice; scouring = heavy ice). In addition, predator nets must be removed at the same time. Some of these netted areas can become vulnerable to predators the following spring if nets are not re-installed in the exact position they were in during the previous November. Sometimes, winterkill occurred when air temperatures dipped below 0^{o}F (-18^{o}C) during extreme tides of the months of December, January, and February. We must remember that this species is at the northern extent of its range and is vulnerable to winterkill under these extreme conditions. ***Third***, storms, especially during the fall, accompanied by heavy southerly tidal surges can pull nets that exposes small seed to green crabs and other benthic predators. None of the methods used to anchor nets (i.e., trenching and weighting the corners) provided results that were 100% effective at keeping netting in place during some severe weather events. ***Fourth***, overwintered seed clams must be planted prior to mid-May each year. This is a time prior to major predator events (because seawater temperatures are typically too low for green crabs to feed efficiently – see Berrill [1982]). This time also allows maximum time for clams to grow during the growth season that ends in late October/early November each year.

To be a viable commercial endeavor, several other things must occur. First, a consistent hatchery production must occur and the clams from the hatchery must be healthy and begin to grow quickly once they are placed in the upweller or in soft benthic bags. Second, smaller clams (500 micron individuals) might be sent from the hatchery to the upweller to boost both hatchery stock-to-nursery survival or somehow grow animals to 2 mm in the hatchery. Third, animals leave the upweller as soon as possible in the growth season at sizes ca. 5 mm SL where they are placed in nursery bags (top net = 4.2 mm aperture) until the end of October (the end of the growth season). Fourth, the animals are removed from the nursery soft bags and overwintered at the Downeast Institute or submerged subtidally. (If animals are large enough – ca. 20 mm SL, they could be seeded directly to the flats, but this would be a decision to make carefully given that overwinter temperatures may result in winterkill for animals that are not burrowed very deeply.) Fifth, during the Spring, animals > 12 mm should be planted in protected plots and any that are smaller than this placed (again) in benthic soft bags.

As the most significant obstacles to growing hard clams in Eastern Maine are diminished and annual production increases, there is a ready market for the resulting production. Prices for a good portion of this production will be in the $.30 range to local and niche markets given our location and product quality. Having said this, there is now a growing population and fishery for hard clams along the southwestern coast of Maine likely due to warming water conditions in the past few years. We expect this will create a lower maximum price point over the larger Northeast Market, though it may create favorable, enhanced name recognition for the "Maine" seafood brand. Hard clams from Maine, particularly the more northerly the animals are raised, have a demonstrably higher quality in flavor and shelf life than their more southern counterparts. We believe we will maintain a good market share as we improve our methods using the knowledge we have gained through this Phase II SBIR grant.

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