Final Report

Piloting Surf Clam Aquaculture Techniques to Create Commercial Opportunities

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Acronyms/Definitions

A.R.C. Aquacultural Research Corporation, aka A.R.C. Hatchery

Butter clam colloquial/marketing name for surf clam, specific to 1.5-2.5" size

CCCFA Cape Cod Commercial Fishermen's Alliance

mm millimeter

NOAA National Oceanographic and Atmospheric Administration

OPN measurement size of handheld sand shaker sieves

PPT parts per thousand (unit of measurement)

PVC polyvinyl chloride thermoplastic material, pipe commonly used for plumbing

R1.5 size measurement of shellfish seed, R1.5 is seed that is large enough to be retained on a sieve size of 1.5mm; the actual size of the seed will be 2.0-3.2mm

R2 size measurement of shellfish seed, R2 is seed that is large enough to be retained on a sieve size of 2mm; the actual size of the seed will be 3.2-4.2mm

R3 size measurement of shellfish seed, R3 is seed that is large enough to be retained on a sieve size of 2mm; the actual size of the seed will be 4.2-5.3mm

R4 size measurement of shellfish seed, R4 is seed that is large enough to be retained on a sieve size of 4mm; the actual size of the seed will be 5.3-8.0mm

R6 size measurement of shellfish seed, R6 is seed that is large enough to be retained on a sieve size of 6mm; the actual size of the seed will be 8.0-11.0mm

SEMAC Southeast Massachusetts Aquaculture Center

T.Iso *T. Isochrysis*, a type of algae

QPX Quahog parasite unknown, is a single-celled protist parasite in the class Labyrinthulomycota. It affects hard clams (Mercenaria mercenaria), or quahogs, both cultured and wild

3H *Thalassiosira pseudanana,* a type of algae

Executive Summary

Atlantic surf clams, *Spisula solidissima*, are marine bivalve mollusks common to the Atlantic coast of North America from the Gulf of St. Lawrence to Cape Hatteras, North Carolina. Surf clams can be found from the surf zone extending offshore throughout the continental shelf to depths of over 100 meters, though they prefer medium to coarse sandy habitats with more shallow to moderate depths, such as Georges Bank and the shoals south of Cape Cod. Traditionally limited to wild harvest at a legal size of five inches and processed into clam strips and chopped clam meat, this project explores the potential of a cultured surf clam, harvested at 1.5"- 2.5" in length. MA Division of Marine Fisheries now allows aquaculture growers to harvest surf clams at a minimum size of 1.5" in length. At this smaller size, surf clams have attributes similar to both softshell clams and littleneck hard clams and are considered a new product with the potential to diversify Massachusetts aquaculture farms, which are dangerously reliant on an oyster monoculture and half shell market.

The purpose of this project was to determine the best location and conditions to commercially grow out surf clam seed, and explore market potential, in order to provide wholesale and retail markets with a new product: cultured "butter clams." This project demonstrated commercial feasibility in order to provide a new commercial aquaculture product that will help to stabilize working waterfronts and support New England's traditional fishing communities.

The project evaluated the best strategies with respect to temperature, sediment type, tidal height, containment equipment and predator control and used this information to demonstrate to the shellfish growers in the region that the surf clam is a viable commercial crop that can be adapted to their growing conditions. A.R.C. Hatchery fine-tuned successful hatchery production of surf clam seed. Field studies completed by the Cape Cod Cooperative Extension evaluated growth and survival of surf clams at four experimental sites under various growing conditions and grow out technologies (planted in plots under protective netting like quahog grow-out, soft nylon mesh bags-often called Florida bags based on FL grow out methods, and box style rigid polyethylene mesh grow bags pinned to the sediment surface). Surf clam samples were given to 21 chefs who provided critical feedback to the project's marketing efforts. Initial marketing findings resulted in a supplemental Sea Grant project to formulate a robust marketing strategy and marketing tools for growers and wholesalers. A surf clam enterprise budget was developed to assist growers in determining the commercial feasibility of this clam. Results were shared with shellfish growers, wholesalers, the broader aquaculture industry, scientists, chefs, and the general public.

The project demonstrated that commercial aquaculture production of surf clams is viable, provided there are improvements in grow out practices to achieve optimal yields, and initiated market interest in a new shellfish product. Bottom planting similar to current quahog culture practices works, with high growth rates; survival is dependent on net setup and maintenance to deter predators and escaping clams. Oyster bags, or other gear, that can sand in naturally showed the best survival and good growth, making them a good albeit inconsistent method that likely needs more experimentation. Two commercial hatcheries in Massachusetts are committed to producing surf clam seed for sale. Growers are utilizing the project findings and investing in surf

clams to diversify their aquaculture farms. Chefs are excited to for there to be a supply of surf clams in the marketplace. It is premature to gauge the long-term commercial impact of the project, but on the whole, the goals and objectives of this project were attained.

Field results suggest potential growth to a marketable size in one to one and a half calendar years is possible. Growth rate is variable and not yet fully understood but appears to be greatest in spring and fall as temperatures are more ideal for the species, slowing in the heat of summer and during winter lows. Sand for burial was not found to be required until they reached ¾-1 inch in length, at which point growth may be stunted if the clams are not allowed to bury themselves in the sediment. Our best survival was seen in bags pinned to the bottom to allow sedimentation and prevent migration and predation. The ideal method allows the surf clams access to sediment for burial but also provides protection from predators and containment from emigration - but this is often easier said than done, as intertidal and subtidal locations offer different challenges. Combined stresses of spawning and heat in the second summer of growth can cause mortality, mostly in intertidal conditions where extremes can be seen. Surf clams can recover from high temperatures toward the lethal limit of 86F if duration of exposure is short. Winter mortality did occur when exposed to extreme low temperature in the intertidal, those clams that were in subtidal or were able to bury themselves in lower intertidal had higher survival rates. Surf clams are very susceptible to predators, especially crabs, whelk, and moon snails. No major disease issues have been noted to date.

The general observations for each gear type include:
Planted under net – surf clams showed the most consistent growth among all the sites when planted under net. Nets are difficult to manage subtidally so are better suited to intertidal sites. Survival did suffer due to sand mounding and predation issues because the nets were not trenched on the sides to better prevent predator entry. There was also a tendency for clams to accumulate on the downwind side or corner of the nets, likely because the clams come to the surface and get washed downwind at lower tides.

Soft mesh (FL) bags – these bags while pinned to the sediment and even after partial filling did not consistently collect and fill with sand. When they did, surf clams seemed to grow well but more often than not sand mounded underneath the bags (rather than inside) leaving the clams out of the sediment where growth lagged. Survival also suffered as crabs and moon snails still attacked the clams through the soft mesh.

Rigid grow bags – these bags also did not accumulate sand consistently and varied by site and bag type. Box style bags and smaller mesh sizes seemed to accumulate sand more naturally (theoretically through slower flow rates facilitating sedimentation). When bags did accumulate sand the surf clams grew pretty well. Survival tended to be higher in these bags as the rigid mesh offered protection from predators in all directions. This method, if further developed, might have the most potential subtidally where deployment and tending in strings or trawls from a vessel could be possible.

Harvest of surf clams at the 1.5-2" size with jerk rake techniques currently employed in local quahog culture caused significant amounts of shell breakage. Hand scratching in the intertidal or use of a hydraulic harvester in subtidal conditions both reduced breakage. Allowing the clams to rest in off bottom holding on the farm after harvest from the sediment was required to ensure clearing of grit.

Cultured surf clams have potential across a range of cuisine and menu applications due to their similarity with other clam species and also offer the potential to offset supply shortages for other clam species. There is relatively broad interest within the wholesale community for butter clams, albeit wary of over-promoting prior to building the supply. Taste tests of the clams produced comments like, "delicious raw or cooked, briny, slightly sweet and very rich." Ninety percent of the chefs that sampled the surf clams were anxious to purchase them and put them on their menus, and 100% of public taste testers said they wanted to eat cultured surf clams again. Market price estimations have varied depending on potential end use, but indicate that butter clams are an underdeveloped market that represents a market potential of $0.6-$1.7million gross revenue for Massachusetts-based farmers within the next three years, assuming steady buildup of seed supply, growing operations, and shell stock. Growers could receive $0.18-0.50/piece (Pentallect 2018 and Zapalac 2019) and that as a limited, unique product surf clams could command a high price. Most estimations of a new surf clam product coming online slowly suggest a price similar to that of littleneck clams (*Mercenaria mercenaria*). During the summer of 2020, the limited surf clams available were sold at $0.40/piece to the grower. Ultimately, consistency in supply will help stabilize the market and yield long term prices. Some suggestions for growers and wholesalers are to begin marketing surf clams as a raw bar item, and to establish relationships with local chefs that will promote the unique product to "early adopter" consumers of seafood and find a niche market.

Project partners are committed to the long term success of cultured surf clams. Consequently, this project spawned several complimentary projects, including a Sea Grant award to complete a robust market assessment on surf clams, as well as the development of a comprehensive marketing and promotional plan for surf clams. Marketing experts recommended branding the new product as "New England Butter Clams" to distinguish them from the 5" wild harvest surf clam. Marketing collateral templates are being developed to support growers and wholesalers' efforts to start selling this new product. Cape Cod Cooperative Extension has started a new project to compare growth rates and survival of the two subspecies of surf clams, Atlantic and southern.

Opportunity exists for surf clams grown in an aquaculture setting for a niche high end clam product. This opportunity is not without the challenges of building new markets and streamlining grow out and harvest. Much work still needs to be done to make this new product a reality and to achieve meaningful farm diversification. Two Massachusetts hatcheries have invested in producing the seed and making it commercially available, growers have begun investing in farming surf clams, and chefs are ready to champion this delicious new product. The next hurdle is ramping up a reliable commercial supply online to broadly introduce the market to the New England Butter Clam.

Purpose

The purpose of this project was to determine the best location and conditions to commercially grow out surf clam seed, in order to provide wholesale and retail markets with a new product: cultured "butter clams." The goal and objectives of this project align with S-K Priority #1, to demonstrate aquaculture technologies in pilot-commercial scale projects that will create jobs in fishing communities and produce healthful local seafood. This project demonstrated commercial feasibility in order to provide a new commercial aquaculture product that will help to stabilize working waterfronts and support New England's traditional fishing communities.

To meet that goal, we evaluated the best strategies with respect to temperature, sediment type, tidal height, containment equipment and predator control and used this information to demonstrate to the shellfish growers in the region that the surf clam is a viable commercial crop that can be adapted to their growing conditions. We focused on the following specific objectives:

- Fine tune hatchery production of surf clam seed and demonstrate commercial-scale production capacity.
- Identify appropriate locations for surf clam culture by evaluating growing conditions in different locations on Cape Cod and selecting 3-4 commercial farms as grow out sites.
- Determine which of three grow out technologies previously demonstrated to be effective for growing surf clams (bottom planting under nets, Florida-style mesh bags, or oyster bags) are the most effective at producing marketable butter clams on Cape Cod.
- Document all costs associated with surf clam production to make a preliminary determination as to the feasibility of this clam transitioning to profitable commercial production.
- Initiate formulation of a marketing strategy by soliciting input from shellfish dealers, growers, and chefs.

Background

Shellfish aquaculture in the northeast is limited to two primary species, the hard clam or quahog (*Mercenaria mercenaria*) and the Eastern oyster (*Crassostrea virginica*), with a variety of other species being grown at the researchlevel. With the current shellfish aquaculture industry in the northeast dependent on only two species, this limitation leaves them highly vulnerable to catastrophic losses to disease or other environmental perturbations due to the lack of diversity in their crop. Shellfish growers are searching for new species to grow to increase their markets, to diversify their crop, to cover loss of any one species and to expand usable sites available for aquaculture. The surf clam (*Spisula solidissima*) has the potential to add a third successful shellfish species for aquaculture growers on the east coast.

Aquaculture of the surf clam would fill a different market niche than the current wild surf clam harvest and complement the existing market for the farmed quahog while being commercially competitive with other clams, especially the farmed Manila clam (*Venerupis phillipinarum)* on the west coast of the United States and the wild harvested soft shell clam (*Mya arenaria*) on the east coast. Numerous attempts have been made to broaden opportunities by introducing new species to commercial aquaculture, e.g. razor clams and bay scallops, but none have overcome significant production bottlenecks to commercialization. A surf clam of 1.5 to 2 inches, marketed

as a “butter clam”, would present an opportunity for a farmed product that could grow rapidly and provide a viable commercial product. The “butter clam” is known for its butter yellow coloration and its smooth taste and texture. Developing a commercial market for cultured butter clams would provide a new opportunity for existing and future shellfish farmers; thereby expanding their commercial viability while adding to our national food security through domestically-produced shellfish.

Additionally, the wild surf clam fishery is experiencing challenges that make cultured surf clams even more important. While the wild fishery is not overfished and overfishing is not occurring, it has seen a leveling off of landings per unit effort in recent years and is facing user conflicts with offshore wind farm development (MAFMC, 2020-a). The commercial fishery continues to see a decrease in landings from a high in 2007 and in 2019 was only able to harvest 57% of its quota. (MAFMC, 2020-b)

Market Opportunity

Prior to this project, farm raised surf clams grown to 1.5-2.0 inches and referred to as "butter clams," did not exist in the market place. The surf clam is familiar to consumers as a larger sized, wild harvest product (minimum size of 5”), but the small "butter clams" present an entirely new opportunity. The positive aspect of introducing a smaller size product of something that is already recognized in the marketplace is that the market penetration should be more readily accomplished.

A comparison with hard clams can be made. When hard clam aquaculture was commercialized several decades ago, no clams could be sold at less than the smallest legal limit of 1" across the hinge (or approximately 12 clams per pound). Now special permits are given to aquaculturists to sell undersized clams up to 20 count per pound. Originally this was a limited niche market that handled what was basically a by-catch of market-sized product. Demand for this product, called "pasta" clams, has continued to grow from Canada to California. (Personal communication, G. Hart).

The anticipated market for butter clams is national wholesale distribution into retail grocery chains, small retail seafood markets, and restaurants. The same distribution network currently used for hard clams should be able to absorb the new product. The first critical condition for national distribution is regular year round availability. The second critical condition is competitive pricing. Because the surf clam is a fast growing species, we anticipate this will determine a sales price that will be attractive to the consumer. Once the supply is available and the price point established, the butter clams can be introduced into the national distribution network.

In 2014, the South Eastern MA Aquaculture Center completed a survey of Massachusetts shellfish wholesale dealers, and reported that 17% said they would be very interested and 26% would be somewhat interested in locally grown butter clams. At the time of the survey, many wholesalers recognized the current prohibition on undersized surf clams, which could have limited the positive responses.

Importance of Developing This New Species

The factors that have changed to make surf clam aquaculture a species of interest for commercial aquaculture are external to the surf clam issues, but relate to industry wide aquaculture changes.

1. Diseases of the primary cultured species: Hard clams have been affected by QPX in a number of locations in our region, making those areas unsuitable for hard clam culture for years (Smolowitz *et al.* 1998). Oysters are routinely affected by Dermo and MSX, and more recently SSO, on a cyclical basis. Approximately every decade there are serious outbreaks that jeopardize whole year classes.
2. Growth rate declines: Hard clams that once grew to market size in 1.5-2.0 years are now taking up to 4.0 years to achieve the same growth (R. Kraus, personal communication).
3. Overproduction: When hard clam culture was introduced to the mid-Atlantic and south, national production quadrupled (Heinonen 2012). The national selling prices fell and farmers in the northeast have never regained the level of pricing present in the 1980's. This fate may befall oysters based on predicted growth in the Chesapeake (McNevin 2007). Environmental disasters in the Gulf of Mexico affecting traditional Gulf oyster production has offset a price slump due to overproduction to date, however, the Gulf is on the mend with regards to oyster production.
4. Price stagnation in the hard clam market: The landed value for a littleneck clam has not changed much over the past 20-30 years (G. Hart, personal communication) while the cost for production has steadily increased over the same time period. Therefore, profitability in growing hard clams has been steadily decreasing over the years.
5. Net income decline: Farmers are experiencing increasing occurrences of losses from diseases, slower growth and price stagnation coupled with steadily increasing operating costs for expenses such as fuel, netting materials, etc. The result is a loss of net income over an annual production cycle.
6. In 2017, the Massachusetts Division of Marine Fisheries added regulatory language to allow for the harvest of aquaculturally reared surf clams at 1.5”, creating the opportunity for a new aquaculture product.

Surf Clam Life History

The surf clam has been commercially harvested on the east coast of the U.S. since early in the twentieth century. In the 1940’s, harvesting increased dramatically to provide a needed source of protein. Annual commercial landings fluctuated throughout the ensuing decades. By the end of the 1970's, a dramatic decline occurred because of overfishing. During the 1980’s, attempts were made to manage the resource and preserve the fishery through regulation. The biomass of surf clams has been declining and is expected to continue to decline through 2015 (NEFSC 2010). The introduction of a smaller sized product through aquaculture would be an enhancement to the existing wild catch market.

The surf clam has a history of market acceptability. There has always been a wild catch dredge fishery centered offshore of the mid-Atlantic states and New Jersey with limited catches from Georgia on the south to New Brunswick, Canada on the north. It has been established that there is a variant *Spisula solidissima similis*, the southern surf clam, which does overlap with *S.*

solidissima solidissima from Long Island Sound but is not a significant fishery (Cargnelli, *et al.* 1999, Fay *et al.*1983, Walker & Heffernan 1994, Weinberg 1998, NEFSC 2010). Because the subspecies *S. s. similis* requires sufficiently different growing conditions, the researchcontributions from that region and for that subspecies has been minimized in this project.

Surf clams are large, suspension feeding, infaunal bivalves with a minimum harvestable shell length of five inches that is used as a prepared clam product (Cessine *et al.* 1978, Goldberg 1989). Considerable researchhas been conducted over the past twenty years on the surf clam; however, this has mainly pertained to wild surf clams and not farm raised. However, this literature has produced a wide body of knowledge about the characteristics of the surf clam that the project leveraged to create commercially available surf clam seed.

Normal growing conditions for natural recruitment of surf clams is quite broad. The growing area depth for surf clams varies with latitude and ranges from the surf zone to 50 meters depths; clam densities occur at the highest concentration at <18 m depth contour along Long Island, NY and New Jersey and further offshore in more southerly latitudes (Ropes 1980). Distribution is concentrated in the middle Atlantic Bight and New Jersey with reduced distribution north to New England (Narvaez *et al.* 2014). Recent researchindicates that the rising ocean temperatures are having an effect on wild surf clam population distribution. Populations have been noted to be moving into deeper and more cooler waters of the north (Ambrose *et al.* 1980). This project took advantage of the northerly shift in the population by exclusively using New England waters.

The maximum size of an adult surf clam is listed at 9 inches (226 mm). It can reach the maximum age of 31 years. The natural cycle is a major spawn event between May and July, depending on the location, while a second spawning may occur in October to early November (Marzec *et al.* 2010). Overall growth rates vary by location, but in New Jersey the best growth is in the spring and early summer. Surf clams do not do well exposed to low levels of dissolved oxygen (Cargnelli 1999). Growth rates are fastest for the first three to five years then becoming slower (Jones, *et al.* 1978). Goldberg and Walker (1990) summarized the annual growth rates of surf clams from a variety of locations along the Atlantic seaboard and noted a range of from 18.0 to 31.6 mm over the course of one year. Surf clams can tolerate a wide range environmental conditions and the general habitat characteristics are presented below.

Adults naturally occur in sandy or gravel substrates (Fay *et al.* 1983) with the variety of sediment types ranging from medium sand to fine sand and/or silty-fine sand (Cargnelli *et al.* 1999). Surf clams have been observed to dig themselves out of substrate, indicating it is an unacceptable environment (Goldberg and Walker 1990). Walker and Heffernan (1990) suggested that the literature on how sediment affects surf clam growth was contradictory. They concluded that the substrate type was not a determining factor and that production success was dependent on other environmental factors.

Salinity is not a significant factor in surf clam spawning and growth (Fay *et al.*1983). Fertilization of Atlantic surf clam eggs is optimal at 20 to 35 ppt salinity while adults thrive within that range but can tolerate a wider range of 14 to 50 ppt (Fay *et al.*1983).

Temperature is the most important determinant in predicting where surf clams will thrive. The consensus from the literature as well as from previous attempts to grow surf clams in the intertidal zone on Cape Cod indicate that the biggest obstacle for surf clam culture is warm temperature. The upper lethal temperature is stated to be from 26 to 28°C (Saila and Pratt 1973, Fay *et al.* 1983) and 30°C (Goldberg and Walker 1990) for adults. Surf clam populations have decreased in the more southern range, most likely resulting from increasing water temperatures. (Weinberg 2005). Optimal temperature range for surf clams burrowing is 16 - 22°C (Marzec *et al.* 2010). Juveniles grew faster at 20°C than 25°C (Goldberg *et al.* 1990,Walker *et al.* 1997), where 20°C is the range for New England sub-tidal waters. Cold temperature does not seem to pose a problem.

Shellfish seed have many predators, mostly various species of crabs, moon snails, starfish, whelks, birds and some fish. Moon snail predation could account for up to 20% of wild surf clam mortality and was higher where the natural set of surf clams was high. (Quijon *et al.* 2007, Weissberger 2003). The survival and distribution of surf clams is in part effected by predation (Quijon *et al.* 2007). There are a few reported pathogens and parasites for surf clams, including a nematode, *Sulcascaris sp.* and a protozoan, *Urosporidium spisul;* however, neither has been reported in the aquaculture research. (Cargnelli 1999). No definitive studies exist describing other diseases in *S. solidissima*.

Project Approach

The project leveraged previous research on surf clams and aquaculture techniques, resulting in a comprehensive, seven-phase approach to determine the best location and conditions to commercially grow out surf clam seed, and to prepare the market for this novel product.

The seven phases included:

1. Hatchery and Nursery Seed Production
2. Selection of Grow out Sites
3. Testing of Grow out Conditions & Monitoring
4. Grow out Site Maintenance
5. Evaluation & Data Analysis
6. Preliminary Market Analysis
7. Industry & Participant Workshops

Hatchery & Nursery Seed Production

In order to produce nursery seed for spring planting, conditioning and spawning activities occurred prior to the start of the grant period. These activities were expected to be straightforward and were not part of project goals. Based on previous studies and experience

with surf clams, it was thought that conditioning could be started in late fall, they would grow well through the winter, and be large enough (R3 or 4-6 mm) for field planting in May/June. However, we had unexpectedly cold weather Feb through June, resulting in negligible growth rates in the cooler months. They survived through the freezing weather, but had unexpectedly slow growth. Growth was so slow, we questioned if we had the southern subspecies instead of the northern subspecies. DNA testing confirmed that the surf clams were the northern variety, which should have better winter performance.

Brood stock was collected by Cape Cod Cooperative Extension (which was from seed stock produced by A.R.C. in 2015). Conditioning began on Oct 10, 2016 where they were kept at an average temperature of 18^{o}C. They were fed *Thalassiosira pseudanana* (3H), about 95% and *T. Isochrysis* (T.Iso), about 5%. After 52 days of conditioning, they spawned on Dec 2, 2016. Normal shellfish hatchery procedures were followed for the surf clam larval culture. The larvae were straight hinged on the following day, as expected, and algae feeding began. The conicals were drained every two days with routine culling to maintain a healthy culture at good growing densities. Survivals were high throughout the larval cycle. The average temperature for the 23 days of larval culture was 20.9^{o}C. The larvae were fed a mix of 3H and T.Iso., with increasing amounts based on the size and density of the culture. Metamorphosis began on day 18.

As the juveniles grew, they were moved into a downweller system which happened over 4 days, such that by day 24 (December 26, 2016), the surf clam juveniles were all in downweller units. This was a bit earlier than planned, as there was a lot of fouling on shells. Larvae were discarded along the way as normal procedure and some were discarded since more were produced than were necessary for the project. The downweller system is made up of 24" round fiberglass units with 210-micron screen on the bottom and a hole near the top for water to enter the unit from a trough. An airlift moved the water down through the units that held the seed on the screen. The tanks were drained daily and the animals were rinsed with saltwater, then refilled with seawater at a temperature of about 12^{o}C. Algae and seawater were added continuously for about 20 hours per day. At this point, they were fed exclusively 3H.

They were growing quickly and soon needed to be moved to the upwellers to allow for appropriate feeding. One group was moved out to the upwellers on February 15, 2017 at 75 days old with an average size of about 2 mm. The rest were moved out to the upwellers on March29, 2017 at about 3- 5 mm. Upwellers were supplied with ambient temperature seawater and there was no supplemental algae added. In total, 9.85 x 10^{6} surf clam seed moved outside, which is ~50% survival rate. Historically, hatchery survival rate has been 38-71%.

Growth was quite slow. The pH of the water fluctuated daily from 7.5 to 8.1 along with the tidal change, with the low pH at low tide. The temperature was unseasonably cold. To adjust for the slow growth in the upwellers, the seed was split into three groups in early May. One group was sent to project partner Dale Leavitt at Roger Williams University, to see if they would grow faster in the warmer Rhode Island waters. The second group was returned to inside the hatchery, to take advantage of hatchery-produced algae: the pH was constant 8 to 8.1 and the seed were fed 3H for about 20 hours a day. The third group remained outside in the upweller; these stunted

seed were eventually sent to Rhode Island on July 23 to finish grow out so the seed could be made available for planting.

Selection of Grow Out Sites

The project team identified several individual shellfish farms as experimental sites for surf clam grow out monitoring. The sites were evaluated for their water depth, sediment type, water temperature, and tidal exposure, to ensure we included a range of environmental conditions necessary to allow for comparison between sites. In each area, appropriate growers were identified that had previous success, were dedicated to following best practices, and willing to host the monitoring team.

Figure 1: Sites Considered for Field Trials summarizes the field trial sites which were considered and discussed with growers in each area:

Site	Tidal	Sediment	Temp	Grower
Wellfleet –Cape Cod Bay	Low intertidal	Sand	Dynamic	Already has surf clam experience
Truro or Provincetown - Cape Cod Bay	Deep water	Highly mobile sand	Cold	n/a (was not selected)
Cotuit – Cotuit Bay	Shallow subtidal, 1-3ft at low tide	Sand with silt	Warm	Participating town propagation site
Cotuit – Nantucket Sound	subtidal, 3-5ft at low tide	Sand	Cool	Established grower
Barnstable Harbor - Cape Cod Bay	Intertidal	Dynamic sand	Cool	Grower who tried surf clams 10 years ago

Figure 1: Sites Considered for Field Trials

Four active shellfish farms in Massachusetts were ultimately selected and confirmed to participate in the experimental deployment of surf clams (Figure 2).

Site	Tidal	Sediment	Temp	Grower
Wellfleet –Cape Cod Bay	Low intertidal	Sand	Dynamic	Jim O'Connell
Cotuit – Cotuit Bay	Shallow subtidal, 1-3ft at low tide	Sand with silt	Warm	Barnstable Little River Town Site
Cotuit – Nantucket Sound	subtidal, 3-5ft at low tide	Sand	Cool	Conrad Geyser
Barnstable Harbor - Cape Cod Bay	Intertidal	Dynamic sand	Cool	Les & Jared Hemmila

Figure 2: Final Site Selections

Testing of Grow out Conditions & Monitoring

The Cape Cod Cooperative Extension team field planted the surf clam seed at the 4 Cape Cod sites. Roughly 35,000 seed were planted at each site, with at least 3 replicates of each grow out methodology or treatment.

Between July 11-14, R3 surf clams from A.R.C., ranging from 4.5 to 7.5mm were planted at each of the 4 Cape Cod sites. For each site's seed planting, 30 seed clams were randomly selected from the seed bag and shell length and width were measured (mm). They were placed into 2mm oyster bags at an initial stocking density of 4000/bag. Each bag was placed in a 6 bag (3 wide by 2 tall) PVC coated wire mesh oyster cage or condo which was secured on a long line or to the bottom with pins. The surface area of each bag is 3.5 square feet.

Between July 20-26, larger surf clams from the Rhode Island batch were tested for disease before being brought back to Cape Cod and field planted under 4mm nets at each of the 4 Cape Cod sites. Standardized quahog field plant aquaculture equipment and planting methods were used among all sites. Surf clams were field planted at each site at a stocking density of 35/sq. ft. (50/sq. ft. had been intended but a discrepancy in counts necessitated a reduction in stocking density). Each site was divided into 3 plots, with the size of 100 square feet. The nets were made of Tenax mesh (4mm laid over 10mm) and secured with rebar U-hooks.

In late August or early September surf clam seed at a size of 5-6mm was redistributed in 2mm oyster bags after grading in an off-bottom 2 tier rack set at a densities of 2500/4000/6000 per bag, and later switching to 6mm bags as they grew further. In late August or early September, the clams that reached 9-10mm after grading from the 2mm bags, about half of the clams, or 28,800 seed, were removed from the oyster bags and placed into 3 replicate soft 4mm Florida bags, at an initial density of 9600/bag.

In early August, each site was sampled for growth and survival of the small seed in the oyster bags. Live vs dead were counted from random subsamples from each of 6 bags to calculate survival. 5 clams from each of 6 bags from one cage were collected for measuring of valve length/width/height.

In late August, each site was sampled for growth and survival of the larger seed planted under the field nets. Several 4" diameter cores were taken from the substrate under each net to retrieve samples, to a depth of 6". Cores were haphazardly repeated in each plot until a total of 100 live clams were collected or until the area had been sufficiently sampled (60 clams for low density). The cores were sieved on a 2mm sieve to retrieve clams. Each live clam and empty paired valves were measured for valve length/width/height and used to estimate percent survival.

Net condition and movement was also recorded, along with temperature and predator presence.

Most of the sample surf clams were too small to adequately measure weight and condition index. The one exception was the larger seed planted under nets which was about an inch when sampled through cores; condition index was measured on these. As the clams reached at least one inch on the other experimental plots, we measured condition index.

In addition, a sediment sample was taken from each site in September. These samples were stored frozen until they could be analyzed by the lab at Roger Williams University (RWU).

Monitoring at all sites continued in September, October and November, and through the winter at one of the sites (Barnstable). Monitoring includes sampling each site for growth. For each treatment (i.e., cage vs. net) at each site on each field sampling day, 15 to 36 clams were measured (sample size depended on clam size): length, width, height. Additionally, they were weighed; when small seed, they were weighed in small groups (6-8 clams each) to calculate average weights (they are too small to measure individually in the field). Net condition and movement was also recorded, along with temperature and predator presence. Condition index was measured as dry weight of the tissues divided by clam length on all clams over 1" in length.

In November 2017, a second bottom plant was added at each site with the remaining seed. These nets were small 5' by 5' nets planted at 50/sq. ft. such that 1250 seed were planted under each net with 3 replicates at each site. These clams were redistributed from the FL bag treatments ant were 10-12mm at the time of planting. The FL bags were wintered minus the seed moved to the smaller planted nets.

Over the winter months, growth was expected to be negligible and disturbing the clams to measure them creates unnecessary stress and/or mortality that would not be experienced during grow out on a commercial shellfish farm. Monitoring and maintenance at all 4 sites resumed in April 2018. The clam densities were adjusted for the second season, according to Figure 3. Additionally, before winter, in November of 2017 all off-bottom bags were pinned to the bottom to allow for sanding in and to reduce structure that could suffer catastrophic loss due to ice.

Gear	Mesh Size	Stocking Density
Bottom Plant	10mm	35 /sq. ft.
Oyster Bags	9mm square	225 /bag (50/ sq.ft) 335 /bag 450 /bag
Florida Bags	½ inch (12mm)	800 /bag 50 /sq. ft.

Figure 3: Second Season Stocking Densities

The clams were then sampled monthly though October for growth (measuring length, width, height, and weight) during the 2018 season. Survival measurements were conducted at longer

intervals in order to reduce sampling-induced mortality, since we needed the clams for marketing work. In October 2018, each site was sampled a final time for growth and survival.

For each bag on each sampling day, a haphazard subsample was taken to measure survival. The number dead and the number alive for each bag was recorded. There are 160 records for Oyster Bags and 45 records for Florida Bags across all field sites. For each net on each sampling day, cores were taken from under the net (Figure 4). The number dead and the number alive for each core was recorded (Figure 5). The number of cores sampled was dependent on clam size and overall density (the larger and fewer the clams, the fewer cores taken).

Location	Number of Cores
Barnstable	232
Wellfleet	227
Cotuit	185
Nantucket	160

Figure 4: Total number of cores sampled

Location	Total Number of Samples	Sampling Period
Barnstable	1423	8/8/2017 - 10/5/2018
Wellfleet	1372	8/10/2017 - 9/28/2018
Cotuit	1498	8/9/2017 -12/18/2018
Nantucket	1445	8/9/2017 - 10/31/2018

Figure 5: Total number of clams measured in the field for growth

Environmental Data Collection

Tidal exposure was checked in a single 2 week period at the 2 intertidal sites, substrate was analyzed twice at each site, and periodic spot checks were done at monthly sampling events where salinity, and dissolved oxygen recordings were also collected at each site. Sediment was analyzed for grain size and organic content. This environmental data was compared to survival and growth to determine trends and identify best growing practices.

Tidal exposure data was collected, at the minute resolution for the intertidal sites. Wellfleet has 21,686 data records. Barnstable has 12,778 data records.

Temperature data was collected via HOBO data loggers for each site during the field season, in 15 minute increments. The final data set includes:

Barnstable data
7/14/2017- 11/3/2017 (10,750 records)
11/1/2017 – 6/29/2018 (23,023 records)
6/29/2018 – 12/19/2018 (16,648 records)

Cotuit data
7/21/2017 – 11/7/2017 (10,514 records)

11/7/2017 -8/28/2018 (28,245 records)
8/22/18 – 12/18/2018 (11,340 records)

Nantucket data
7/25/2017 – 12/6/2017 (12,897 records)
8/23/2018 - 11/1/2018 (6,718 records)

Wellfleet data
7/12/2017 – 11/8/2017 (11,435 records)
11/8/2017- 7/13/2018 (23,732 records)
7/13/2018 – 10/11/2018 (8,654 records)

Substrate organic content was measured twice at each site (once per year), with three replicates for each sampling occurrence. Organic content was determined by measuring the weight loss after ashing the sample at 500°C. The replicates were then averaged.

Sand profiles were measured twice at each site (once per year) using standard sand profiling shaker sieves and separating fractions by weight. Fines were first through a #200 sieve (particles <0.074mm) and different in dry weight determined. The remaining dried sample was then used in shaker with following sieves: 72 OPN (1.83mm), 40 OPN (1mm), 20 OPN (0.5mm), 09 OPN (0.229mm), and 046 OPN (.1168mm). Each fraction determined by weight to a percent of the total sample weight.

Grow out Site Maintenance

Participating site operators are able to regularly check on conditions of gear and report back on any concerns and perform gear maintenance. Any important observations were recorded by extension staff in a logbook. 2mm oyster type bags were brushed and flipped every 2 weeks until upgrading to new bags. When predators such as crabs, whelk, or moon snails were seen in the surf clam planting area they were removed from the site.

As the seed grew, they were sized and, as appropriate, moved into treatments of bottom planting for the larger seed or standard sized mesh oyster bags and Florida style bags. The clams in the 6mm oyster bags and 8mm FL bags had not reached the ideal 14-18mm by November of 2017, but a subsample from the 8mm FL bags was bottom planted at 50 seed per square foot using traditional hard clam protocols to diversify the overwintering strategy.

Maintenance activities were curtailed for the winter months. It is standard aquaculture operations to secure shellfish for the winter and disturb them as little as possible until the weather improves. Exposing clams to frigid temperatures can increase stress and mortality unnecessarily. With the threat of damaging winter ice, all clams in oyster bags were removed from the cages and clipped to longlines spread across the bottom for lower profile wintering.

Given initial results of stunted clams in the off-bottom treatments, all bags were pinned on the bottom during the second season. In September and October, at the sites where the clams have

stagnant growth in the FL bags, the sub-legal clams were transferred to oyster bags or bottom planted in an attempt to produce legal-sized product in time for the market sampling.

Evaluation & Data Analysis

Results in terms of growth were analyzed descriptively, taking mean length for each time period and treatment and plotting that in a time series for comparison within individual sites. Survival was calculated as a percentage from counts of live and dead animals after periods of specific interest: following summer deployment in nursery gear in summer 2017, through initial grow out in fall of 2017, after the winter of 2017-18, and then finally following the final season of grow out in 2018.

Yield by site characteristics was also quantified to provide a summary metric across the sites that accounts for both survival and growth rate, and to help growers with business planning.

Ultimately, we did not follow the expected analysis in the grant proposal of multiple linear regression associated growth with environmental variables as we did not have robust enough environmental data to complete that analysis with spot samples.

Project partners held a workshop with the growers that hosted the study sites, to review initial results, incorporate their ideas and feedback into the final analysis and industry workshop content. It was through feedback in meetings like these we learned that descriptive statistics and visualizing the results were most important to industry members, along with general "lessons learned."

Lessons learned and caveats were summarized and shared with the industry, as described in the Outreach section.

Project partners continued to collect anecdotal growth and survival information from the growers after the field studies were completed.

Preliminary Market Analysis

Marketing efforts started ahead of schedule, to take advantage of surf clams (aka "butter clams") on the Cooperative Extension's grant that were planted for a previous project and were legal sized for sampling in spring 2017. The project partners expanded their marketing capacity by hosting a project for the University of Massachusetts Boston Innovation Clinic, which provided three undergrad seniors, 4 PhDs and the course instructor. With their help, CCCFA developed a chef survey on shellfish and butter clams to gauge market potential. We had hoped to do a formal event with chefs, but the chefs' preference, for scheduling reasons, was to taste them on their own schedule instead of attending an event. We distributed this survey (Appendix 6) to 18 chefs from Boston and Cape Cod, along with 80 dozen butter clams for sampling (average sample size per chef was 4 dozen). Seven chefs completed and returned the survey but all 18 provided verbal feedback. Chef feedback guided the development of a one page butter clam fact sheet and story (Appendix 5), to be used for future promotions.

Additionally, we handed out butter clam samples and fact sheets to several dozen people during a public seafood event in April 2018 at the Boston Public Market. The quantities were limited to less than 700 clams due to availability of legal sized butter clams at the time of the event.

Cape Cod Cooperative Extension completed an analysis of surf clams at various sizes to build a length weight relationship table, to calculate how many clams of a certain size are in pound (Appendix 8). This was essential for discussing surf clams with chefs and comparing to similar shellfish, as most buy pasta and Manilla clams by the pound.

A small portion of the clams planted in summer 2017 were legal sized and ready to harvest during the first quarter of 2018. Harvesting in January and March was delayed due to coastal storm-related shellfish closures (https://www.mass.gov/doc/030118-coast-wide-shellfish-closure/download and https://www.mass.gov/files/documents/2018/01/05/State%20winter%20storm%201-5-18.pdf). The supply of legal sized clams for additional sampling in was limited, as the Barnstable intertidal sites experienced extreme freezing temperature in late December 2017/early January 2018 that killed one third of the planted clams due to two weeks of water averaging 29°F and exposure to temperatures as low as 20°F (Figure 20). Unfortunately, it was these bottom planted clams that had the fastest growth rate; the remaining clams that survived were much smaller and not ready to sample.

The project had enough legal sized clams in the spring of 2018 to provided two separate samples of 12 dozen each to a national seafood company, Oceans 97, which is interested in creating a value-added product with the new clams. Oceans 97 is known for creating ready to eat frozen seafood meals featuring Gulf of Mexico shrimp, widely available through Walmart and other grocery outlets. Their most recent offering is a canned shrimp pate. The company's owner is former New England Patriot's player Jarvis Green, who is very interested in expanding the Louisiana-based company to include northeast seafood. The company remains interested but is waiting for adequate supply of surf clams.

In early August 2018, harvesting was again restricted due to a rainfall event shellfish closure (https://www.mass.gov/doc/080518-oc-2-10-ccb-1-14-rainfall-closure-notice/download). During and following the closure, another weather-related mortality event occurred at the Wellfleet intertidal site due to extremely warm weather (Figure 21) where water temperatures averages greater than 80°F and at low tide, the clams were exposed to >90°F temperatures. This killed half of the experimental surf clams at the Wellfleet site. Again, it was these bottom planted clams that had the fastest growth rate; the remaining clams that survived were much smaller and not large enough to legally harvest for promotional sampling.

The majority of the remaining surf clams were of legal size in the fall of 2018 and ready for market sampling. These clams were located in the southern subtidal sites, which were subject to rainfall event shellfish closures in early October (https://www.mass.gov/doc/101118-gosnold-cape-cod-nantucket-sound-nantucket-and-marthas-vineyard-rainfall-closure-notice/download).

In October 2018, butter clams made their debut at the Wellfleet Oyster Festival, as one of three alternative shellfish species featured in a cooking demonstration and taste testing. An optional survey was distributed to the 50 demonstration attendees and 22 completed the survey. Prior to the demonstration, the chef was provided butter clam samples to develop recipes.

A.R.C. drafted a market survey and lined up several restaurants to receive a free sample of surf clams, to occur in mid-December 2018, in exchange for filling out the project's marketing survey. The remaining legal sized project clams were dug up before the freezing weather and put into wet storage for this sample/survey effort. A series of unforeseen events prevented the market sample/survey from being accomplished:

- At the last minute, the restaurants wanted to wait until after the holidays, when they had time to provide more attention to the new clams.
- We agreed and the clams were put into A.R.C.'s salt pond, which would have resulted in better survival than wet storage while we waited for the holidays to pass.
- The wall to the salt pond was unexpectedly breached, likely due to a nor'easter storm, causing it to drain, and the exposed clams froze to death.
- We tried to source other surf clams to use for the market samples (even buying them at an additional cost to A.R.C.), but there were none available.

As a result, the project received a no cost extension to have another year to secure legal surf clam samples and complete the marketing work. At their own expense, A.R.C. planted additional large surf clam seed in spring 2019, with the intent to harvest it in early fall and conduct the sampling and surveys at that time. While initially the clams grew well over the summer, they ultimately were not of legal size before the project period ended on Feb 27, 2020. Consequently, A.R.C. was unable to legally harvest the clams and use them for the market analysis survey and promotion work. A.R.C. tried to secure legal surf clams from some of the growers that had also planted seed in 2018 and 2019, but none had legal sized clams available before the project period ended. The additional survey and promotion work was not completed before the grant ended. In preparation for the sampling and survey work, A.R.C. did talk to most of their wholesale clients and many restaurants about butter clams and laid the groundwork for future sales once butter clams supply is available. A.R.C. discussed butter clams with 10 of its wholesale customers and all but 1 expressed interest in selling surf clams (90% interest). Most were interested in selling them once a market was created and once a reliable supply was created, so A.R.C. decided to work exclusively with 2 of its distributors to test marketability. They are prepared to actively market surf clams to their customers. Additionally, 4 chefs/restaurants were identified who expressed interest in testing surf clams in their restaurants when available. The restaurants are in Detroit, Washington D.C., New Jersey and Boston. All agreed to fill out surveys before (to ascertain perception) and after testing and share comments and ideas in exchange for a limited supply of free surf clams.

However, despite the close of the SK grant period, A.R.C. is committed to continuing to promote surf clams and will complete the sampling and survey work once legal sized clams are available. As of August 15, 2020, the surviving surf clams on A.R.C.'s grant are just shy of a legal 1.5."

A.R.C. was an exhibiter at January 2019 Northeast Aquaculture Conference and Exposition (550+ attendees) and included surf clam information as part of the display to educate conference attendees, including wholesalers and shellfish sales teams. Additionally, the project results were presented during the scheduled NACE program.

A.R.C. attended the Seafood Expo North East (SENA) in Boston in March 2019. At A.R.C. booth, staff spoke with U.S. and international buyers about their interest in surf clams.

The A.R.C. president spoke with 60-75 of A.R.C.'s seed customers about surf clams as part of the 1st Annual Grower's Open House in October, 2019

All butter clams planted by the SK project that survived to legal size were harvested for taste testing and promotional samples. Unexpected mortality events and slow growth severely limited the amount of clams available for sampling.

After initial planning for how to update the SEMAC market survey, and evaluating project resources, our project team determined that we needed additional funds to properly complete a truly useful and updated market survey/assessment. Cape Cod Cooperative Extension and Cape Cod Commercial Fishermen's Alliance partnered on a separate but complimentary project in 2018 with the non-profit Wellfleet Shellfish Promotion and Tasting to secure NOAA Sea Grant funds (award number NA17OAR4170240). This additional award allowed us to assemble an industry working group of shellfishermen, wholesalers, and retailers to provide guidance and hire expert consultants to advance marketing efforts. This Sea Grant project hired an expert consultant, Pentallect, to more thoroughly complete an updated market assessment on alternative shellfish species, including surf clams. The resulting 30 page market assessment is included in Appendix 9. Additional information on the Sea Grant project activities is included later in this report.

A.R.C. worked with DMF to secure the required permits for 1.5" cultured surf clams. In 2017, the state of Massachusetts made it legal for aquaculture reared surf clams to be harvested at a minimum size of 1.5" (322 CMR 6.08 (3)(c)(3)) and amended A.R.C.'s propagation permit to include surf clam seed. This regulatory change created a new aquaculture product, as wild harvest surf clam are still required to be at least 5" at harvest.

All findings from our marketing efforts, the Sea Grant market assessment, and field trials were incorporated into an enterprise budget excel worksheet that was made available to the growers to help them with their business planning for surf clams. The enterprise budget excel spreadsheet is included as a separate attachment to this report, to preserve functionality (Appendix 3b).

We introduced and promoted the novel surf clams to the general public through three opportunities:

1. August 2017: Radio interview on butter clams with National Public Radio WCAI's "Local Food Report."

2. April 2018, Boston Public Market Sampling Event.

3. October 2018: Public cooking demonstration and sampling of butter clams at the Wellfleet Oysterfest "Clam Slam Cooking Demonstration" with Chef Mark Orfaly of the Reelhouse (40+ attendees, 22 completed survey).

Industry & Participant Workshops/Outreach

In February 2019 we held a formal in-person meeting among A.R.C. Hatchery staff, extension agents and growers to discuss the field trial results and determine where the production technology can be refined, as well as how to best coordinate hatchery seed production to optimize grow out efforts. Additional analysis that the growers wanted to see as a result of the conversation were included in the final grower workshop and outreach materials

Workshops:

1. February 2018: Cape Cod Cooperative Extension presented the goals and proposed methods of the project to the Massachusetts Aquaculture Association members. This was followed by a discussion with the members regarding the potential of butter clams. This occurred during an hour of their all day Annual Meeting in Woods Hole, MA (60 attendees, mostly shellfish growers from around the state).

2. January 2019: Northeast Aquaculture Conference and Exposition in Boston (50+ attendees: shellfish growers from around the New England region, aquaculture industry, academics). Included a presentation of results by Cape Cod Cooperative Extension and subsequent discussion period with attendees. Slides are including in Appendix 2.

3. April 2019: Cape Cod Grower Workshop. Cape Cod Cooperative Extension, A.R.C. Hatchery, Roger Williams University and Cape Cod Commercial Fishermen's Alliance hosted a three hour surf clam project workshop with 33 shellfishermen from 12 towns and two states (MA & RI) in attendance plus one researcher, one volunteer, and one recreational harvester (see Appendix 11 for participant list). The workshop included presentations by project partners and robust discussions. The outreach materials were provided to the industry in paper and electronic form; these are included in Appendix 3. The workshop covered history of growing efforts, results from the project, lesson learned, caveats, yield calculations for business planning (enterprise budget), preliminary market feedback, suggestions on pricing (from a separate alternative species market assessment done by Woods Hole Sea Grant in conjunction with our project), and seed availability.

There were 7 others who registered for the workshop but were unable to attend; they also received an email with all workshop materials.

Other:

1. January 2019: A.R.C. Hatchery staff hosted an exhibitor booth at the Northeast Aquaculture Conference and Exposition in Boston, providing information about surf clams to over 550 attendees.

2. A.R.C. reached out through its electronic newsletter to all its customers to advertise the availability of surf clam seed for sale in 2019 and 2020. At their own cost (outside of this project), they spawned four million surf clams in early 2019 and seed was made available for sale at a range of sizes: (R1.5, R2, R3, R4, R6, and field plant). A.R.C. sold 275,000 surf clam seeds. Unsold seed was supposed to be planted on A.R.C.'s farms to provide additional marketing samples and supply in 2020, but more than 80% of them (2,980,000) were killed due to a tornado in July 23 2019. This highly unusual event (the last Cape Cod tornado was in 1977) caused widespread power outages for over 24 hours, which stopped the pumps and the water flow in the upwellers. A.R.C. had recently expanded from one nursery location to three, and did not yet have a generator at the nursery with the surf clams. Only 745,000 seed survived to be planted, which will potentially result in at least 300,000 clams for sampling and sales in late summer 2020/early spring 2021. A.R.C. spawned another four million surf clams for the 2020 season and, despite COVID-19, projects robust sales. Any seed that isn't sold will be planted on A.R.C.'s shellfish farm.

3. An article about the project results was published in the aquaculture industry publication Aquaculture North America, March-April 2019 issue with title: "Study: Surf clam aquaculture has commercial potential." It is included in Appendix 4 or available online at https://mydigitalpublication.com/publication/?m=53591&i=569516&p=20

4. The results of the field studies were written up by project partners in a January 2020 Sea Grant Marine Bulletin, as an additional resource for growers (included in Appendix 1). This pamphlet will remain widely available through the Sea Grant network and online at the County Cooperative Extension/Sea Grant website (https://seagrant.whoi.edu/regional-topics/aquaculture-fisheries/). It was updated in August 2020 to reflect additional findings from follow up work. Targeted distribution of the marine bulletin will continue throughout 2020.

5. All of the findings on surf clams has been incorporated into the Roger Williams University Applied Shellfish Farming course curriculum, in the session on growing alternative clam species. The course's power point slides that covered the surf clam discussion are included in Appendix 7. The in-class narrative by project partner Dale Leavitt was more extensive than the slide materials. Prior to the shutdown caused by the COVID 19 pandemic, there were 15 students taking the course in person and another 50+ students registered for the online course for 2020. Dr. Leavitt will continue to include the surf clam information in future courses.

6. The Cape Cod Cooperative Extension offers a biannual Fundamentals of Shellfish Farming 8 week course for new or aspiring growers. They will incorporate the project findings into the course materials, including best growing practices, the enterprise budget, and marketing materials.

Project Management

The following A.R.C. Hatchery staff and project partners managed and implemented the project:

Rob Doane, A.R.C. President & CEO, served as PI for the project through September 2019, and was responsible for high level oversight of the project. He left the organization in September 2019 and was replaced by Rick Sawyer, who took over as acting President and project PI.

Susan Machie (A.R.C.) managed the surf clam seed spawn and hatchery schedule.
Paul Wittenstein (A.R.C.) managed the seed once it moved outside to the upwellers.
Gail Hart (A.R.C.) managed initial marketing efforts until she left the organization in early 2018 and was replaced by Rick Sawyer. Rick developed promotional plans and surveys for sampling.

Cape Cod Cooperative Extension/Woods Hole Sea Grant staff managed the field trials, worked with the participating growers and completed all field work and data collection. They conducted the field trial statistical analysis and developed outreach materials to disseminate to commercial growers.

Melissa Sanderson (Cape Cod Commercial Fishermen's Alliance) assisted in marketing efforts, serving as project lead with the UMass Innovation Clinic and conducting the first round of chef samples. Melissa also organized and implemented project planning meetings, tracked project progress and managed SK grant reporting deliverables, and contributed to outreach efforts.

Dale Leavitt (Roger Williams University) provided shellfish research expertise, lent the project sampling equipment, conducted the soil analysis using RWU facilities, and provided an alternative (warmer) upweller to grow the seed to field plant size.

The following shellfish growers provided a field site for the experiment, personal expertise, and assistance in maintenance and monitoring: Jim O'Connell, Les and Jared Hemmila, Chris Gargioulo, Town of Barnstable Shellfish Department.

Project Results & Findings

Seed Production

The project demonstrates that commercial scale production of surf clam seed is viable and consistent.

19.6 x 10^6 surf clam juveniles were set and grew quickly inside the hatchery. In total, 9.85 x 10^6 were moved outside, which is ~50% survival rate. Historically, hatchery survival rate has been 38-71%.

Growth outside in the upweller was quite slow. The pH of the water fluctuated daily from 7.5 to 8.1 along with the tidal change, with the low pH at low tide. The temperature was unseasonably cold. The average temperatures were as follows:

Month	Recorded Monthly Average Temperature in 2017
April	10.9 °C
May	14.1 °C
June	18.1 °C
July	20.6 °C

Figure 6: Average 2017 Temperatures at A.R.C. Hatchery/Chase Garden Creek

In April, there was limited food available in the upwellers, likely due to colder water temperatures and increased cloud cover. Seed growth was not fast enough, so the seed were split into three groups as described in the Approach section. The seed grew well inside the hatchery and by July 304,000 R3 surf clams available for field planting.

The surf clam seed responded better to the warmer waters in Rhode Island. 100,000 slow growing surf clams were was sent from the A.R.C. outdoor upwellers to Rhode Island on July 23, 2017 and was ready to plant 9 weeks later, the week of 25 Sept.

Similar to other shellfish seed production, surf clams also require the hatchery to control or schedule to accommodate temperature and food availability. The timing of hatchery production will need to be refined to each individual hatchery business, to mesh well with the hatchery schedule for oyster and quahog production.

Surf clam juveniles did not prove to be as productive during winter temperatures as some historical trials suggested, although they were hearty and survived the winter temperatures. The slow growth observed during Feb-May may have been a result of uncontrollable environmental variables (temperature, algae availability) or may represent the need for a modified hatchery schedule where they are spawned later. In hindsight, the surf clams should have been spawned in January or February, so they would have been placed outside into the upwellers during more favorable weather. It is important to note that all varieties of shellfish seed, including oysters and quahogs, experienced delayed growth in the spring of 2017.

Field Trials

Surf clam growth, like most shellfish is highly dependent on the environment and food availability. The project demonstrated that a one year product is possible if surf clams are grown

under ideal conditions, where they can dig into the sediment and avoid extreme temperatures, while being contained and protected. Surf clams must be able to dig into the sand, even shallowly, in order to grow to legal size. If not able to dig, they usually would exhibit stunted their growth upon reaching 0.75-1" in length.

Overall Observations on Maintenance and Harvest of Clams

Bottom Planting/Nets:

Mounding sand on nets was an issue, exacerbated on nets with larger areas. Smaller nets had less mounding in dynamic locations. Clams had a tendency to accumulate at down-wind edge/corner of nets. Clams would move or wash away while the net was removed for maintenance. Predation was more likely with nets than the other gear types, largely due to the fact that the nets were not trenched along the sides where persistent predators could eventually find entry. Planting/maintaining subtidal nets was especially challenging. During harvest, traditional quahog type bull raking damaged up to 15% of clams. A hydraulic harvester proved most efficient, with less than 1% breakage.

Oyster Bags:

The 2mm mesh oyster bags had fouling problems. Growth was stunted/slower when the clams could not dig into the sediment, even if just shallowly. Smaller mesh bags seem to sand in better. Worked best pinned to ground in areas that sanded in naturally.

Florida Bags:

Crab and moon snail predation was possible through the soft FL bag mesh. Growth was stunted/slower when the clams could not dig into the sediment, even if just shallowly. Worked best pinned to ground in areas that sanded in naturally. Retrieving the FL bags could be difficult if too much sand inside (heavy and slow to clear the sand through the mesh).

Off-Bottom Culture:

Clam shells were fouled and misshapen when grown off-bottom. Clams left out of the sand for a season were observed with boring sponge and mud blisters.

Growth of Surf Clams

Surf clams showed inconsistent growth through the season; they do grow quickly in the more moderate temperatures of spring and fall, though growth may slow during the height of summer and dead of winter, with the fastest growth in the spring. Results indicate that a single season, even shorter than the single year expected, could be possible under ideal conditions that mimic wild surf clam natural habitat (high flow rates, sub-tidal, able to bury in coarse sand). If starting with larger seed (0.75"), a legal sized product was achieved in 5 months under ideal conditions.

In subtidal sites, the bottom planting technique consistently produced the fastest growth (Figure 7 & Figure 8), as other methods did not provide the clams the opportunity to dig into the sediment consistently and were subject to fouling.

In intertidal sites, the bottom planting technique initially produced the fastest growth at both sites; it continued to be faster in Wellfleet until the heat kill event (Figure 9). Bottom planting was also effective at the Barnstable site until exposure to extreme cold limited survival for the remainder of the trial. The oyster bags also produced similarly fast intertidal growth at the Barnstable Site **Error! Reference source not found.**Figure 10), likely due to the bags sanding in well.

Overall, at the subtidal sites, bottom planted clams grew the fastest of all the options, likely because of the ability to naturally dig into the sediment and limited gear fouling compared to the other methods (Figure 7).

Growing surf clams is like farming, and growers are subject to changing environmental conditions, extreme weather events, predation and disease. Anecdotal comments from growers in 2019-2020 indicate that surf clams may need a solid 1 to 2 years to reach legal size, depending on the site. Their slower growth in 2019 and 2020 is consistent with the slow growth experienced at the A.R.C. farm. The two seasons of field sampling, while an excellent start at quantifying growth rates, may not have been long enough to capture the impacts of environmental variability on the growth rates.

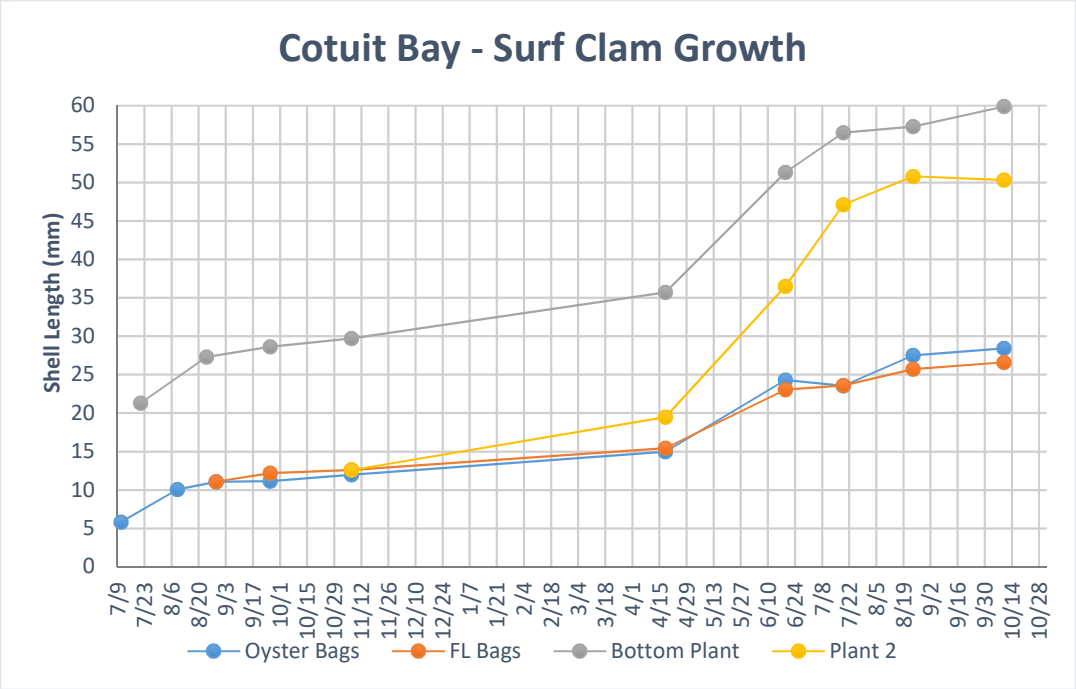

Figure 7: Surf Clam Growth at Subtidal Site in Cotuit Bay, July 2017 – October 2018.

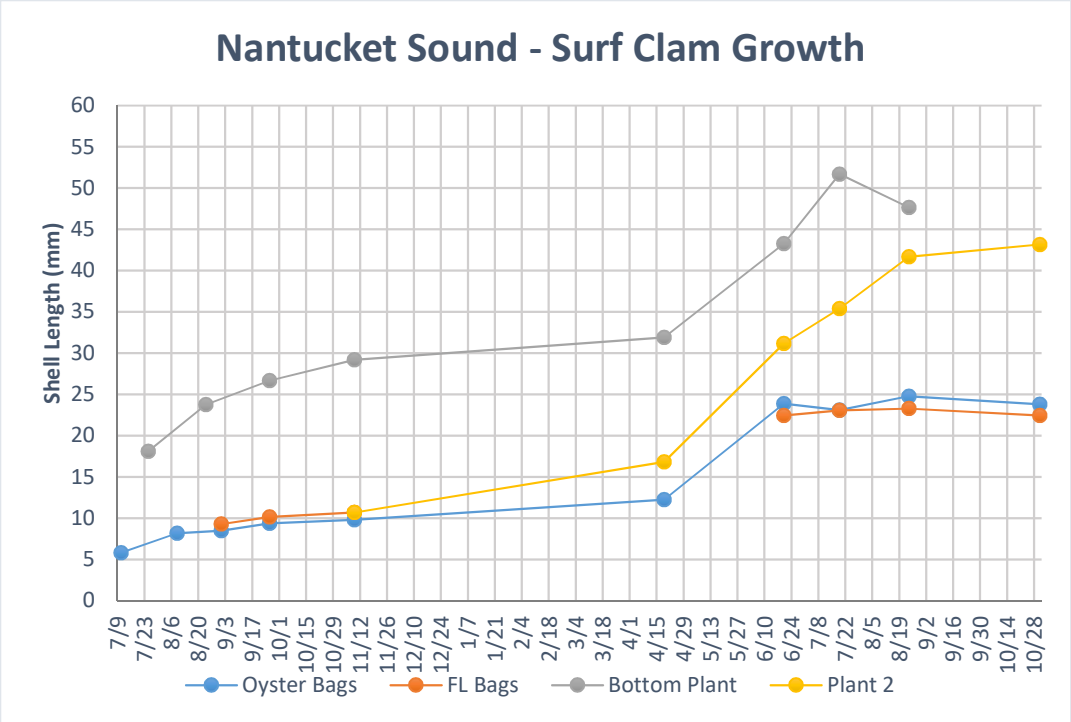

Figure 8: Surf Clam Growth at Subtidal Site in Nantucket Sound, July 2017 – October 2018.

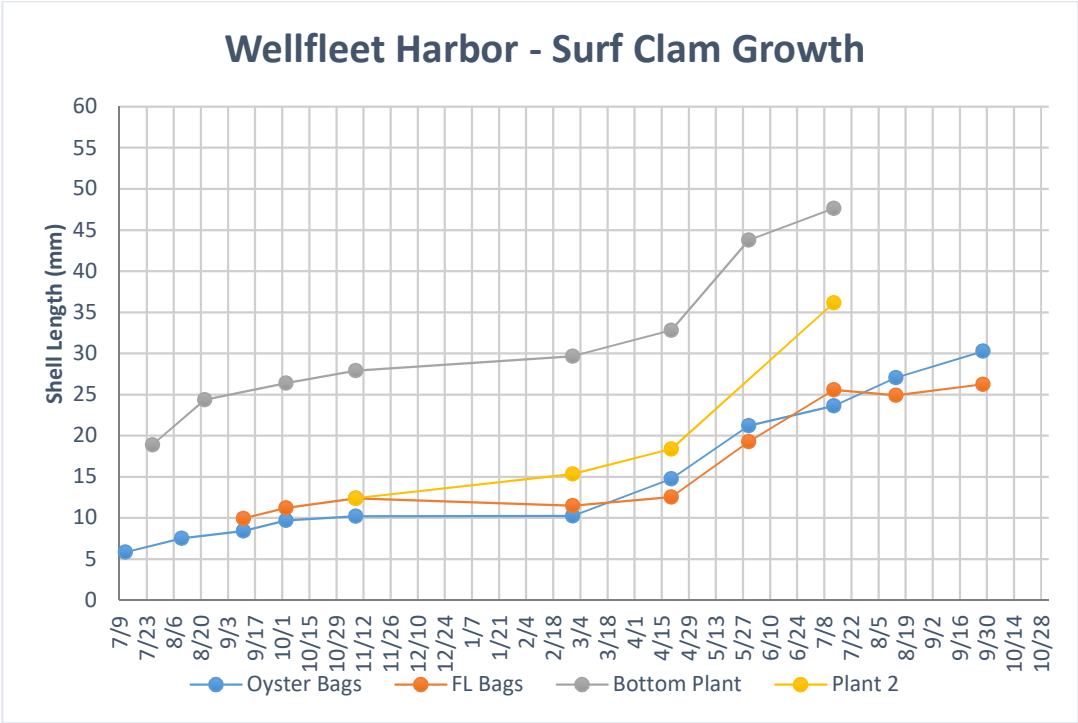

Figure 9: Surf Clam Growth at Intertidal Site in Wellfleet Harbor, July 2017 – October 2018.

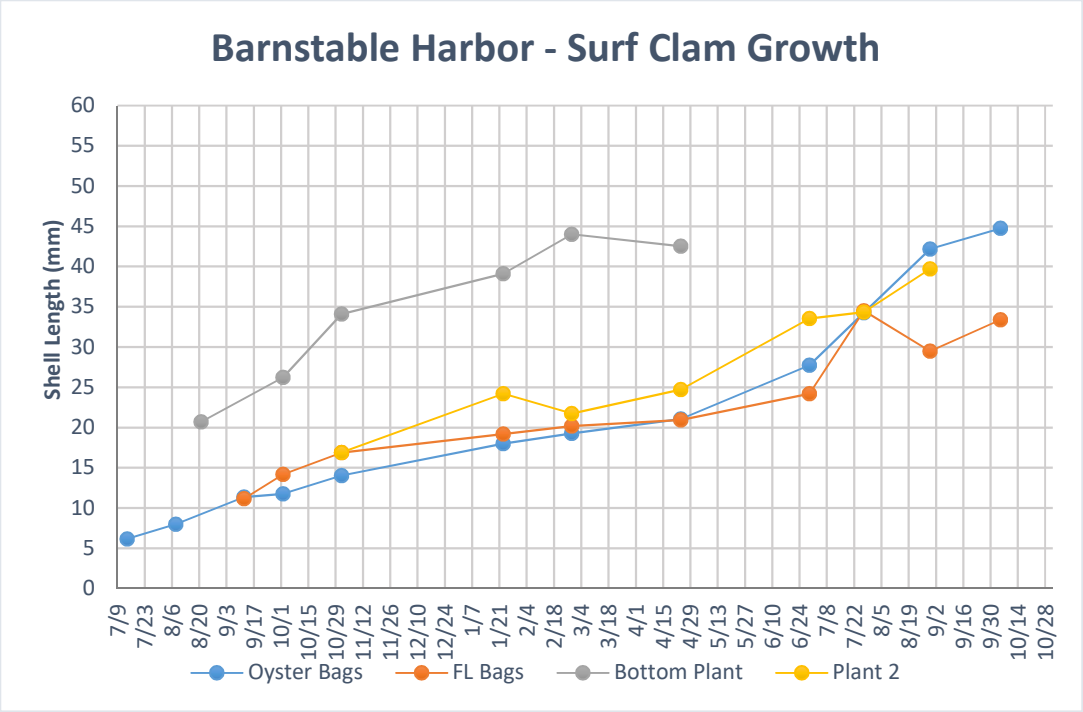

Figure 10: Surf Clam Growth at Intertidal Site in Barnstable Harbor, July 2017 – October 2018.

Survival of Surf Clams

Ultimately, survival is often more important than growth, since you can't sell a dead clam. There was a lot of predation observed in the bottom planted clams, as we took a minimalist approach to removing predators regularly. Bottom planting is difficult to maintain in subtidal sites and near impossible to trench nets (industry standard for intertidal planting) for adequate predator exclusion from the sides of the nets. Since we could not trench the nets subtidally we also did not trench them intertidally to keep methodologies uniform, and survival suffered. With the limited protection the bottom planted plots/nets had lower survival than the bags; highest survival was in the oysters bags pinned into the sand (Figure 11), likely do to the protection of the rigid mesh on all sides.

We did see high mortality at the Barnstable and Wellfleet sites. The initial higher mortality rates on the intertidal oyster bags were from the top tier of the off-bottom oyster cages during routine air exposure to summer heat. This summer heat intertidal exposure proved too much for the seed in the top tier but the seed just below in shaded bags did just fine. After analyzing the data and environmental variables related to subsequent mortality events, the overall acute mortality across all gear is likely due to extreme weather exposure at these two inter-tidal sites. One happened during a very hot, low-low tide summer day (Wellfleet) and the other corresponded to extreme cold and ice conditions during low tide (Barnstable). Additionally, nets were lost in Cotuit and Nantucket Sound due to ice or wind storms over the winter.

First Survival Measurement: Initial Post Deployment – Aug/Sept 2017				
Site	Oyster Bag, 2mm	FL Bag, 4mm	Bottom Plant 1, 10mm	Bottom Plant 2
Barnstable Harbor	86.1%	97.3%	53.5%	n/a
Cotuit Bay	99.6%	90.8%	86.2%	n/a
Nantucket Sound	94.7%	92.5%	73.7%	n/a
Wellfleet Harbor	40.9%	94.4%	92.6%	n/a
Second Survival Measurement: End of First Growing Season – Nov 2017				
Site	Oyster Bag, 6mm	FL Bag 4mm	Bottom Plant 1, 10mm	Bottom Plant 2
Barnstable Harbor	99.6%	97.1%	32.2%	n/a
Cotuit Bay	94.1%	90.4%	69.1%	n/a
Nantucket Sound	97.2%	63.5%	37.4%	n/a
Wellfleet Harbor	98.6%	94.7%	47.3%	n/a
Third Survival Measurement: Post Winter – April 2018				
Site	Oyster Bag, 6mm	FL Bag 4mm	Bottom Plant 1, 10mm	Bottom Plant 2, 10mm
Barnstable Harbor	4.0%	42.2%	0.0%	30.1%
Cotuit Bay	64.2%	30.0%	59.6%*	70.2%
Nantucket Sound	53.4%	0.0%	44.5%*	36.3%
Wellfleet Harbor	92.2%	41.9%	40.2%	86.6%
** Does not include lost nets which when added adjusts to 19.9% Cotuit and 14.9% Nantucket*				
Fourth Survival Measurement: End of Second Growing Season – Oct 2018				
Site	Oyster Bag, 9mm	FL Bag, 10mm	Bottom Plant 1, 10mm	Bottom Plant 2, 10mm
Barnstable Harbor	51.4%	51.7%	0.0%	0.0%
Cotuit Bay	47.9%	20.7%	39.9%	20.4%
Nantucket Sound	63.9%	42.8%	0.0%	16.2%
Wellfleet Harbor	4.4%	9.2%	0.0%	0.0%

Figure 11: Survival by Gear Type and Site at each survival assessment.

Ultimately, the best survival was in oyster bags in the sand (Figure 12).

Survival Ranges Across All Sites			
	Gear Type	**Lowest Survival**	**Highest Survival**
Season 1 (July – Nov 2017)			
	Oyster Bags	40% (high intertidal heat)	99%
	FL Bags	63% (damage, mounded)	97%
	Bottom Plant	0% (mounded or torn net)	75%
Winter (Dec 2017- April 2018)			
	Oyster Bags on bottom	4% (winter exposure)	92%

	FL Bags	0% (storm/winter damage)	42%
	Bottom Plant 1 (July 2017)	0% (winter kill)	60%
	Bottom Plant 2 (Dec 2017)	5% (storm/winter)	90%
Season 2 (May 2018-Nov 2018)			
	Oyster Bags on bottom	0% (heat kill)	70%
	FL Bags	9% (heat kill)	52%
	Bottom Plant 1 (July 2017)	0% (winter/heat/wind)	40%
	Bottom Plant 2 (Dec 2017)	0% (winter/heat)	40%

Figure 12: Average Survival Ranges Across All Sites, by Season.

Additionally, survival was impacted by stocking densities in the oyster bags. Figure 13 shows the summary of the density trial that was completed, to determine optimal number of clams per bag. Different from oysters, the surf clams actually had slightly higher survival with higher densities. Removing Wellfleet because of the extreme heat mortality event, survival was 62.5% at 450 clams per bag. However, growth rates did decrease with increasing density

Site	225 Clams/Bag	335 Clams/Bag	450 Clams/Bag
Barnstable Harbor	40.4%	53.6%	60.1%
Cotuit Bay	32.1%	54.6%	57.1%
Nantucket Sound	59.6%	61.8%	70.2%
Wellfleet Harbor	0.0%	5.2%	7.8%
AVERAGE	**33.0%**	**43.8%**	**48.9%**
AVERAGE WITHOUT WELLFLEET	**44.0%**	**56.7%**	**62.5%**

Figure 13: Oyster Bag Density Trial – Survival Results

In additional to basic growth and survival, additional analyses on yield calculations were completed (Figure 14). While growth decreased with density, higher densities produce better yields in areas that will let them sand in effectively.

Yield Calculations

	Oyster Bag - Density Trial				Bottom Plant
# clams planted	**225**	**335**	**450**		**50**
	per bag	per bag	per bag		per sq. ft.
Mean survival	40.4%	53.6%	60.1%		50.0%
Yield (#/clams)	91	180	270		25

Mean Length (mm)	46.9	44.7	42.4		50.8
Mean Length (in.)	1.85	1.76	1.67		2.00
Mean Weight (g)	19.92	15.65	13.82		21.9
Yield Weight (g)	1810.7	2810.1	3737.6		547.5
Yield (lbs)	3.99	6.20	8.24		1.21
Price per pound	$ 3.00	$ 3.00	$ 3.00		$ 3.00
Net harvest value (per bag)	$ 11.98	$ 18.59	$ 24.72		$ 3.62
Yield per sq. ft.	$ 2.99	$ 4.65	$ 6.18		$ 3.62

Figure 14: Yield Calculations on the most promising gear types, the oyster bag and bottom planting.

Environmental Conditions During Field Studies

The 4 sites had fairly similar sand profiles, mostly medium sand, with Barnstable having a bit more varied grain size (Figure 15 & Figure 16).

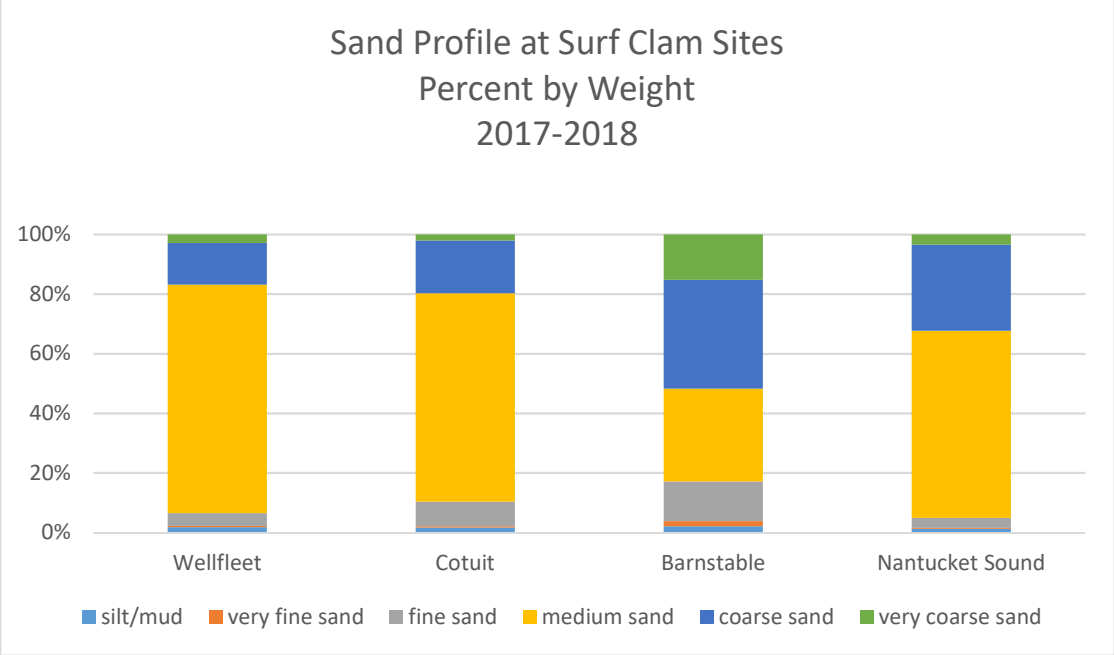

Figure 15: Graph of Sand Profile at Surf Clam Sites, percent by weight.

Site	Silt/Mud	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand
Wellfleet	1.7%	0.4%	4.2%	74.6%	13.6%	2.8%
Cotuit	1.7%	0.4%	8.2%	69.9%	17.7%	2.0%
Barnstable	2.1%	1.7%	13.3%	31.2%	36.4%	15.3%
Nantucket Sound	1.2%	0.3%	3.4%	62.8%	28.9%	3.4%

Figure 16: Percent by weight of sand profile at surf clam sites.

Wellfleet had the highest organic matter (0.462%), followed by Cotuit (0.429%), Barnstable (0.328%), and Nantucket Sound (0.230%) (Figure 17). It is uncertain to date what sediment characteristics indicate as to surf clam growth potential as clams effectively dug in and grew at all the sites. Temperature and predation issues seemed to be larger challenges than sediment type though we did not attempt grow out at a muddier site with higher organic matter. One factor which may be of consideration related to sediment at sites for surf clam grow out is how gear may sit in or catch sand for the clams to dig into. We found that in dynamic areas with more coarse sand (Barnstable and Nantucket Sound) had the greatest potential to natural catch sand in bags fixed to the bottom. These same sites also tended to have the biggest challenges with mounding sand in deployed nets, such that sediment mounding should be considered a potential challenge.

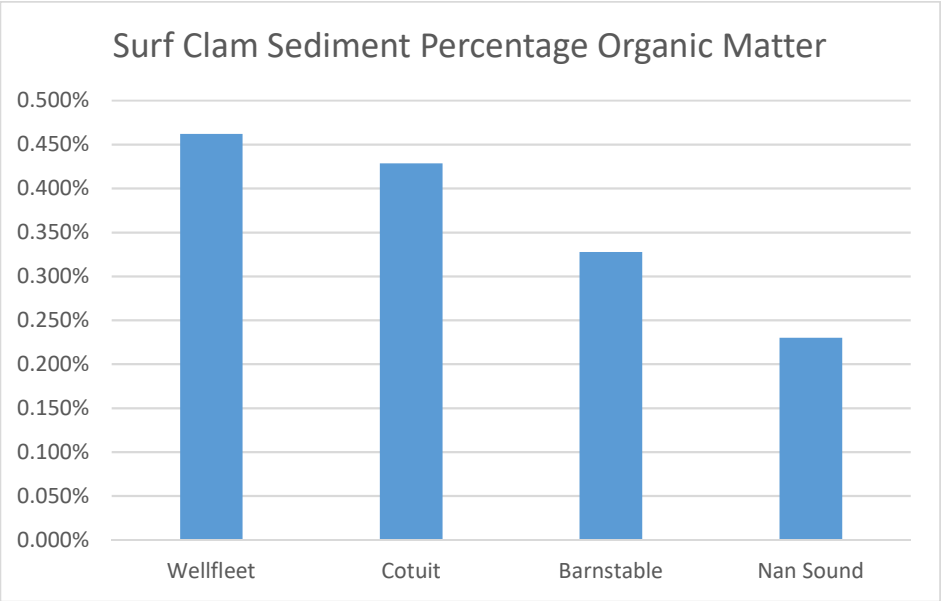

Figure 17: Organic Sediment Analysis at Surf Clam Sites, percent organic matter

The two intertidal sites had similar tidal ranges, with between 8 and 11 feet of water at high tide. Barnstable did have longer air exposure at low tide, with maximum water of around 1 foot although usually completely dry (Figure 18), compared to Wellfleet's 1-2 feet of water, with some days being completely dry (Figure 19).

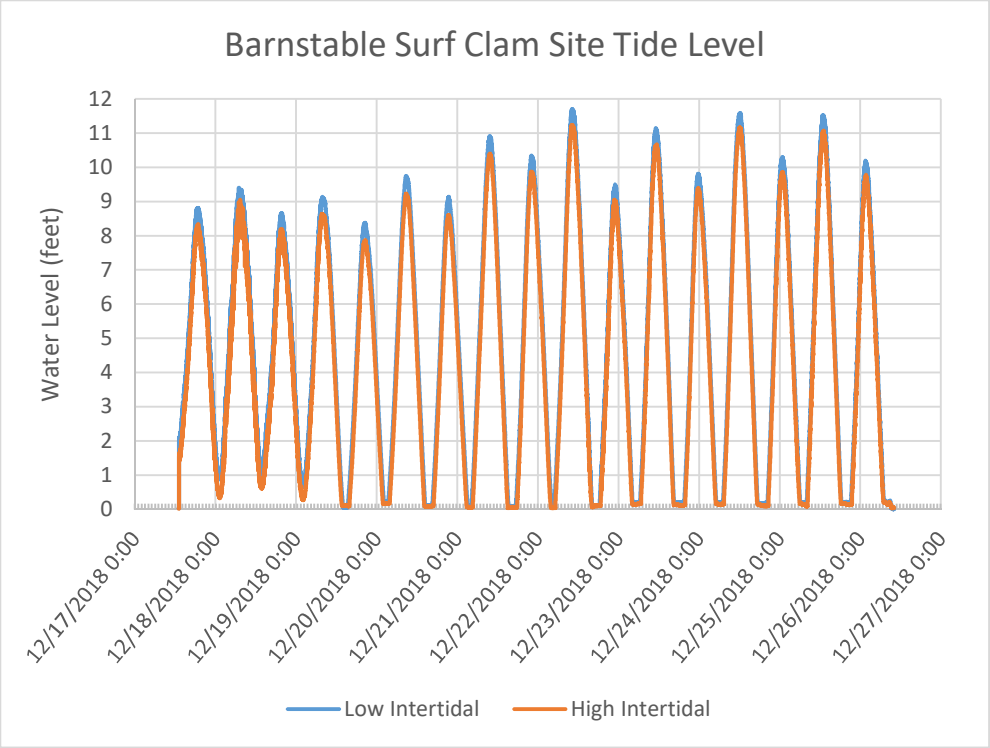

Figure 18: Water depth between 12/17/2018 and 12/27/2018 at the Barnstable Site

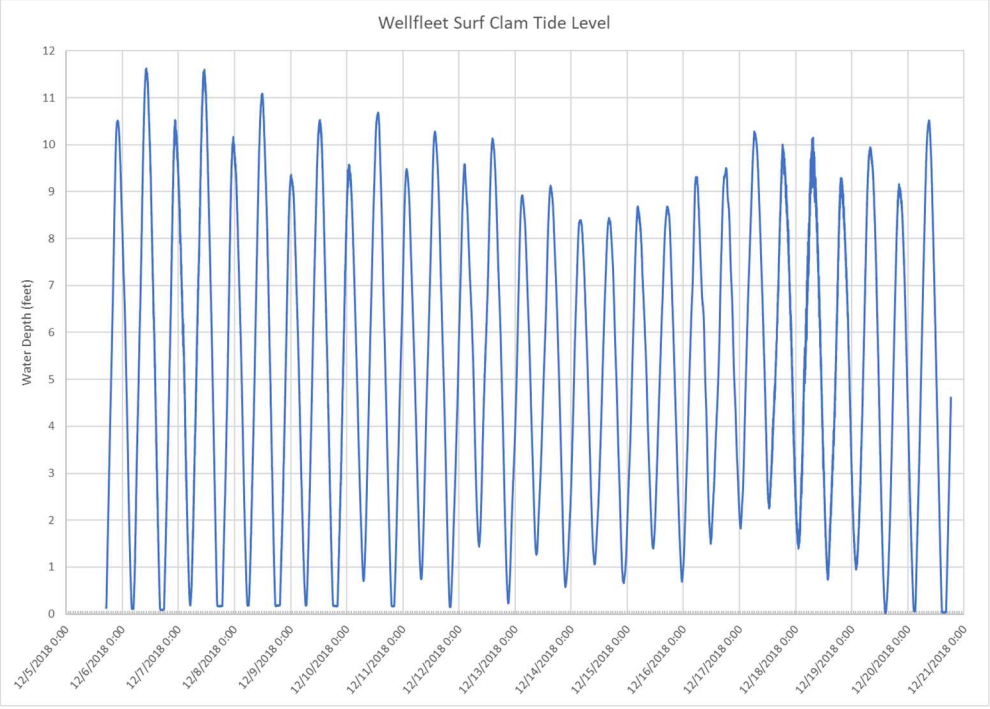

Figure 19: Water depth between 12/5/2018 and 12/21/2018 at the Wellfleet Site

Extreme temperature events were observed at the intertidal sites. The reported tolerance of surf clams is a low of 32°F and high of 86°F. In Barnstable, there was 2 weeks of water around

29°F and brief exposure to 20°F (Figure 20). In Wellfleet, the summer water temperatures on the site averaged above 80°F with brief exposure above 90°F (Figure 21). These extreme temperature events correlated with increased mortality at those sites. If exposure had been more brief or moderate due to lower intertidal deployment, results may have been better. In both temperature related mortality events, clams dug in the sediment were more likely to have survive than those out of the sediment. It would be interesting to compare southern surf clam (*S.s. similis*) survival to that of the stock used in this trial (*S.s. solidissima*).

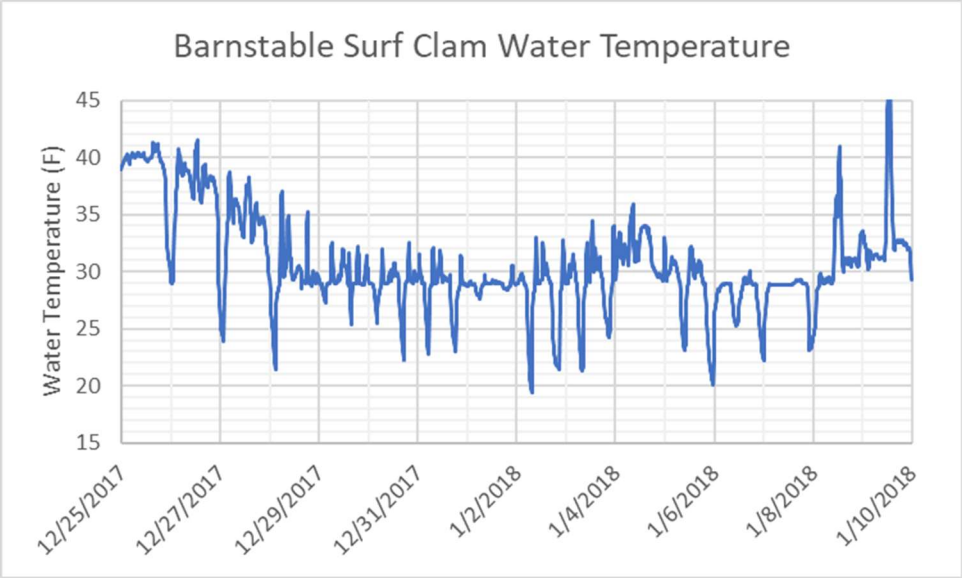

Figure 20: Extreme temperature events at the Barnstable site during winter 2017-2018, with a low of 19 °F on Jan 2, 2018.

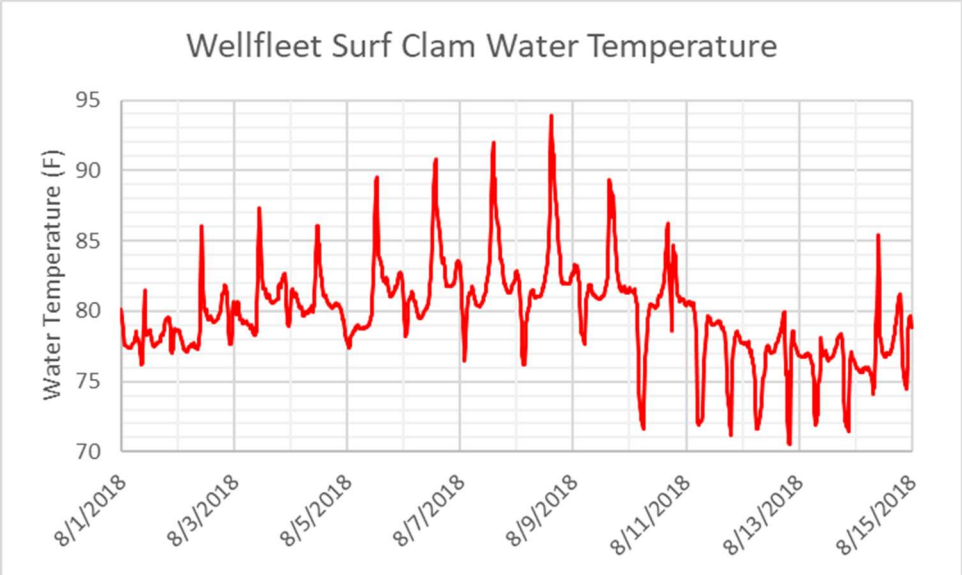

Figure 21: Extreme temperature events at the Wellfleet site during summer 2018, with a high of 94 °F on Aug 8, 2018.

Marketing of Surf Clams

Despite the limited availability of surf clams for sampling and promotional work, there was significant progress made in introducing the product to chefs and wholesalers, and preparing for marketing efforts once butter clams are available for sale. Chefs loved the new product and wanted to order it immediately; wholesalers were more bullish, wary of promotional efforts to create demand prior to having a consistent supply available.

Product Receptivity

Market potential for surf clams appears to be good and people do like to eat them. Chefs were overwhelmingly excited about butter clams and wanted to be able to buy them immediately (despite the disclaimer that came with the sample: "these are not available for sale until next summer at the earliest"). They are versatile and can be cooked and served like a steamer or like a quahog. Many chefs indicated that they would not just substitute surf clams for other shellfish on their menu, but instead create new applications specific to surf clams and promote this new, local seafood. Surf clams are delicious raw or cooked, briny, slightly sweet and very rich in flavor. The preferred size is under 2.5." We did determine that surf clams need to be purged before retail sale and consumption, to remove the sand.

Results from surveying public who tried the surf clam yielded glowing testimonials, such as:

- Loved the light but clean flavor.
- A taste of the sea. Tender, clean, delicious.
- Soooo good. Loved the size of surf clams served.

Surveyed chefs that tasted the butter clams described the flavor as:

- Buttery, complex ocean flavor, sweet
- Briny, slightly sweet, very rich
- Similar to a steamer
- Quahog light
- Salty, meaty, fatty

100% of the Oysterfest demonstration participants wanted to eat surf clams again. Despite not having the second round of samples for the planned promotion, several wholesale and restaurant customers of A.R.C. are interested in the new product and willing to try it once supply is available. Twenty of the 21 chefs who sampled the clams want to purchase them and put them on their menus. That demand alone would be more than the current supply of clams.

Our findings were documented and provided direction to the subsequent Woods Hole Sea Grant project, which then brought in a promotional consultant to develop a formal marketing and promotional plan for surf clams. We worked with the Sea Grant project to identify 57 chefs across the eastern seaboard that could help introduce surf clams to the dining public and 5 chefs that could be potential butter clam champions during the initial supply distribution (Zapalac 2019).

Product Pricing

Chefs participating in the first surf clams sample effort estimated that they would expect to pay prices similar to a littleneck quahog and more than a pasta clam, at a range of $0.18-0.38/piece. This range would result in a sale price to the grower of $0.10-0.25/piece. Additional market assessment work by the Cape Cod Cooperative Extension's alternative species project provided anecdotes that indicate growers could receive $0.18-0.50/piece (Pentallect 2018 and Zapalac 2019) and that as a niche product surf clams could command a high price. During the summer of 2020, the limited surf clams available were sold at $0.40/piece to the grower. Ultimately, consistency in supply will help stabilize the market and yield long term prices.

When compared to quahogs over two years, even at a lower sale price, surf clams have a similar profit margin given their faster growth, so a farmer can grow twice as many surf clams as quahogs in the same amount of time (Figure 22). The faster growth also decreases mortality risks from overwintering, natural disasters, or unusual disease events. With the anticipated higher price of at least $0.20 to the grower, the profit margin on surf clams is 5% higher than quahogs.

Financial Projections: Comparison of Quahogs and Surf Clams Over Two Years

	Quahogs	Surf Clams
Harvest cycle per 2 yr period	1	2
Seed planted per 2 yrs	100,000	200,000
Seed Cost	$3,500	$6,000
Gear Cost	$517	$775.50
Labor Cost	$2,540	$2,540
Total Costs	**$6,557**	**$9,315.50**
Survival Rate	50%	50%
Clams Sold over 2 yrs	50,000	100,000
Price per piece	$0.25	$0.20
Income	**$12,500**	**$20,000**
Return Over Expenses	**$5943**	**$10,685**
Profit Margin	**48%**	**53%**

Figure 22: Chart comparing potential profit on quahogs vs. surf clams over two years. 100,000 clams was used as an example for simplified math and extrapolation; it is not representative of normal business practices.

Our market assessment work was supplemented by additional findings from the Cape Cod Cooperative Extension's Woods Hole Sea Grant project. CCCE assimilated the field trials and market assessment findings into an enterprise budget worksheet that was made available to the growers to help them with their business planning for surf clams. The worksheet can be customized to the grower's business specifications. The example budget provided in Figure 23 is for bottom planting and assumes surf clam production costs will be similar to quahog production costs. It also uses the small starting amount of 100,000 seed clams; this is to make the math easy for growers to scale up according to their business size, or as a small crop to augment other crops grown. Even at the low end of the assumed sale price ($0.15), there is a 28.9% profit margin (including labor); at $0.25, the profit margin is 57.3%. The enterprise budget is an excel worksheet and will be included as an attachment to this report.

Surf Clams (butter clams)

Variable Costs					
Seed	Number to be purchased	Seed Price (per 1000)	Total Cost		Space Need (Sq ft.)
	100,000	$ 30.00	$ 3,000.00		3240
		Need		Unit Cost	Total Cost
Planting Gear Costs	Plant density	50	per sq ft		
	Run length	50	feet		
	Run width	10	feet		
	Runs needed	4			
	Hook spacing	2			
	Rebar needed	28	in 20' lengths of 1/2"	$ 4.00	$ 112.00
	Hooks Needed	240	bent 3/8" rebar	$ 1.00	$ 240.00
	Net Needed	220	linear feet	$ 0.75	$ 165.00
				Total	$ 517.00
Operating Expense (seed + gear)	$ 3,517.00				
			Planting of:		
Estimated Labor Need (per planting cycle)		Hours	100,000	Need/cycle	Hours
	Prep	5	per cycle	1	5
	Planting	7	per cycle	1	7
	Maintenance	26	per season	1	26
	Harvest	27	per cycle	1	27
				Total Hours	65
Pay rate	$ 25.00	per hour			
	$ 1.91	FICA			
	$ 1.00	Workmans Comp			
	$ 27.91	Total payroll cost per hour			
Labor Cost	$ 1,814.31				
Returns					
Sales	Survival Rate	Number to Market	Target Harvest Size (inches)	Market Price (each)	Gross Return
	50%	50000	2" length	$ 0.15	$ 7,500.00
			if needed to determine value		
Return over expenses (no labor cost)	$ 3,983.00		Profit margin	53.1%	
Return over expenses (including paid labor)	$ 2,168.69		Profit margin	28.9%	

Figure 23: Surf Clam Enterprise Budget Worksheet. Assumes low market price of $0.15 from recent market study. More recent information indicates that the market price will likely hold around $0.20-25 per piece or higher.

Formal Market Assessment

The Pentallect market assessment completed with Sea Grant funds produced the following findings related to butter clams:

> *Butter Clams, or juvenile surf clams, are currently a relatively undeveloped market that represents projected market potential of $0.6 - $1.7 million gross revenue for MA-based harvesters. Butter Clams have potential for broad fit across a range of cuisine / menu applications due to their similarity with other clam species and also offer the potential to offset supply shortages for other clam species. There is relatively broad interest within the wholesale / distribution community for Butter Clams. Realizing the gross revenue potential will require an estimated 3+ years to build up seed supply, growing operations and shell stock. Building market penetration for Butter Clams will also require marketing investment to build awareness, create restaurant demand and minimize cannibalization of other clam species.*

Additional market assessment details and methodology are in Appendix 9; the butter clam section starts on page 12 of the Market Assessment Report).

Subsequent Surf Clam Efforts, External to SK Project

This SK project has spun off several pieces of follow-up work by project partners and others that are not a part of the SK award, jump starting the surf clam's launch into the retail market and demonstrating partner commitment to the success of the surf clam as an alternative species to the oyster monoculture.

As mentioned above, the project partners were able to leverage this project's findings to secure funds to pursue additional work to market surf clams. Cape Cod Cooperative Extension and Cape Cod Commercial Fishermen's Alliance partnered with the non-profit Wellfleet Shellfish Promotion and Tasting to receive a Sea Grant award to explore the potential of alternative shellfish species, including surf clams. As part of this complimentary project, a marketing expert, Zapalac Advisors (2019) developed a surf clam promotional plan and templates of marketing collateral to assist growers, wholesalers, and chefs. The marketing consultant met with the SK project's surf clam growers and partners, regional wholesalers, other growers not yet growing surf clams, and chefs from New York to Cape Cod to Portland, Maine, to solicit feedback and ideas. The resulting marketing and promotional plan for "New England Butter Clams" (Appendix 10) provides a guide for anyone wanting to take the next step to market surf clams, including a phased in approach to accommodate the challenges with limited supply in the early years.

The following will also be accomplished as part of the Sea Grant project (award number NA17OAR4170240), further leveraging the SK project findings and relationships:

- October 2019: Public cooking demonstration and sampling of butter clams at the Wellfleet Oysterfest "Diversifying our Seafood Diets" event with non-profit Eating with the Ecosystem and Chef Rizwan Ahmed from Johnson & Wales University (50+ attendees)
- July –August 2020: Surf clam samples were provided to two chefs for trial runs and feedback in their restaurants, to start promoting a limited-quantity, niche market product.

- Shelf life study to determine the best way to achieve maximum shelf life of butter clams in a restaurant's walk in fridge.
- Nutritional testing of 1.5-2" surf clams, to provide nutrition facts to consumers specific to the smaller sized butter clams (in case it is significantly different from 5" adult surf clams).
- Two sets of professional surf clam photographs, including on the water harvesting and restaurant preparation/serving, to be used for promotional collateral development.
- Two page glossy promotional handout template that any grower or wholesaler can customize and use to help market butter clams to retail outlets and chefs.

Additionally, in collaboration with Buy Fresh Buy Local, there are plans later in 2020 to produce a promotional video (1 minute) to be used by chefs and growers on social media to promote butter clams.

Cape Cod Cooperative Extension and Woods Hole Sea Grant are curating a page of resources for alternative shellfish species, which will eventually include materials from this SK project: https://seagrant.whoi.edu/funding-2/all-funded-projects-2010-2020/market-development-to-diversify-shellfish-aquaculture-products-in-massachusetts/

A.R.C. Hatchery continues to be committed to providing surf clam seed for growers and to assist in ongoing marketing efforts, now and well into the future. A.R.C. spawned and offered surf clam seed for sale in 2020, despite the challenges brought on by the COVID-19 pandemic, and will continue to plant surf clam on its own shellfish farms to assist in building the supply.

In 2020, the other Massachusetts shellfish hatchery, Island Creek Oysters, also started offering surf clam seed for sale, making the extra effort to promote them to their customers as a "Surf Clam Starter Kit," which included: 15,000 surf clam seed, ¼ inch and a 4-mil soft-mesh nursery bag, for $600. Additional details: *The Surf Clam Kit includes directions to culture. Can culture multiple kits together. Surf clam seed was spawned from Duxbury, MA broodstock in the ICO hatchery this season; clean pathology available. Additional costs for fall grow-out bags available as well. Other options include mesh/pins on the bottom. Please reach out to Hatchery Manager Hannah Pearson for any questions or to order a kit, (401) 573-1223 or pearson@islandcreekoysters.com.*

Cape Cod Cooperative Extension Marine Program is also pursuing additional field studies to compare the growth rates and survival of the two subspecies of surf clam: the northern Atlantic *S. s. solidissima* and the Southern surf clam, *S. s. similis*.

Evaluation

The project demonstrated that commercial aquaculture production of surf clams is viable, provided there are improvements in grow out practices to achieve optimal yields, and initiated market interest in a new shellfish product. Bottom planting similar to current quahog culture practices works, with high growth rates; survival is dependent on net setup and maintenance to deter predators and escaping clams. Oyster bags, or other gear, that can sand in naturally showed the best survival and good growth, making them a good albeit inconsistent method that likely

needs more experimentation. Two commercial hatcheries in Massachusetts are providing surf clam seed for sale. Growers are utilizing the project findings and investing in surf clams to diversify their aquaculture farms. Chefs are excited to for there to be a supply of surf clams in the marketplace. It is premature to gauge the long-term commercial impact of the project, but on the whole, the goals and objectives of this project were attained.

Metric Evaluation

We planned to evaluate success with the following metrics:

1. *At the hatchery level, success is defined by the amount of seed available for transfer to the nursery stage of farming. The survival and growth of the larval stage and the transition to post-set juveniles will be measured at the hatchery to evaluate the success at the various stages of hatchery production.*

   Evaluation: The hatchery was successful at producing commercial scale surf clam seed able to transfer to the nursery stage. Survival was within hatchery range for success, at approximately 50%. Scheduling refinements are necessary to ensure seed availability at certain months and certain sizes.

2. *At the nursery stage, growth and survival are the key indicators of success and these parameters will be monitored throughout the nursery stage.*

   Evaluation: Survival was generally good in the nursery phase under upwelling conditions, with no noted mortality, though growth was somewhat unpredictable. Field based nursery was susceptible to mortality due to extreme summer heat in intertidal exposure and also had somewhat unpredictable growth, they seemed to grow in spurts. Standard nursery practices for quahog aquaculture seem acceptable for surf clams.

3. *Similarly, growth rate and survival are the key indicators of success at the grow out stage. Again, these parameters will be measured as an integral part of the grow out evaluation of the various technologies proposed for growing surf clams. Because the sites will be selected based on environmental characteristics, not only will we be able to evaluate the technology but also the relative success of these technologies under a suite of environmental grow out conditions.*

   Evaluation: The field trials successfully measured growth and survival across 4 sites and their unique environmental conditions.

4. *Key to the wide-spread commercialization of butter clams is demonstrating the commercial viability for farmers to decide if it will be worth their efforts. This will be evaluated by estimating cost of production of the surf clams and comparing with potential market return.*

   Evaluation: Cost of production and yield calculations were completed, based on the field trial results and initial market assessment. Initial estimates indicate that surf clams are

commercially viable, with comparable profit margins to quahogs due to more rapid growth rate. Ultimately, the market price will determine if surf clams are a good investment for growers.

5. *The success of the marketability and industry acceptance of butter clams will be measured through responsiveness and commitment to the product during the market analysis and workshops.*

   Evaluation: The overwhelming public response to butter clams has been positive: chefs and the public think they are delicious and want to buy them once they are available. The market is ready to embrace butter clams. A portion of industry is very interested in the diversification option provided by surf clams. Not all aquaculture farms have the right growing conditions to profitably grow surf clams. At least 11 early adaptors have invested in surf clam seed and their success or failure will guide the immediate future of this new product (measured by A.R.C. surf clam seed customers; does not include the ICO hatchery sales).

Intended Impacts Evaluation

1. *Expansion of commercial aquaculture production of butter clams.*

   Evaluation: Surf clams, also known as butter clams, have drawn a lot of interest from commercial aquaculturists in New England. More than 30 growers have learned from this project's findings and we are aware of at least 11 growers that have invested in growing surf clams by purchasing surf clam seed from one of the regional hatcheries. At least two regional hatcheries offered surf clam seed for sale in 2019 and 2020.

2. *Regulatory permissions in place for the harvest of undersized aquaculture grown surf clam.*

   Evaluation: The state of Massachusetts has made it legal to harvest aquaculture grown surf clams at the size of 1.5 inches; wild harvest legal size remains at 5 inches.

3. *Regional shellfish hatcheries can expand their production capacity with a species to be grown during their down period, resulting in year round hatchery production.*

   Evaluation: Surf clams can be put outside into the nursery at colder temperatures than oysters and quahogs, providing potential for a winter spawn and expansion of the hatchery production calendar. To have seed in early spring, the upwellers may need temperature and food controls. Alternately, the seed can move outdoors during the winter, knowing that it will not grow much until spring, making it available for summer/fall planting.

4. *Replicable techniques for growing a new aquaculture product, butter clam, in the northeast region.*

Evaluation: The field trials indicated that surf clams can be grown in the northeast region using three different gear configurations. These techniques are being replicated by at least 11 commercial growers that have invested in surf clam seed.

5. *Participating growers gain experience growing butter clams.*

   Evaluation: Three growers participated in the project and gained direct experience growing surf clams during the field trials. Additionally, the Cape Cod Cooperative Extension staff conducted the field trials; as extension agents, their knowledge is available to share with any interested grower.

6. *Commercial growers are trained in the optimal production of butter clams.*

   Evaluation: 33 shellfishermen from 12 towns and two states (MA & RI), one researcher, one volunteer, and one recreational harvester attended a workshop to learn which environmental conditions and gear configurations are most suited for producing surf clams on Cape Cod.

7. *Improved business prospects for shellfish growers through decreased risk of catastrophic losses by adding a third species to aquaculture grants and increasing overall production.*

   Evaluation: It is too soon to quantify actual business improvements. However, 11 growers have invested in surf clam seed and are optimistic that they will increase their production and protect their business against the challenges of a monoculture. Initial sales in 2020 yielded $0.40/piece to the grower.

8. *Marketing strategies are ready to be deployed to promote butter clams.*

   Evaluation: A.R.C Hatchery worked with its wholesale customers to promote surf clams. Once supply is available, they have strategies in place to promote and sell surf clams. The initial findings from this project leveraged additional funding and expanded marketing efforts. Project partner Cape Cod Cooperative Extension secured Sea Grant funding to contract the completion of an expanded and thorough Market Assessment and corresponding Marketing Plan for butter clams (along with blood clams and Massachusetts shucked oysters). As a result, our findings provided the basis for an expanded and detailed New England Butter Clam Marketing & Promotional Plan available at https://www.capecodextension.org/wp-content/uploads/2019/09/New-England-Butter-Clams-Marketing-and-Promotion-Plan-Zapalac-7-10-19.pdf. Templates for marketing collateral are being developed, to be made freely available to growers and wholesalers.

9. *Chefs are familiar with and excited about a new butter clam product.*

   Evaluation: This project worked directly with 21 chefs to introduce them to surf clams through direct sampling; all but one were excited about the new product. Another 12-15 are aware

of them through conversation but they did not get the chance to sample them. Additionally, project partners secured Sea Grant funding to build upon project findings and expand the surf clam marketing efforts.

10. *Domestic product of high quality, superior taste and reliable supply available to shellfish consumers.*

    Evaluation: It is too soon to quantify if a reliable supply will be available. Growers have begun to invest in surf clam seed and will be harvesting and selling in 2020. The current limited seed supply means that it is difficult to stagger plantings to ensure a year-round supply. We anticipate that as more growers invest in surf clams, supply will increase and become more reliable. Informal taste testing of project clams indicates that surf clams are high quality and delicious.

11. *Higher profitability for shellfish dealers due to new product with good shelf life and high customer appeal.*

    Evaluation: It is too soon to quantify profitability for shellfish dealers. Harvest in 2020 will be the first year that surf clams enter the seafood supply chain. Our findings indicate that chefs and customers are excited about surf clams and they do have a longer shelf life than steamers (soft shelled clams).

12. *Additional revenue generated by increased aquaculture production provides economic benefits to coastal communities, as well as cultural preservation of the waterfront.*

    Evaluation: It is too soon to quantify revenue generated by growers who have invested in surf clams; most are optimistic that they will increase their revenue and protect their business against the challenges of a monoculture.

13. *Environmental benefit of increased water filtration from additional shellfish production.*

    Evaluation: Surf clams are filter feeders and were actively feeding during the project. The project can be credited with adding 500,000 surf clams to the environment, plus contributing to farmers' decision to plant additional surf clams (outside of the project).

14. *Marine shellfish aquaculture is inherently sustainable. Once the clams leave the hatchery confines, they survive in the ambient environment and feed off naturally occurring food. Unlike finfish farms, nothing is added to the natural environment.*

    Evaluation: Surf clam aquaculture is sustainable and like other shellfish aquaculture; we did not use feed, medication, or other additives to grow the clams.

15. *Surf clam aquaculture offers an opportunity for enhanced food security within the seafood sector.*

Evaluation: Surf clam aquaculture is financially feasible for farms with surf clam-friendly environmental growing conditions, making it possible for business diversification and enhanced food security.

16. *At the end of the project, there is the potential for at least $62,500 gross revenue to growers, which translates into $156,250 benefit for the community (conservative 2.5 economic multiplier). This is based on the minimum hatchery spawn amount of 250,000 seed, conservative 50% survival rate, two years to market size, and $0.25 wholesale price.*

    Evaluation: The clams grown during the field trials were not sold; the project clams that survived to legal size were harvested and used for samples for the project marketing activities. However, as a direct result of the project findings, A.R.C. Hatchery spawned 4 million surf clam seed and sold and/or planted 745,000 surf clam seed in 2019. Planting was lower than expected because of the tornado-related mortality. Assuming an estimated 50% survival rate and a projected average wholesale price of $0.25, we anticipate the growers that utilized the project's findings will gross ~$93,000 during the 2020-21 harvest season. A.R.C. Hatchery continued to spawn and sell surf clam seed for the 2020 planting season.

Publications, Videos, and Acknowledgement of Sponsorship

- All project publications and presentations included an acknowledgement of NOAA funding and the required language.
- The project findings were summarized and published in a Sea Grant Marine Bulletin, included in Appendix 1, which will be widely distributed throughout the remainder of 2020. The Sea Grant Marine Bulletin will remain permanently available online at the Woods Hole Sea Grant website: https://seagrant.whoi.edu/regional-topics/aquaculture-fisheries/
- The public presentation slide decks are included in Appendices 2 & 3.
- Data collected during the field trials will be permanently available online:
    - Harvard Dataverse: https://dataverse.harvard.edu/dataverse/ARC-surfclams/
- The project secured earned media to further promote butter clams:
    - Radio interview on butter clams with National Public Radio WCAI's "Local Food Report"
    - Cape Cod.com: https://www.capecod.com/newscenter/new-twist-on-a-well-respected-clam-debuts-to-applause-oysterfest/
    - Wicked Local: https://capecod.wickedlocal.com/news/20180413/fishing-life-diving-into-aquaculture
    - CCCFA E-Mag (distributed to over 4,000 e-magazine subscribers):
        - https://capecodfishermen.org/item/plumbrecipe-1025
        - https://capecodfishermen.org/item/plumbsurf-1025
    - An article about the project was published in the industry publication Aquaculture North America, March-April 2019 issue with title: "Study: Surf clam aquaculture has

commercial potential". This is included in Appendix 4. https://mydigitalpublication.com/publication/?m=53591&i=569516&p=20
  - After the project period, results were also summarized and shared in a Sea Grant informational short video.
- Project partners are preparing a manuscript of the field study findings for submission to a peer-reviewed publication, likely National Shellfisheries Association's Journal of Shellfish Research, targeting a submission date of December 2020. While this submission and publication is happening outside of the scope of the project period, we will acknowledge NOAA funding in the manuscript and send NOAA a copy once it is available.
- Project partners will continue to seek opportunities to present project findings at professional conferences and meetings, such as the National Shellfisheries Association's next annual meeting in March2021, the Northeast Aquaculture Conference and Exposition and Milford Lab Symposium (now postponed to January 2022 because of COVID-19), and various American Fisheries Society regional or national meetings. (Dependent on COVID-19 travel restrictions).

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NOAA's Mission: Science, Service and Stewardship
1. To understand and predict changes in climate, weather, oceans and coasts;
2. To share that knowledge and information with others; and
3. To conserve and manage coastal and marine ecosystems and resources.

We would like to thank the Saltonstall-Kennedy grant for their invaluable support of this project. Additionally, the support of shellfish growers who provided time, expertise, and aquaculture grant space was invaluable. Our work could not be accomplished without the partnerships and subject matter expertise of multiple organizations and individuals. We hope that this report can serve as a guide for those members of the aquaculture industry, government, and our local community who are interested in surf clam production.

Data Management Plan

Access to Data

Project environmental data and information collected under this award will be made visible, and accessible to general users, free of charge. Data is expected to be made available to the public within one (by Feb 2021), but no more than two, years of project completion.

The project data will be publically available online at:
https://dataverse.harvard.edu/dataverse/ARC-surfclams/

Point of contact for this data management plan is:

Name: Melissa Sanderson
Title: Chief Operating Officer
Location: Cape Cod Commercial Fishermen's Alliance (CCCFA)
Email: info@capecodfishermen.org or melissa@capecodfishermen.org
Phone: (508) 945-2432
http://www.capecodfishermen.org

Specific questions about the data should be directed to Barnstable County's Cape Cod Cooperative Extension Marine Program:

Abigail Archer: aarcher@barnstablecounty.org
Joshua Reitsma: jreitsma@barnstablecounty.org
Mailing Address: P.O. Box 367, Barnstable, MA 02630
Phone: 508-375-6690
https://www.capecodextension.org/marine/

None of the data collected will contain information identifying the individual who collected it or any information whose distribution may be restricted by law or national security.

Products of the Research

The following data products are available:

1. Substrate Organic Content Data
    - Date substrate collected
    - Site ID (location)
    - Replicate number
    - Tare (g)
    - Wet + T (g)
    - Dry + T (g)
    - Ash + T (g)
    - Percent organic matter
    - Average organic matter (average of replicates per date and site)

- Standard deviation of the average organic matter (stdev)

2. Sand Profile Data
    - Date Collected
    - Site ID (location)
    - Empty Dish weight (g)
    - Initial dry weight (g)
    - Dry weight minus silt (g)
    - Silt/mud weight (g): less than 0.053mm particle size
    - Very fine sand weight (g): 0.053mm – 0.125mm particle size
    - Fine sand weight (g): 0.125mm – 0.250mm particle size
    - Medium sand weight (g): 0.250mm-0.50mm particle size
    - Course sand weight (g): 0.50mm – 1.0mm particle size
    - Very coarse sand weight (g): greater than 1.0mm particle size
    - Silt/mud percentage
    - Very fine sand percentage
    - Fine sand percentage
    - Medium sand percentage
    - Course sand percentage
    - Very coarse sand percentage

3. Environmental Data, collected by HOBO sensors:
    - Temperature (°F)
    - Water depth over the sensor (feet)
    - Date Time (GMT offset to be specified)
    - Site ID (location)
    - Plot ID (unique identifying number)
    - Absolute Pressure (psi) *
    - Absolute Pressure Barometer (psi) *

4. Surf Clam Deployment Data: starting size
    - Sample Date
    - Source
    - Deployed to Experimental Site ID
    - Clam sample ID number
    - Length of clam (mm)
    - Width of clam (mm)*

5. Surf Clam Growth Data
    - Sample Date
    - Site ID (location)
    - Treatment (gear type)

- Bag or Net ID number
- Length of clam (mm)
- Width of clam (mm)
- Height of clam (mm)
- Density of clams*
- Cage Tier level*
- Initial size-length (mm)*
- Days since deployment*
- Daily Growth Rate, average (mm)*
- Wet weight (g)*

6. Surf Clam Survival Data
    - Sample Date
    - Site ID (location)
    - Water body
    - Gear type
    - Number of clams per bag*
    - Bag mesh size (mm)*
    - Bag identification number*
    - Cage Tier level*
    - Core identification number*
    - Net identification number*
    - Number of clams live
    - Number of clams dead
    - Total number of clams in sample
    - Percent survival
    - Percent mortality
    - Estimated number remaining after survival measurement
    - Notes

* = not available across all experimental sites

Data Formats

Data will be made available in a machine-readable, widely-used format (.CSV) and will be accompanied by machine-readable metadata documentation (pdf) that includes key data collection and processing information.

Data will undergo quality control checks prior to making available, including:

- Double check of data entry from paper data sheets
- Evaluate and tag data for known issues and quality status
- Use scripts to automate evaluation of data against accepted ranges or domains

- Verify data integrity when values are transformed using scripted or automated processes
- Validate data products against original quality criteria

Policies for Re-Use

The project environmental data may be re-used upon seeking permission from Barnstable County's Cape Cod Cooperative Extension Marine Program:

Abigail Archer: aarcher@barnstablecounty.org
Joshua Reitsma: jreitsma@barnstablecounty.org
P.O. Box 367, Barnstable, MA 02630
508-375-6690
https://www.capecodextension.org/marine/

Any subsequent publication or report using the project data should contain the accompanying acknowledgement:

Contributing data was collected by J. Reitsma, A. Archer, and D. Murphy under NOAA Fisheries Service Grant #NA16NMF4270241 in cooperation with the Saltonstall-Kennedy Program, Woods Hole Sea Grant through NOAA's National Sea Grant College Program, U.S.Dept. of Commerce; and was supported by Barnstable County's Cape Cod Cooperative Extension and the Massachusetts Department of Agricultural Resources, A.R.C. Hatchery and the Cape Cod Commercial Fishermen's Alliance.

NOAA may, at its own discretion, make publicly visible this Data Management Plan, or use information from the Data Management Plan to produce a formal metadata record and include that metadata in a Catalog to indicate the pending availability of new data.

Archiving of Data

All data, analyses, and documentation such as progress reports, final reports and presentations will be backed up to an off-site system (Datto), thus protecting it from accidental or malicious modification or deletion. The CCCFA IT contractor is responsible for data storage, backup, and data disaster recovery activities.

Additionally, project partner Cape Cod Cooperative Extension Marine Program will maintain a copy of all data and analyses. https://www.capecodextension.org/marine/

Environmental data will also be submitted to NODC NOAA Data Center https://www.nodc.noaa.gov/

Process for Sharing Data

In addition to distributing the data through https://dataverse.harvard.edu/dataverse/ARC-surfclams/, the raw data will be submitted to NOAA Fisheries at the time of posting to Harvard Dataverse.

Any publications resulting from the data will be shared through the Harvard Dataverse link, to provide context and general understanding of the project.

Inquiries for data access from communities, government or businesses will be directed to the Harvard Dataverse link.

References

Ambrose, W.G. Jr., D.S. Jones, and I. Thompson. 1980. Distance from shore and growth rate of the suspension feeding bivalve, *Spisula solidissima*. Proc. Nat. Shellfish. Assoc. 70: 207-215.

Cargnelli, Luca M., S.J Griesbach, D.B Packer and E. Weissberger. 1999. Atlantic surfclam, *Spisula solidissima*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-142. NOAA NEFSC, Woods Hole, MA. 13 pp.

Cessine, Robert S. and Ivar Strand. 1978. The analysis of surf clam production using an exhaustible resource model. J. of the Northeastern Agr. Econ. Council. 7(2):99-103.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- surf clam. U.S. Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.13. U.S. Army Corps of Engineers, TR EL-82-4. 23 pp.

Goldberg, R. 1989. Biology and culture of surf clams. in J. J. Manzi and M. A.Castagna (eds.) Clam Mariculture in North America, Elsevier, New York, New York, USA. Pgs. 267-276.

Goldberg, R. and R. L. Walker, 1990. Cage culture of yearling surfclams, *Spisula solidissima* (Dillwyn, 1817) in coastal Georgia. J. Shellfish Res. 9:187-193.

Heinonen, K. 2012. Clams. Monterey Bay Aquarium Seafood Watch. Monterey, CA. 44 pp. (http://www.seafoodwatch.org/-/m/sfw/pdf/reports/mba_seafoodwatch_farmedclamsreport.pdf) accessed 9 Jan. 2015.

Jones, D. S., I. Thompson, and W. Ambrose. 1978. Age and growth rate determinations for the Atlantic surf clam *Spisula solidissima* (Bivalvia: Mactracea) based on internal growth lines in shell cross-sections. Mar. Biol 47:63–70.

Marzec, R., Yungkul K. and E.N. Powell. 2010. Geographical trends in weight and condition index of surfclams (*Spisula solidissima*) in the Mid-Atlantic Bight. J. Shellf. Res. 29(1):117-128.

McNevin, A.A. 2007. Farmed oysters. Monterey Bay Aquarium Seafood Watch. Monterey, CA. 42 pp. (http://www.seafoodwatch.org/-/m/sfw/pdf/reports/mba_seafoodwatch_farmedoysters.pdf) accessed 9 Jan. 2015,

Narváez,D.A, D.M. Munroe, E.E. Hofmann, J.M. Klinck, E.N. Powell, R. Mann, and E. Curchitser. 2015. Long-term dynamics in Atlantic surfclam (*Spisula solidissima*) populations: The role of bottom water temperature. J. Mar. Sys. 141:136-148.

Northeast Fisheries Science Center (NEFSC). 2010. Report of the 50thNortheast Regional Stock Assessment Workshop(50th SAW).

Pentallect. 2018. Aquaculture Market Assessment Report: The Status of Existing and Potential Markets for Massachusetts Blood Clams, Butter Clams and Shucked Oyster Products. Available from Cape Cod Cooperative Extension.

Quijon, P.A. and J.P. Grassle. 2007. Naticid snail predation on early post-settlement juvenile surfclams (Spisula solidissima) on the New Jersey inner shelf, 1998–2001. Mar. Biol. 150:873-882.

Ropes, J. W. 1980. Biological and fisheries data on the Atlantic surf clam, *Spisula solidissima* (Dillwyn). Woods Hole Laboratory Technical Series, Report No. 24 Woods Hole Oceanographic Institution.

Saila, S.B. & S.D. Pratt 1973. Mid-Atlantic Bight fisheries. In S. B. Saila (ed.) Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals. University of Rhode Island. Press. Kingston. RI. Pgs. 1-125.

Smolowitz, R., D. Leavitt, and F. Perkins. 1998. Observations of a protistan disease similar to QPX in *Mercenaria mercenaria* (hard clams) from the coast of Massachusetts. J. Invert. Path. 71:9-25.

Walker, R.L. and P.B. Heffernan. 1990. The effects of cage mesh size and tidal level cage placement on the growth and survival of clams, *Mercenaria mercenaria* (L.) and *Spisula solidissima* (Dillwyn), in the coastal waters of Georgia. NE Gulf Sci. 11(1):29-38.

Walker, R.L. and P.B. Heffernan. 1994. Age, growth rate, and size of the southern surf clam, *Spisula solidissirna similis* (Say, 1822). (Bivalvia: Mactridae). J. Shellf. Res. 13:433- 441.

Walker, R.L., D.H. Hurley and D. Moroney. 1997. Culture of juvenile atlantic surfclams, Spisula solidissima solidissima and Spisula solidissima similis, in forced –flow upwellers in a bivalve hatchery in coastal Georgia. J. World Aquac. Soc. 28(1):27-33.

Weinberg, J.R. 1998. Density-dependent growth in the Atlantic surfclam, *Spisula solidissima*, off the coast of the Delmarva Peninsula, USA. Mar. Biol. 130: 621- 630.

Weinberg, J.R., 2005. Bathymetric shift in the distribution of Atlantic surfclams: response to warmer ocean temperature. ICES J. Mar. Sci. 62:1444–1453.

Weissberger, E.J. & J.P. Grassle. 2003. Settlement, first year growth, and mortality of surf clams *Spisula solidissima*. Est. Coast. Shelf Sci. 56:669-684

Zapalac Advisors. 2019 New England Butter Clam Marketing & Promotional Plan. Online: https://www.capecodextension.org/wp-content/uploads/2019/09/New-England-Butter-Clams-Marketing-and-Promotion-Plan-Zapalac-7-10-19.pdf

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