An Investigation of the Harvest Practice of Salting Razor Clams and the Brewster Razor Clam Fishery

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Introduction

The Atlantic razor clam also known as the jackknife clam or even razor fish, *Ensis leei* (formerly *Ensis directus*), is a filter feeding bivalve mollusk native to the Atlantic seaboard of North America. The native range encompasses the maritime provinces of Canada (Kenchington et al. 1998) south to Florida (Theroux and Wigley 1983), though it has since invaded waters of the North Sea in Europe in the 1970's (Armonies and Reise 1999). Its name relates to its unique shape roughly 5-8 times longer than it is wide with a slight arc resembling an old fashioned razor (Leavitt 2010). The shells are covered with a yellow to olive brown periostracum, though younger individuals or fresher growth may appear reddish purple. Maximum reported size is about 20cm with maximum age of 7-8 years (Leavitt 2010) though year classes tend to decrease after an age of 2-4 years is attained (Armonies and Reise 1999).

The primary habitat of Atlantic razor clams is sandy to even muddy substrates with moderate flow of the low subtidal zone, or roughly mean low water to shallow subtidal areas, though they have been found to depths of 100m (Theroux and Wigley 1983, Kenchington et al. 1998, Leavitt 2010). They can be patchy in distribution and may set at high densities of 2000 per square meter (Armonies and Reise 1999) and are suggested to be most common in near-shore waters of US distribution (Theroux and Wigley 1983). Somewhat unique to this species they are very active bivalves with a high degree of mobility (Drew 1907). With a muscular foot that can be extended to over half of total shell length and retracted quickly, razor clams can sense movement or vibrations and dig rapidly to a meter in depth, can jump, and can even swim (Verrill and Smith 1874, Drew 1907). With this level of mobility razor clams are often known to move or migrate, especially at smaller sizes through bysuss-drifting (Armonies 1996) looking for preferred habitat if the site of first settlement is not ideal (Armonies and Reise 1999).

With a strong market and some perceived increase in prevalence in recent years, the razor clam fishery has grown rapidly over the last decade in Massachusetts, making it a multi-million dollar fishery important to a number of communities. Harvest statewide has grown from ~137,000lbs worth $303,000 in 2008 to 728,000lbs worth over $3,000,000 in 2018 (Schillaci et al. 2019 Appendix A). The fishery in Southeastern Massachusetts has focused on shallow subtidal areas, and also intertidal areas with a large tidal range and extensive flats. The primary method of harvest in this region has been "salting" where food grade salt, usually in the form of a brine made with seawater, is applied to a razor clam burrow irritating the razor clams so that they emerge from the sediment and can be manually retrieved.

Salting has been a somewhat controversial practice for razor clams locally with at least one town in the Northeastern part of MA prohibiting the practice as there were concerns over what solutions beyond salt were being used (https://www.newburyportnews.com/news/local_news/state-sues-shellfish-official/article_7bd8ae09-a723-5768-8596-7f9e41fa6bc4.html). In addition, limited laboratory studies have also suggested applying a high salinity brine to extracted razor clam gill tissue (Krzyzewski and Chery 2005) or juvenile razor clams (Harrigan 2014) can either cause noticeable tissue damage or hinder ability to recover and rebury, respectively. Field investigations with similar razor clam species in Europe suggested an intertidal razor clam fishery with salt could be considered "environmentally friendly" in Portugal (Constantino et al 2009), and another describing the subtidal diver salting razor fishery in Scotland as having limited impact on small discards (Muir 2003). Field-based studies on potential effects of salting as it pertains to the local razor clam fishery have been lacking.

Considering the lack of local field-based investigations on salting, and the evaluation occurring with the Brewster razor clam fishery as a pilot program, it was an opportune time to examine salting. Harvesters in Brewster use hand pressurized multi-use sprayers to apply field-mixed brine solutions to visually identified razor clam holes on the intertidal flats. With the intertidal nature of the Brewster fishery also representing a potential extreme in effects as salt is being applied to relatively dry flats whereas subtidal waters may allow for more immediate and continuous dilution. Most of the questions being posed with the growth of this fishery regard the effects of "salting" on the razor clams themselves, especially the ones salted but not large enough to harvest, and secondly how the salt interacts with the environment where it is applied. This investigation sought to help answer some of these questions to better inform local resource managers, harvesters, and other interested parties.

Study Methodology

Assessing the Salting Methods in the Environment

The method of salting was observed routinely through the summer of 2019. To gather data on the concentration of salt being used by commercial harvesters, the brine being applied was randomly sampled for concentration determined by a handheld temperature compensated refractometer (range 0-25%, Cole Parmer). The volume of brine being applied was also sampled randomly by asking harvesters to dispense a typical squirt (by muscle memory, assumed after salting many holes it would be relatively uniform) to a cup which was then measured using a graduated cylinder.

In initial lab tests we found it was typically feasible to dissolve salt in 30ppt (3% salt) seawater until around 23.5-25% at which point any additional salt became very difficult to dissolve. A standard brine recipe was used for all experiments where CCCE applied a brine. This field-mixed brine was 1500g of salt brought to 6 liters of total volume with seawater and mixed until we could get no more into solution, usually pretty close to fully dissolved. The resultant brine had a salinity of 23.5-25% when measured with a refractometer. Theoretical saturation state is a salinity around 26% but that is difficult to accomplish in the field.

To see how the salt brine solutions affect the salinity of standing or pore water in the holes (burrows) being salted, a 3ml transfer pipette was used to extract a small amount of water (<1ml) from the site of application to be immediately measured for salinity (in %) by a refractometer. The depth below the sediment surface the pore water was being pulled from varied in initial attempts, so on two separate occasions salinity was checked at 4 different depths (surface or 0, then at 4, 8, and 12cm deep). After sampling 25 different sites of brine application and on two separate days, the depth of 4cm was observed as the zone of highest concentration. This depth was then used for further sampling of salt concentrations.

While the brine is applied by commercial harvesters to a discrete hole (burrow) on a dry intertidal flat, it is largely unknown how that applied brine may spread in the sediment given there would be interaction with surface water until the tide returns. To examine the extent of horizontal spread from the site of application, on 2 separate occasions pore water samples were extracted from sediment approximately 1-1.5 inches (or 3-4cm though distance was not measured but estimated) in each compass direction from the site of application, as well as from the site of application. The first involved applying 10ml of 25% brine to marked holes and a 10-15 minute soak before measurement, and the 2nd involved using various commercial harvester application sites. A 3ml transfer pipette was used to extract the sample at a standardized depth of 4cm for each sample. Salinity was measured immediately with the handheld refractometer.

How much time the elevated salinity persisted was assessed on 3 occasions. On the first occasion we observed salinity in 12 marked holes salted with a 24% brine solution applied liberally with a multiuse sprayer (volume applied was not measured). Salt concentrations were measured at 4cm depth at the site of application immediately, then roughly 10, 20, 30, and 60 minutes following the time of application. The second occasion involved measuring salt concentration at the site of application with two known volumes being applied to 10 marked holes for each volume. The brine applied had a salinity of 25% and was applied to the holes using a 10ml pipette at 2 volumes, 10ml and 20ml, with salinity measurements taken immediately, 1 hour, and 2 hours post-salting at the standard 4cm depth. The third occasion involved marking with a flag 20 sites of brine application by various commercial harvesters and measuring salinity immediately, after 1-2 hours, and then again after 24 hours the following day to see how flux of the tide affects remaining salt. All salinity measures were taken with the handheld refractometer described above, and a background salinity was also taken from Cape Cod Bay waters with the same refractometer.

Post-Salting Survival and Health

In June of 2019, survival trials commenced to assess the post-salting survival of razor clams in comparison to controls that were not exposed to any salt in excess of the natural seawater environment during harvest. Control animals were dug by hand from the same Brewster tidal flats as those that were salted. To learn how to hand dig razor clams without damaging them we consulted Town of Ipswich shellfish constable Scott LaPreste because the razor clam fishery is a hand dug fishery in that town. Great care had to be taken when digging to prevent razor clam shell breakage and/or damage to the foot. Any razor clams that were broken or noticeably damaged were not used in the study.

Salted razor clams were sourced in 2 different ways. The “salted legal” were animals of a legal harvest size (greater than 5 inches in shell length) salted by the authors with a standardized brine solution that was applied with a hand pumped 2-gallon multi-use sprayer. Salt used was food grade “fish salt” (Cargill

Top-Flo Granulated Salt) commonly used by commercial harvesters. The same brine mixture as described above, 1500g of salt brought to 6 liters of total volume with seawater and mixed until we could get no more into solution, was used for the standardized salting of legal sized animals. The resultant brine had a salinity of 23.5-25% when measured with a refractometer.

While the "salted legal" razor clams were harvested by the investigators with a standardized brine, the "salted shorts" were sub legal sized (less than 5" shell length) harvested by various commercial harvesters on the same day and gathered and mixed prior to planting in the survival trial so each pot contained "salted shorts" from multiple harvesters. Each group (control, salted-legal, and salted-shorts) was planted in 3 replicate pots per survival trial. Not every salted group was included in each trial but controls were included in every trial. Each pot received 10-15 razor clams and was covered with 10mm square Tenax clam netting with a bungee collar to prevent predation and razor clam escape. The pots were 14 inch in diameter and 14 inch deep landscape/nursery pots that were buried into the flats at around the mean low tide line, filling them with the excavated sediment leaving about 2 inches of freeboard at the top of each pot (12 inch sediment depth) to allow for razor clam movement and to facilitate them digging in.

The pots of razor clams were then allowed to recover for different periods of time ranging from 3 days to 29 days. A total of 6 trials were done in this way, with the 5th trial having a second portion after the 29 days in which a small subset were replanted (trial 5b) to allow them to recover even further (bringing the total time post-salting to 85 days). At the end of each trial period the pots were dug up and sediment was sieved for surviving razor clams and any shells of dead clams. Live and dead razors clams were recorded along with associated shell length from each pot. This data was then compiled as live and dead animals from each group by trial date and compared for statistical differences in distribution of live and dead using Chi-square in Microsoft Excel.

To look for potential tissue damage, which was previously suggested related to salting in lab experiments (Krzyzewski and Chery 2005), a subset of razor clams from each group were cut for specific tissues and examined by standard histopathology methods at the Aquatic Diagnostic Laboratory (ADL) at Roger Williams University. The razor clams examined by the ADL included freshly salted legal and short clams and freshly dug controls (fresh meaning they were delivered to the lab on the same day the salting or digging occurred. Any abnormalities in tissue sections were described by the shellfish pathologist and lab director (Roxanna Smolowitz, DVM).

Post-Harvest Condition

One of the other questions regarding the salting practice for razor clams was whether the harvest practice affects the post-harvest condition of the razor clams. Razor clams tend to be considered a short shelf life animal to begin with and some anecdotes suggested salting may decrease shelf life. To examine potential differences 10-12 salted legal sized razors and 10-12 controls (hand dug) were gathered on 4 occasions and held in a refrigerator at 40-45F and near constant 100% humidity (as measured with an Onset HOBO datalogger). The razor clams were banded with rubber bands while in storage much like asparugus as is local industry practice (Wellfleet Shellfish Company, personal communication) and generally recommended (Younger 1999, Pyke 2002) to improve storage condition. At several points in the days that followed harvest, each individual razor clam was scored for condition using the system developed for similar razor clam species (Younger 1999). The groupings of individual scores by control vs salted legal treatments were compared by two-sample test after verifying the assumption of equal variance in Microsoft Excel.

Basic Metrics of the Brewster Fishery

The town of Brewster was in a pilot commercial fishery during the 2018-2019 period of this investigation. During the fall of 2018 several trips were made with commercial razor clam harvesters participating in the Brewster pilot fishery of Cape Cod Bay waters. The Brewster fishery is intertidal, primarily on dry exposed flats of the town, such that most effort is focused on the "moon" tides or those that recede more than an average low tide event exposing the habitat more. Given that effort is somewhat tide/weather dependent the Town developed a catch report for harvesters to submit with each trip recording basic information including conditions, catch, and time spent fishing so that catch per unit effort (CPUE) could be estimated.

The catch of Brewster commercial harvesters was also sampled periodically starting in November of 2018 to collect data on length frequency distribution of the catch to the nearest ¼ inch, and relative efficiency in targeting animals of legal size (or greater than 5 inches in shell length in the town of Brewster). This catch sampling was repeated in early August of 2019, and again in December of 2019. The data were then compiled in length frequency histograms for comparison.

To get a better estimate of growth rate and size at age annual growth rings, or winter growth checks, were visually assessed from razor clam shells as has been previously suggested as a reasonable way to estimate age of *Ensis* sp. (Swennen et al 1985, Cardosa et al 2011 & 2013). Shells of dead razor clams were collected on multiple occasions from near the commercial fishery in Brewster, a total of 111 were analyzed. Growth rings were visually identified and measured to the nearest millimeter with digital calipers. Measurements were grouped by putative age (i.e. winter 1, winter 2, winter 3, etc.) and plotted for estimated size at each point.

Results and Discussion

Salt and the Environment

The concentration of salt/brine solutions being mixed and used by harvesters in the Brewster fishery ranged from 18 – 26% with an average of 22.6% (Table 1), most getting very near to the physical maximum concentration of around 26%. Each harvester had their own system of field mixing a brine and used a similar amount each time. There did seem to be a tendency for concentration to increase with time in the sprayer as any salt that did not go into solution upon initial mixing may have slowly dissolved adding to the concentration over time though our samples were taken at random so should capture that in the range reported. Given there is a degree of variability in both the concentration and volume being applied it may be that some use a lower concentration but a higher volume to get the razor clams to respond. Plotted individual data points did not show this trend largely due to the small sample size and one particular outlier of high volume and high concentration.

Harvester Salt Concentration		
	Salt Conc (%)	Volume (ml)
Mean	22.6	9.6
Median	22.8	7.0
N	20	9
Minimum	18	4
Maximum	26	25

Table 1. Commercial harvester brine concentrations and volume being applied. Salinity values are represented as percent or parts per hundred.

As mentioned in the methodology we found looking at pore water or interstitial salinity at depth in the sediment at the point of brine application to show highest salinity concentrations at 4cm (1.5 inches) below the surface. Surface salinity (within 1cm of the surface of hole water) was variable but was also elevated while descending deeper in the sediment showed concentrations tended to decrease with increasing depth (Table 2). This indicated there tended to be a pocket of higher concentration brine, and spread by depth was limited. Given that brine was being applied at a concentration of 23-25% and average concentration at the depth of 4cm averaged 13.4% there seems to be dilution of up to half as the brine is being applied to the pore water.

Pore Water Concentration by Depth

Depth (cm)	Depth (in)	Mean (%)	Median (%)	Min	Max	N
1	0.5	8.4	6.5	3	22	24
4	1.5	13.4	14	4	22	26
8	3	5.1	4	3	12	26
12	4.5	4.4	3	2	14	26

Table 2. Pore water concentration at the site of application by depth in the sediment. Salinity values are represented as percent or parts per hundred.

When salinity was measured from pore water around the site of application (roughly 1-1.5 inch in each compass direction) there was limited evidence it spread consistently. The data presented in table 3 represent 10 holes salted at a constant concentration and volume, data taken from holes of harvesters was very similar. Occasionally a value would be elevated above background salinity (3%), such that the mean was elevated above background, though the median was at background given most samples showed values at or near background. The second experiment (data not shown) involving use of commercial harvesters had mean values of 6.9% at the center, 3.7% to the North, 3.3% to the East, 3.4% to the South, and 4% to the West, with a background salinity of 3.1% In both experiments the Northerly and Westerly directions had the higher salt signal, which seems to be consistent with the direction of the receding tide. It should be noted, since these samples were taken so closely to the site of application the position of the pipette likely makes a difference, especially if a razor clam emerged and at an angle, and distance from the point of application was not measured exactly.

These results suggest given the small volume applied it’s likely it mixes with interstitial water and dilutes slowly such that concentrations do not elevate much in any one direction surrounding the point of application. One other study (Muir 2003) examined 25cm away from the point of application, which is close to 10 times the distance used here (we used an approximate 3cm vs 25cm by Muir), and found no elevation of interstitial water over a 60 minute time series. Since the current results showed such limited salinity spread at the short distance from the point of application we did not take samples from any further away assuming it would be further diluted. It's possible the diluting brine tends to move more vertically than horizontally given the high density of the brine solution and the likelihood the path of least resistance is following the burrow of a razor clam (or worm) downward. Regardless, using the 12cm depth we saw some salinity signal remain, a 3 cm radius would amount to around a 1:30 dilution (assuming the brine diluted cylindrically) so that 10ml of 25% brine solution would dilute in 30ppt Cape Cod Bay water to a point where it would be getting down near to the range of seawater (<35ppt).

Pore Water Salinity Around the Application Site					
	Center	North	South	East	West
Mean	14.3	3.6	3	3	3.3
Median	13	3	3	3	3
Minimum	4	3	3	3	3
Maximum	23	8	3	3	6

Table 3. Pore water concentration at the site of application (center) and around the site of application about 1-1.5 inches in each compass direction. All values are salt concentration in parts per hundred (%). Background salinity was 3%.

The first experiment regarding the length of time the elevated salinity remains at the point of brine application showed a signal that remains high for the first 10 minutes but then starts to dilute rapidly though it remained slightly above background level of 3-3.2% for the full 60 minutes (Figure 1). The second experiment (Figure 2) demonstrated the volume applied does affect the initial salinity though both decreased dramatically after 1 hour, and were at or close to background salinity values after 2 hours (3.2% and 3.3% for 10ml and 20ml of brine respectively). The third experiment, which involved following randomly selected holes of multiple harvesters, added a 24-hour post salting point that showed no signs of any brine remaining at that point (Figure 3).

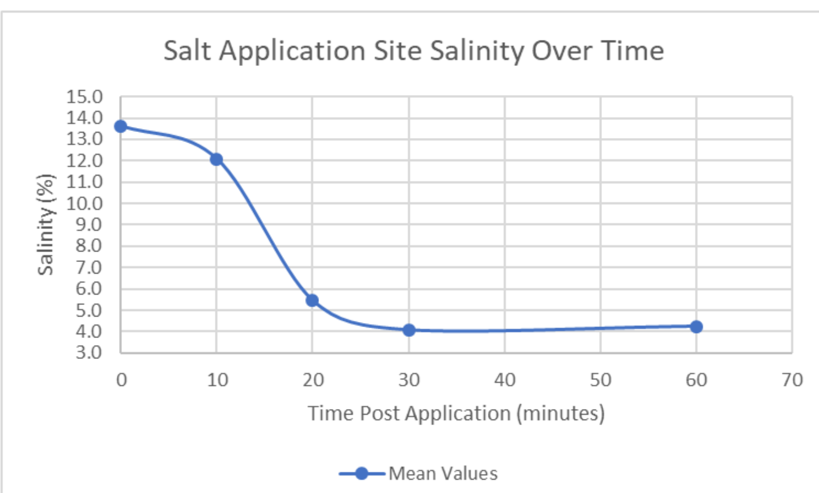

Figure 1. Salinity at the site of application of a 24% brine over time. Y-axis was set to start at 3% as that is roughly background salinity (30-32ppt).

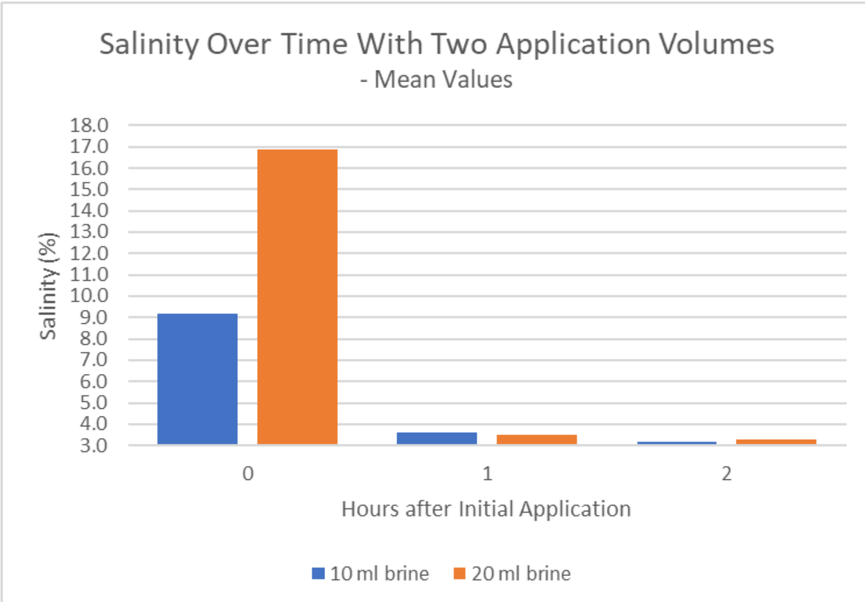

Figure 2. Salinity at the site of application of a 25% brine at volumes of 10ml and 20ml over time. Y-axis was set to start at 3% as that is roughly background salinity (30-32ppt).

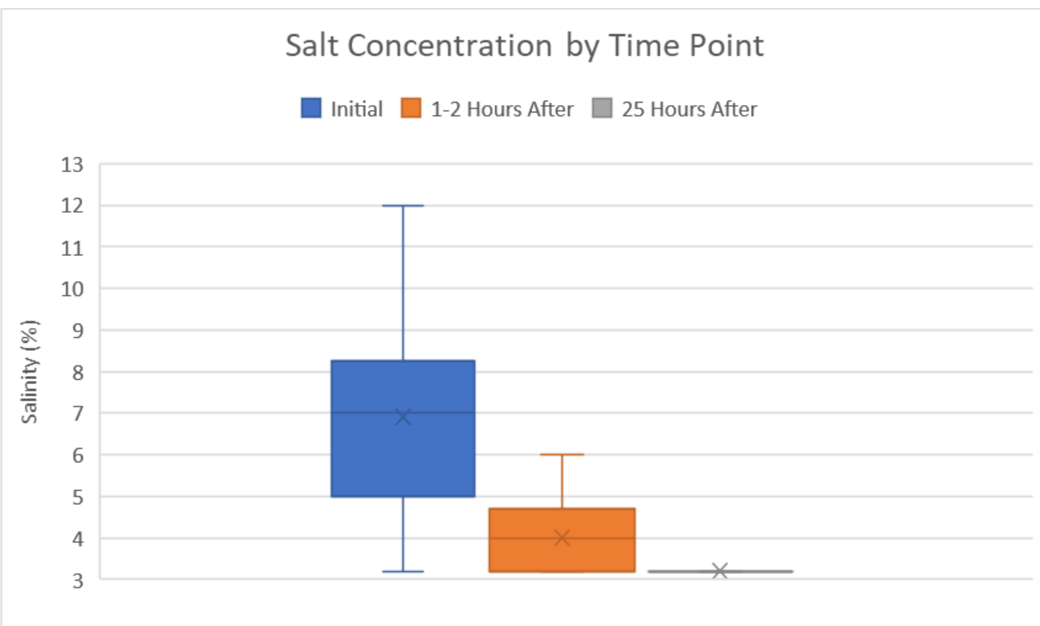

Figure 3. Box and whisker plot showing the salinity values of holes brined by commercial harvesters initially, after 1-2 hours, and following 24 hours and 2 tide cycles. Bars represent minimum and maximum values, lines represent the 25^{th} and 75^{th} percentiles as well as the median, and the X represents the mean. Y-axis was set to start at 3% as that is roughly background salinity (30-32ppt).

While salinity does remain above background over an hour or 2, the level of salinity does dissipate rapidly and is non detectable after 24 hours. This is not unlike that reported by Canstantino et al. (2009)

who found an intertidal plot covered with granular salt had elevated salt for the first 2 hours but was back at background by 24 hours later. Muir (2003) found salinity at points of application of granular salt in a subtidal environment remained elevated for 60 minutes but did not measure any further. Both these studies used a granular salt as opposed to a brine which seemed to cause somewhat of a delay as the granular salt needed dissolve before the salinity may increase over a period of time before decreasing. Since the brine is already dissolved, the highest measures were immediately following application, after which they seemed to fall or dilute quickly.

While a benthic community analysis was not performed in this study, a comparison can be made to a salting experiment that did involve a benthic community assessment in comparison to a control site. Constantino et al. (2009) found no major effects on benthic communities in comparison to non-salted control areas after covering an entire plot with salt and seeing elevated sediment salinity over that region for at least 2 hours. They further suggest animals capable of intertidal life are likely somewhat resilient to rapid changes in environment. Given their results, and considering the elevated salt concentration in the Brewster fishery remained close to the application site and seemed to decrease rapidly with limited spatial spread, it is likely that effects of salting on benthic communities would not be any different from the Constantino study. The Constantino study went on to suggest that salting of razors in the intertidal, and maybe even more so in the subtidal, can be considered “environmentally friendly” over alternatives of digging or dredging which each have their own effects on benthic communities.

Post-Salting Survival and Health

Survival of both groups of salted clams was as good or better than control clams that were harvested without salt by hand with clam forks (Table 4). Three of the six trials showed no statistical difference in survival between the groups. In trial 1, which was the shortest at only 3 days, the salted clams had statistically higher survival than controls. In trial 4, which lasted 8 days, both salted size classes of razor clams had statistically higher survival than control clams. Taking the mean of each trial the overall survival of control razor clams was 84.5%, salted short or sub-legal sized was 88.9%, and salted legal sized razor clams was 96.6%.

Summary of Razor Clam Survival Trial Statistical Analysis

			Average Size (cm)			Percent Survival (%)			N						
Trial	**Start Date**	**Days**	**Cntrl**	**S-Short**	**S-Legal**	**Cntrl**	**S-Short**	**S-Legal**	**Cntrl**	**S-Short**	**S-Legal**	**df**	**X2**	**p-value**	**Result Summary**
1	6/7/2019	3	15.2		15.1	85.3		100.0	34		33	1	5.24	**0.0220**	SL survival > C
2	6/10/2019	9	14.4	11.2		75.9	90.9		29	44		1	3.09	0.0787	No difference
3	6/19/2019	13	14.0	12.0	14.2	88.0	88.9	92.3	25	36	26	2	0.29	0.8630	No difference
4	7/2/2019	8	14.6	11.9	14.7	73.3	97.1	100.0	30	35	29	2	15.02	**0.0006**	SL=SS>C
5a	8/5/2019	29	14.8	11.9	14.2	85.7	78.3	96.9	35	46	32	2	5.38	0.0679	No difference
5b	8/5/2019	85	14.8	12.3	14.6	93.3	93.3	100.0	15	15	14	2	0.98	0.6133	No difference
6	6/25/2020	27	14.4	11.3	14.3	90.0	84.8	90.3	30	33	31	2	0.59	0.7456	No difference
Mean			14.6	11.8	14.5	84.5	88.9	96.6	28	35	28				

Table 4. Summary of razor clam survival trials comparing two size classes of razor clams that were harvested through salting to controls that were not salted. Statistical significance via chi-square analysis was denoted as $p<0.05$, values in **bold**. In Result Summary column, C is control, SS is salted short clams, and SL is salted legal sized clams.

The razor clams that were examined histologically, the only abnormalities were noted in the gills in comparison to control (non-salted) razor clams. The abnormalities were seen primarily in razor clams harvested immediately following salting, and consisted of lesions in the gills that varied in severity between filaments in each animal, from mild to moderate and focally extensive to diffuse, and varied slightly between animals. The variable gill tissue damage was characterized by vacuolation and necrosis with individual cell loss of frontal, frontal lateral ciliated filament cells, and non-ciliated basal filament cells, though the lateral cells were less affected. The lesions were similar in both salted legal sized and salted short or sub-legal.

The razor clams examined histologically after 3 days of reburial and recovery in the field showed proliferation of filament cells around areas of damage, or simply put, healing of the gill tissue damage. The findings noted in the gills of the salt treated vs. controls were characterized by proliferation of filament cells. The findings varied in the amount of cellular proliferation response between filaments within each salted animal and between salted and controls. Results were again the same between the legal-sized and short or sub-legal sized salted razor clams (which were salted by commercial industry).

The results indicate the salting method of harvest as practiced in the Brewster razor clam fishery results in some sparse damage to the gill tissues. Histology also showed extensive healing activity after just 3 days in recovery, and survival at various times in recovery was the same or greater than controls that were not salted. Taken together this seems to indicate limited long-term damage to salted razor clams, including sub-legal sized animals.

The plotting of survival vs. time in recovery showed a slight negative trend with time but only in the salted short razor clams. Given the salted short clams were handled by various commercial harvesters and likely had more variable post-harvest handling. Handling, and particularly temperature exposure, post-harvest have been suggested as important factors in condition (Pyke 2002). Mortality seems likely to be within the first several days based on these experiments, histological observations, and observations made in the final trial where shell of mortalities were seen at the surface of the pot after only 7 days equaling mortality at the 27 day final assessment.

Similar to the results of this study, salted razor clams in Scotland also showed good survival and reburial in relation to hand harvested controls though season affected the time of reburial (Muir 2003). The intertidal salting of razor clams in Portugal was thought to have limited impact on razor clam survival, though time to reburial was the challenge to avoid bird predation with both salted and hand harvested discards (Constantino et al. 2009). Bird predation of sub-legal discards was also noted in the Brewster fishery such that it might be recommended commercial harvesters rebury any discards, or discard them subtidally, to enhance potential survival.

The reason for mortality in control animals is uncertain as histology of various tissues did not reveal any abnormalities, but one hypothesis is the digging process causes unseen physical or even biochemical stress. While only unbroken or undamaged clams (removal of the foot by excess pulling was also an issue) were used as controls, the rate of breakage was about 30% by the investigators with little experience digging razor clams. Given the mobile nature and thin shells of razor clams, some damage is going to be inherent to harvest by hand and in particular damage due to pulling of the foot (Muir 2003). Damaged razor clams are common in the dredge fishery in Europe (Pyke 2002), the diver hand-picked fishery (Muir 2003), and hand tool fishery (Constantino et al. 2009). With damage of one kind or another difficult to avoid with any form of harvest, a true “control” group is a challenge for this sort of study.

Post-Harvest Condition

There was no significant difference in post-harvest condition scoring between the control group and the razor clams that were salted, in any comparison among each individual trial and day of comparison. In general, the clams were in consistently good condition and at around day 5 in storage condition seemed to deteriorate (Figure 4). Weight loss was also measured in storage for 6 days (data not shown), and while there was significant water weight lost in both groups it did not appear higher in one over another. The earliest we recorded a mortality, or a razor clam that did not respond at all when handled, was 3 days post-harvest in the control group. One trial lasting 6 days had no mortalities, another had a first mortality after 6 days, and another had a mortality after 7 days. The pattern of mortality was similar between control and salted clams, though the day 3 mortality was an outlier and may have had some unnoticed damage, it did not affect overall analysis.

The method of harvest and post-harvest handling can affect the condition or quality of razor clams as a food product (Muir 2003, Younger 1999, Pyke 2002). The results here indicate no significant difference in post-harvest quality of razor clams harvested by hand without salt or with a saturated brine solution as used in the Brewster fishery. Thus, the condition of animals for sale does not seem to be altered by the salting methods. The literature does indicate handling, and specifically exposure to hot summer temperatures, can affect quality (Pyke 2002). Commercial harvesters would be wise to keep razor clams from excessive heat exposure and desiccation while harvesting, especially during summer, i.e. keep them moist and cool.

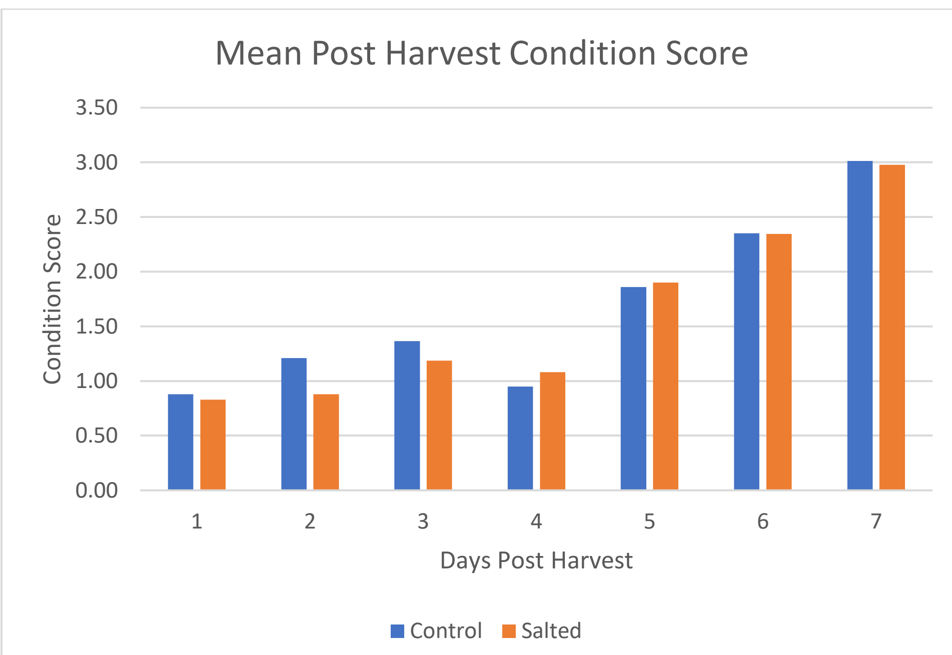

Figure 4. Mean post-harvest condition values of control and salted razor clams held in refrigerated storage. Lower scores indicate better condition. The results shown are combined from several trials, in

some cases there were multiple measures for a particular day. Day 1 (N=2), Day 2 (N=1), Day 3 (N=2), Day 4 (N=1), Day 5 (N=1), Day 6 (N=3), Day 7 (N=3).

Basic Metrics of the Brewster Fishery

The catch per unit effort (CPUE) can be used as a fishery indicator, in that decreases of catch per unit of effort can indicate the resource is less available for harvest for one reason or another. Data to calculate the 2018 CPUE for the Brewster razor clam fishery was limited but showed a steady increase in CPUE over the course of the season. This is somewhat to be expected as the fishery was new and many harvesters were still gaining experience. In 2019, CPUE was fairly steady across the season, but varied by harvester. In general, there was a wide range of CPUE across the 14 harvesters reporting.

The data on CPUE was very limited for 2018 (17.7 lbs/hr) with a new fishery so should be considered preliminary. CPUE seemed to peak in 2019 at 26.1 lbs/hr among the license holders and has since declined in 2020 (21.7 lbs/hr) and 2021 (17.7 lbs/hr) leading to conversations about allowing certain areas to repopulate. Using CPUE in future years may be helpful in assessing how to manage the fishery locally.

Similarly, length frequency distribution of the species can be an important indicator of change in a population. Length frequencies measured at 3 time points since the fall of 2018 show the pattern of lengths being captured by various harvesters (Figure 5a-c). The majority of clams taken through salting were of legal size. After 11 different trips with harvesters in the fall of 2018 the catch mean was 95.8% of legal size (>5 inches). This can be seen in the length frequencies where the most frequently harvested size was distributed around 5.75 or 6 inches. The catch appeared to get slightly larger from 2018 into 2019. In all 3 time periods there appeared to be a slight peak in the sub-legal sized animals (4-5 inches) which likely represent a year class of razors approaching legal size.

The length-frequency sampling showed the fishery to be very efficient in targeting razor clams of legal size. It is uncertain why so few sub-legal razor clams are seen. It could be efficiency in targeting holes of the proper size to represent legal sized clams, or alternatively it could be a difference in habitat preference by size classes of razor clams. Razor clams are a highly mobile species, especially at smaller sizes when they are thought to move often to find optimal habitat (Armonies 1996, Armonies and Reise 1999). Highest abundances of juvenile razor clams are in subtidal waters (Armonies and Reise 1999). Given that the Brewster fishery is an intertidal fishery, it may be that the smaller classes largely remain subtidal and are rarely seen. In October of 2018, a single 1.75 inch razor clam was encountered in the fishing area.

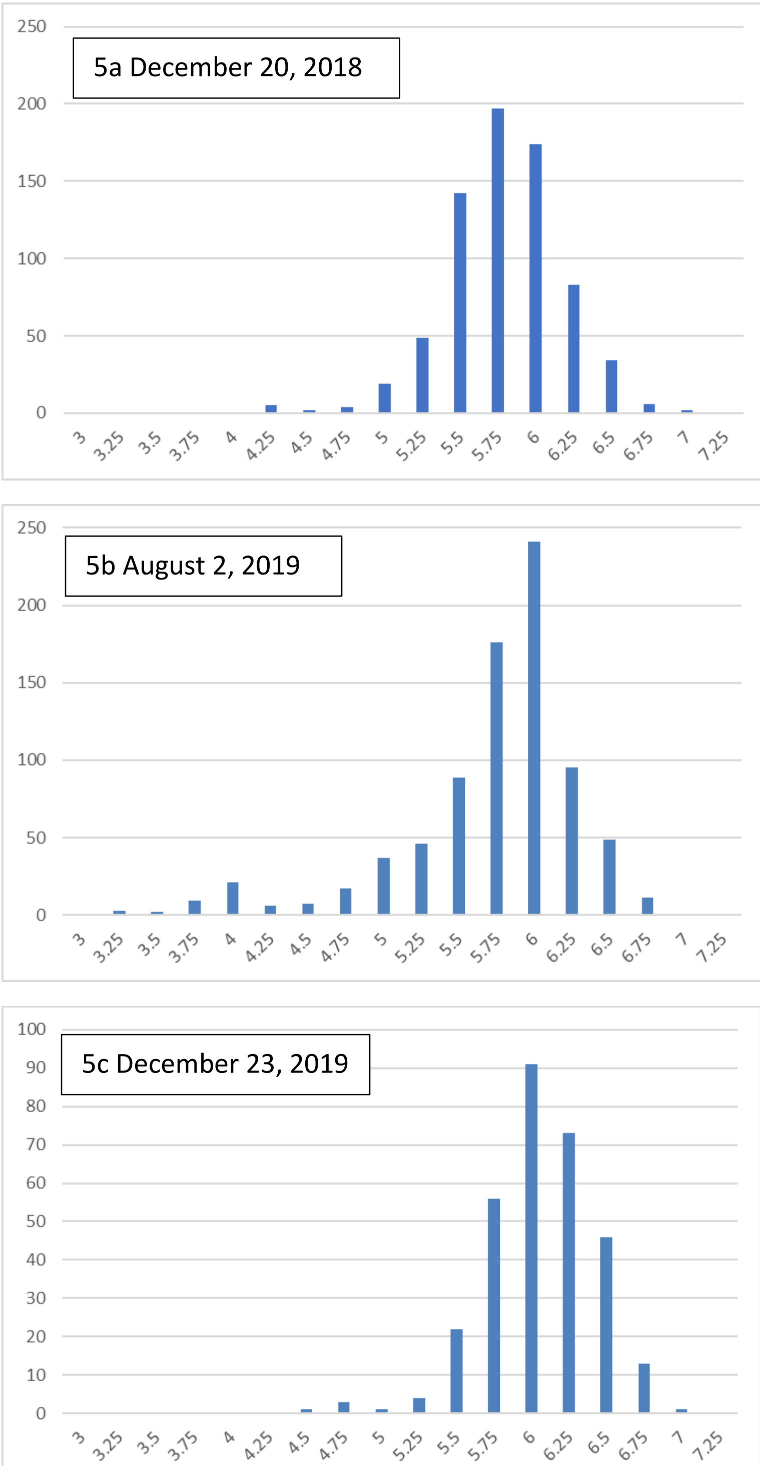

Figure 5. Length frequency distribution of razor clams in December 2018 (5a), August 2019 (5b), and December 2019 (5c).

The growth rate and reproductive size/age are also questions common to emerging fisheries that are still settling on management measures like minimum legal size. Unfortunately, we do not have a lot of local information on this species. Razor clams do tend to have very distinct growth lines left as seasonal growth ceases in winter (Figure 6), these have been verified as a method to estimate growth rate in *Ensis sp.* (Cardosa et al. 2011, 2013). It's somewhat subjective as lines are not always obvious, so a line can be missed potentially removing a year class but with care it can be a helpful tool when other measures of growth are not available.

Figure 6. An Example of razor clam growth lines or growth checks. They are marked by pencil marks on the shell and red arrows.

Razor clams grow rapidly in their first 2 seasons of life (Swennen 1985, Cardosa et al 2011). The analysis of Brewster razor clam growth rings showed the same pattern (Figure 6 and 7). Not knowing exactly when the razor clams were "born" we used 0.5 to for clams at their first growth ring, or first winter, under the assumption they started life the previous summer and added a year for each successive growth ring. The estimated mean size for clams at age was: 58.5mm at age 0.5, 110.6mm at age 1.5, 134mm at age 2.5, 144.2mm at age 3.5. The fifth ring, age 4.5, had only 4 samples (n=4) so data are unreliable. This rate of growth would be more rapid than growth reported in Europe, but that may not be that unexpected considering it is not native there and some areas like the Wadden Sea may be food limited (Cardosa et al. 2011). In support of the growth rate suggested in this study, particularly the first season which seems most variable, a hatchery spawn of razor clams in late spring of 2009 and held in a nursery facility reached an average size of 57mm in November of the same year (unpublished data). Wild set razor clams have also been regularly encountered in a nearby annual experiment averaging 37mm at the beginning of September with significant growing season remaining (unpublished data).

Beyond the size at the end of the first season the pattern of growth is similar to other reports (Swennen 1985, Cardosa et al 2011), with growth slowing down after the second growth ring. The Brewster razor clam data suggest a 5 inch (127mm) will most likely be the result of 3 seasons of growth. The 127mm needed to be a legal sized clam is just under the 25th percentile of animals in the 2.5 age class, or that have grown for a full 3 seasons, suggesting roughly 75% of the population at age 2.5 were of legal size for harvest. Growth really seems to slow after the 3rd season of growth and plateaus between 140-160mm.

Figure 7. Plot of analysis of growth rings on 111 razor clam shells. Age was denoted as 0.5 for clams at the end of their first season, 1.5 for clams at their second winter, and so on. Bars represent minimum and maximum values, lines represent the 25th and 75th percentiles as well as the median (center), and the X represents the mean.

Age or size at first spawning can also be an important consideration. A literature review did not produce much information on timing and size at first spawning for US populations. However, it appears that the timing of spawning based on other regions is likely April/May in Europe (Cardosa et al. 2011) or May in Nova Scotia (Kenchington et al. 1998). A second spawning event has also been suggested for late summer in a European population (Cardosa et al. 2009). The smallest size reported to spawn in a European population was 48.1mm at an estimated age of 388 days (Cardosa et al. 2011). Fecundity is likely to increase with size, and while it appears some may be able to spawn between age 0.5 and 1.5 it is more likely maturity occurs between age 1.5 and 2.5. Maturity at an age of 2 would still provide a spawning event (or 2) in the early season before the animals reach a harvestable size of 5 inches (127mm), potentially later that growing season.

A recent series of squash preparation microscopic exams of razor clam gonad tissues from Brewster (Cape Cod Bay) have indicated spawning activity starting and peaking in May (possibly continuing into June) and then again in late August or September. Razor clams sampled were generally 100 mm (4 inches) in size or greater, and all clams of this size did show significant gonadal development in the season of spawning. It is uncertain at what size gonadal development begins but the smallest razor clam examined was 88mm (3.5 inches) and showed egg development in April. This smallest size would likely be consistent with razor clams at an age of roughly 1.5-2 and entering a 3rd season of growth.

Summary

The salting practices employed by the Brewster fishery appears to be an efficient means of harvesting the razor clam. The salting can cause some noticeable tissue damage to the gills of razor clams. However, this damage appears to be generally tolerable as the razor clams are able to heal and survive at a rate similar to or better than hand dug razor clams, including sub-legal sized clams returned to the flats. The post-harvest condition also does not appear to be affected by salting. The salt solution applied to the intertidal flats does not appear to spread very far and dissipates quickly over the hours following application, and likely even more rapidly as the tide returns, as no trace was found a full day after application. This result combined with a published report suggesting an even harsher salting strategy had no significant effect on the benthic community (Constantino et al. 1999), suggests the salting practice likely has minimal impact on the local environment. While some damage is likely to occur with all fishing methods, salting seems to be a method not without impacts, but with impacts that are limited.

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