Effect of Flexible Netting on Wild Soft-Shell Clam Survival and Recruitment: Manipulative Field Trials at Six Intertidal Flats Along the Maine Coast (Summer-Fall 2014)

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Abstract

A comparative manipulative field experiment was conducted during the summer and fall of 2014 to determine effects of netting discrete plots of the intertidal on survival of 1+ year class and recruitment of 0-year class individuals (recruits) of the soft-shell clam, *Mya arenaria*. The study was conducted at two intertidal flats in each of three locations along the Maine coast: Jonesboro, St. George River, and Boothbay. During 30 June-2 July, five netted (plastic, flexible, 4.2 mm aperture and 18.21 m² each) plots and adjacent control plots of a similar size were established at each of the six flats. Benthic cores were taken in the vicinity of the plots at the beginning of the study to establish ambient densities and size-frequency distribution of 1+ year class individuals. After approximately 120 days, nets were removed, and core samples taken from both netted and control plots. Recruitment was enhanced significantly due to the presence of netting at only one of the six sites (16.7%). At one of the two sites in Jonesboro, recruitment was 25x greater in netted (4,183.1 ± 712.6 ind m⁻²) vs. control plots (158.9 ± 163.9 ind. m⁻²). Sediment build-up on top of all nets at both flats in the St. George River created anoxic patches within each netted plot that resulted in high mortality rates of extant (1+ year class) clams, and reduced the ability of the nets to protect recruits from predators. Although nets remained structurally sound and received no large amounts of sediment, no recruitment enhancement occurred in netted plots at either of the Boothbay sites. Along with routine monitoring of nets to ensure they are performing as intended, we propose two additional measures that may result in improved results in future. First, additional flotation for each net would help to counteract high sedimentation rates. Second, deploying nets earlier in the spring (during the first two weeks of May) at all sites along the Maine coast would likely ensure that nets are in place prior to the beginning of the settlement phase of clam larvae from the water column.
1.0 Introduction

Historically, management of soft-shell clams, *Mya arenaria* L., in Maine has focused on what to do once clams have settled from their two- to three-week planktonic (floating/swimming) phase. Coastal communities co-manage their intertidal stocks of clams with the Maine Department of Marine Resources (DMR) according to a local, or specific, shellfish ordinance. The ordinance typically recognizes a number of control methods including: 1) limiting the number of commercial and recreational harvesters; 2) restricting the times and areas harvested; and, 3) limiting the amount of commercial and recreational harvest. In addition, active methods include: 1) predator protection using fencing, netting, or trapping; 2) seeding areas using wild or hatchery stock; 3) stock assessment surveys or collecting catch data from harvesters; 4) enhancing natural recruitment through brushing, roughing, etc.; and, 5) flat rotation through conservation closures ([http://www.maine.gov/dmr/msf/forms/AnnualReviewNew2014fillable.pdf](http://www.maine.gov/dmr/msf/forms/AnnualReviewNew2014fillable.pdf)). Not all communities engage in all control or active methods; however, one overarching management control tool is used that places a limit on the minimum size of clams harvested at 2-inches (50.8 mm) in shell length (SL). Communities are required to submit an annual shellfish review to the DMR that categorizes which control or other management tools they have used during the previous year, but are not required to report on the results of those activities.

Many of the management measures, except the 2-inch law and the use of hatchery stock for re-seeding efforts, have not changed dramatically during the past 55 years (see Dow and Wallace, 1961; Hanks, 1963), yet statewide clam landings since that time have been highly variable (Fig. 1), peaking in 1977 (3,554 mt; 7.84 million pounds) and falling to its lowest level in 1991 (670 mt; 1.48 million pounds).
Since 1987, four years after the 2-inch law was established, landings have averaged 983 mt (2.17 million pounds) with little interannual variation.

It is safe to say that due to the nature of reproduction in soft-shell clams, in which gametes are released into the water column at high tide – eggs are ca. 44-microns in diameter (1/577th of an inch); sperm are ca. 2-microns in diameter (1/12,700th of an inch) – and where fertilization and subsequent larval development (2-3 weeks) occur, no single management tool can explain or predict the level of landings in a particular community for a particular year.

Attempts to increase statewide clam landings using various combinations of current or future management measures are decades away because we still are
novices at understanding the mechanisms that control spawning and recruitment success. What we can do, however, is to try various management schemes and measure responses at the level of a single flat or an area within a single flat. By repeating attempts to enhance local clam abundance at various sites along the entire coast over many years, we can measure annual responses, look for patterns, and determine both spatially and temporally which schemes, tools, or procedures result in the desired outcomes.

One straightforward management measure to enhance local soft-shell clam abundance in Maine and the northeast U.S. has been the use of predator-deterrent fences, nets, and other devices (Smith and Chin, 1951; Glude, 1955; Smith et al., 1955; Beal and Kraus, 2002; Beal, 2006 a,b). Netting can be used to protect wild or cultured clam seed (5-15 mm SL) as well as to protect 0-year class recruits (Beal et al., 2001; Figs. 2-3).

Here, we describe a comparative manipulative experiment conducted during the summer and fall of 2014 at three intertidal locations along the coast of Maine (Jonesboro – Washington County; St. George River – Knox County; Boothbay – Lincoln County) designed to examine effects of predator-deterrent netting on 0- and 1-year class individuals of the soft-shell clam.
Figure 2. A 6-inch plastic plant pot from Littler River Flat (Freeport, Maine) on 14 November 2013. The experimental unit was filled with ambient sediments containing no wild clams and seeded with 12 cultured soft-shell clams on 28 April 2013. The unit was covered with a piece of flexible netting (4.2 mm aperture). In addition to the 12 clams surviving in the unit, 695 live wild clams were found (Average SL = 8.09 mm, range = 3.09-13.83 mm). See Final Report at: http://www.downeastinstitute.org/assets/files/manuals/1_24%20Final%20Report%20-%20Freeport%20Shellfish%20Restoration%20Project%20-%20B.%20Beal.pdf This information (as well as that contained in Fig. 3) is included in this Report to show the potential effects of predator-deterrent netting to protect 0-year class individuals. Results such as these have been observed in a variety of communities along the Maine coast for over 25 years.
Figure 3. Wolf Neck, Harraseeket River, Freeport, Maine (13 November 2014). a) 6-inch coring device on a portion of intertidal mudflat that had been protected since 18 April 2014 using a piece of 4.2 mm flexible, plastic netting. Small holes adjacent to the corer show the presence of numerous 0-year class soft-shell clams that had settled under the netting sometime during the late spring or early summer. b) Contents of the same core showing 1,005 wild soft-shell clam individuals (55,098 m$^{-2}$, or 5,119 ft$^{-2}$) that averaged 8.24 mm SL (range = 1.5-22.4 mm).

2.0 Methods

To determine the effect of predator-deterrent netting on survival of 1-year class and older soft-shell clams as well as on the presence of 0-year class individuals, we initiated a series of manipulative field experiments near the mid-intertidal zone at two intertidal flats within three communities along the Maine coast (Table 1).

Table 1. Name of community, Maine county, intertidal flat, GPS coordinates, and date when experiment was established.

<table>
<thead>
<tr>
<th>Community</th>
<th>County</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Flat name</th>
<th>Date (2014)</th>
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<td>-67.54922</td>
<td>Arthur Hill</td>
<td>30 June</td>
</tr>
<tr>
<td>Jonesboro</td>
<td>Washington</td>
<td>44.62490</td>
<td>-67.55582</td>
<td>Bob’s Cove</td>
<td>30 June</td>
</tr>
<tr>
<td>South Thomaston</td>
<td>Knox</td>
<td>44.04671</td>
<td>-69.18947</td>
<td>Potato Patch</td>
<td>2 July</td>
</tr>
<tr>
<td>St. George</td>
<td>Knox</td>
<td>44.02724</td>
<td>-69.20219</td>
<td>Barney’s Cove</td>
<td>2 July</td>
</tr>
<tr>
<td>Boothbay</td>
<td>Lincoln</td>
<td>43.91854</td>
<td>-69.59597</td>
<td>Pleasant Cove</td>
<td>1 July</td>
</tr>
<tr>
<td>Boothbay</td>
<td>Lincoln</td>
<td>43.92356</td>
<td>-69.62274</td>
<td>Cross River</td>
<td>1 July</td>
</tr>
</tbody>
</table>
At each site (Figs. 4-6), we established five 18.21 m² flexible, plastic nets (4.2 mm aperture; polypropylene – see [http://www.industrialnetting.com/industry-solutions/aquaculture/clam-netting/ov7100.html](http://www.industrialnetting.com/industry-solutions/aquaculture/clam-netting/ov7100.html); productOV 7100). Nets were situated approximately 10 m apart and were adjacent to control areas of the same dimension (Fig. 7).

**Figure 4.** Study sites in Jonesboro (Arthur Hill Flat; Bob’s Cove).

**Figure 5.** Study sites in the St. George’s River (Barney’s Cove; Potato Patch).
Figure 6. Study sites in Boothbay (Pleasant Cove; Cross River).

Figure 7. Experimental design used at each intertidal flat in the study. Netted and adjacent (control) plots were 18.21 m² (14-ft x 14-ft).

Five Styrofoam floats (10 cm diameter x 10 cm thick) were arrayed in a quincunx pattern on the bottom side of each net so that the net would extend into the water column several cm during tidal inundation. Each float was affixed to nets separately by placing a 10 cm wooden lath on top of the net and pounding three trap nails through it and into the float that was situated on the bottom side of the net. Nets were secured either by walking the perimeter into the mudflat surface.
approximately 10-15 cm (St. George River; Boothbay) or by digging a furrow around the perimeter using clam hoes, then placing the edge of the netting into the furrow and back-filling the dug mud onto the netting in the furrow (Figs. 8-9).

To establish ambient clam density and size-frequency distribution at the beginning of the trial, 10 benthic cores (0.1824 m²) were taken to a depth of 15 cm at each intertidal flat. Samples were washed through a 1 mm sieve and all live clams were enumerated and the SL of each measured to the nearest 0.01 mm using digital calipers.

Each flat was re-visited every 2-4 weeks during the experimental period to check on the status of the nets (i.e., whether ripped or torn; whether excess sedimentation was occurring; whether one or more edges had lifted) and to examine the control areas for signs of worming or clamming. On 27-29 October, flats in each

![Figure 8.](image) Net being secured at Pleasant Cove, Boothbay, on 1 July 2014. Sediment was soft enough so that the edge of the net could be stepped on forcing it into the mud 10-15 cm. Then, sediments were back-filled into the furrow with feet.
location (Jonesboro, St. George River, and Boothbay, respectively) were visited to remove nets and take samples from each netted plot (n = 2) and adjacent control plot (n = 2). That is, a total of 20 benthic cores were taken from each site, ten from netted plots and ten from control plots. Each sample was washed through a 1 mm sieve and the contents processed as described above.

Analysis of variance was used to test for treatment effects of netting on mean number per core and mean SL using the following linear model:

\[ Y_{ijk} = \mu + A_i + B(A)_{j(i)} + e_{k(ij)} \]

where:

\[ Y_{ijk} = \text{dependent variable (mean number per core; mean SL)}; \]
\[ \mu = \text{theoretical mean}; \]
\[ A_i = \text{Treatment (i = 1 to 2; factor is fixed – Netted vs. Control plots)}; \]
\[ B_j = \text{Core (j = 1 to 5; factor is random, and nested within the Treatment factor)}; \]
\[ e_k = \text{Experimental error (difference from core-to-core within a given treatment)}; \]

All means are presented with their 95% confidence interval.
3.0 Results

3.10 Initial sampling and observations (June-October 2014)

3.11 Jonesboro

Both study sites were visited on five occasions prior to final sampling. No activity (worming or clamming) was ever observed at the Arthur Hill Flat. Nets showed some sediment deposition during late July (Fig. 10), but this did not continue and nets were free of sediments by late October. No edges were observed lifted. A visit to the Bob’s Cove site on 4 August revealed that clamming had occurred in all of the control plots, and a clammer was observed digging in one of the plots on that date. At the end of the study, one of the five nets at Bob’s Cove had a large rip that we conjecture was due to a propeller from an outboard motor. No damage occurred to the other four nets at this site.

3.11(a) Arthur Hill Flat (30 June 2014)

Four clams were found in the ten core samples (50.26 mm, 53.35 mm, 36.31 mm, and 11.94 mm). Ambient density was 21.9 ± 27.5 ind. m⁻², or 2.04 ± 2.55 ind. ft⁻².

3.11 (b) Bob’s Cove (30 June 2014)

A total of 49 clams occurred in the ten core samples (268.6 ± 132.7 ind. m⁻², or 17.2 ± 20.1 ind. ft⁻²). The size-frequency distribution was skewed to the right with a single mode near 10 mm (Fig. 11). The average size of the juvenile clams (N = 46) was 9.7 ± 0.78 mm, and each had a distinct overwinter mark near the umbo similar to that described by Beal and Kraus (2002) indicating that these were 1-year class individuals that had settled sometime during the previous fall, overwintered, and had begun to grow during 2014.
Figure 10. A net with some sediment build-up at the Arthur Hill Flat on 31 July 2014.
3.12 St. George River

The sites were visited six times during the study period. On 8 July, worm digging was first observed within the control plots at the Potato Patch. Siltation on the nets was most problematic at the Potato Patch (see below); however, none of the nets were ripped or otherwise damaged at either site.

3.12 (a) Barney’s Cove (2 July 2014)

High densities of juvenile clams occurred at this site (1326.8 ± 680.0 ind. m$^{-2}$; 123.3 ± 63.2 ind. ft$^{-2}$). Mean SL of clams was 17.0 ± 0.62 mm (n = 237; Fig. 12). Only one distinct overwinter mark occurred on the valves of each clam suggesting that these were 0-year class individuals that had settled the previous summer/fall. Sedimentation was problematic and began soon after the investigation began (Figs. 13-14). By early August, sediment covered the nets so that all of the apertures were occluded except those in the immediate vicinity of the Styrofoam floats.
Figure 12. Size-frequency distribution of clams in core samples taken from Barney’s Cove, St. George on 2 July 2014. (N = 237)
Figure 13. Netted plot at Barney’s Cove on 21 July 2014 with sediment build-up. Many mud snails, *Ilyanassa obsoleta* can be observed on and adjacent to the plot.

Figure 14. Netted plot at Barney’s Cove on 16 September 2014. Siltation has covered all the netted area except the small space around each Styrofoam float.
3.12 (b) Potato Patch (2 July 2014)

Initial density of soft-shell clams was $307.0 \pm 188.7$ ind. $\text{m}^{-2}$ ($28.5 \pm 17.5$ ind. $\text{ft}^{-2}$). Over 95% of the clams were 0-year class juveniles (Fig. 15). Mean shell length of animals less than 35 mm (55 of 56) was $15.2 \pm 1.3$ mm. Sedimentation was steady over the study period (Figs. 16-17), and reached depths of 3-5 cm on top of nets by late October.

![Figure 16. Initial size-frequency distribution of clams sampled in benthic cores at the Potato Patch on 2 July 2014 (N = 56). Mean SL of individuals < 35 mm SL was $15.1 \pm 1.3$ mm (n = 55).]
Figure 17. Net with layer of sediment at the Potato Patch, South Thomaston, on 21 July 2014.

Figure 18. Sediment build-up on top of net at the Potato Patch, South Thomaston, on 2 September 2014.
3.13 Boothbay

The sites were visited three times during the study period. No significant siltation on the nets occurred at either site. A visit in mid-August indicated that worming had occurred at Pleasant Cove, but all occurred outside the study area. No clamming or worming was apparent on any visit to the Cross River site.

3.13 (a) Pleasant River (1 July 2014)

No clams occurred in any of the ten benthic cores taken on 1 July 2014.

3.13 (b) Cross River (1 July 2014)

Two clams occurred in the cores (10.9 ± 16.5 ind. m⁻²; 1.0 ± 1.5 ind. ft⁻²). These were 60.53 mm and 63.55 mm.

3.20 Final sampling (27-29 October 2014)

3.21 Jonesboro (27 October 2014)

3.21 (a) Arthur Hill Flat

Netting resulted in a significant enhancement of 0-year class clams (Fig. 19). Approximately 25x as many clams occurred in cores taken from netted (4183.1 ± 712.6 ind m⁻²; 388.7 ± 66.2 in. ft⁻²; n = 5) vs. control plots (158.9 ± 163.9 ind. m⁻²; 14.8 ± 15.2 ind. ft⁻²; n = 5). This difference was statistically significant (P < 0.0001). Clams were significantly larger (P = 0.0031) in the netted (3.91 ± 0.58 mm, n = 5) vs. control plots (2.78 ± 0.16 mm, n = 4; Fig. 20).

3.21 (b) Bob’s Cove

No significant enhancement due to predator-deterrent netting occurred (P = 0.8967). Density of all clams in control plots was 356.4 ± 217.9 ind. m⁻² (33.1 ± 20.3 ind. ft⁻²; n = 5) and was nearly identical to that in the netted plots (372.8 ± 262.1 ind. m⁻², or 34.6 ± 24.4 ind. ft⁻²; n = 5). When 1+ year class individuals were removed from the analysis (i.e, clams > 15 mm SL), a similar result was found (P = 0.9266). The mean SL of 0-year class clams did not differ between the two treatments (P = 0.3156; \( \bar{x}_{SL\ control} = 4.15 \pm 0.41 \) mm vs. \( \bar{x}_{SL\ nets} = 5.88 \pm 4.46, n = 5 \).
Figure 19. Effects of predator-deterrent netting on density of 0-year class soft-shell clams at Arthur Hill Flat (27 October 2014). ANOVA demonstrated a statistically significant difference between the two means (P < 0.0001). n = 5.
Figure 20. Size-frequency distribution of soft-shell clams in benthic cores on 27 October 2014 from the Arthur Hill Flat, Jonesboro, Maine. Mean shell length of clams in the netted plots was approximately 40% larger than those in the control plots (P = 0.0031).

3.22 St. George River (28 October 2014)

3.22 (a) Barney’s Cove

A layer of sediment covered each net, but the depth of the sediment was not enough to sample quantitatively with a coring device. Netting provided no enhancement for clams of all sizes. In fact, significantly (P = 0.0448) more clams were sampled in cores taken from control plots (285.1 ± 275.0 ind. m$^{-2}$; 26.5 ± 25.6 ind. ft$^{-2}$; n = 5) than in netted plots (43.9 ± 61.8 ind. m$^{-2}$; 4.1 ± 5.7 ind. ft$^{-2}$; n = 5). For 0-year class individuals (animals < 15 mm SL), no significant difference was
found in mean density between netted and control plots ($P = 0.0886$); however, nearly 20x more small clams were sampled from control plots. For larger clams ($\geq 1$-year class individuals), netting provided no significant enhancement ($P = 0.8798$).

Size-frequency distribution for both control and netted plots (Fig. 20) showed clearly the two sizes of clams (0-year class individuals $< 15$ mm SL and 1+-year class individuals $> 15$ mm SL). Mean SL did not differ significantly between the two treatments ($P = 0.3295$).

**Figure 20.** Size-frequency distribution of soft-shell clams from benthic cores taken at Barney’s Cove, St. George, on 28 October 2014.

### 3.22 (b) Potato Patch

Sediment build-up on each of the five nets was so thick (5-6 cm) that we took one small (4-inch diameter) core ($A = 0.0081 \text{ m}^2$) from the top of each net in addition to two larger cores beneath each net. Removing the nets (i.e., pulling the netting
back to get at the sediments below) was extremely difficult because of the excessive weight of the mud on each net. As each net was pulled off the plot, the mud on top of each rolled up so that once finished, a pile of mud several hundred pounds was created at one end of the plot. Clams that had been in the sediments at the beginning of the experiment had tried to force their siphons through the netting to communicate with the overlying water column (Fig. 21). In many instances, removing the netting from the plot pulled clams from the sediment, as the siphons of some clams were caught in the 4.2 mm aperture. This reduced the apparent density of clams sampled in the benthic cores. In one instance (Fig 22), all clams that were pulled out of the mud with the net were counted and the SL of each measured as described above. The size-frequency distribution of those individuals (Fig. 23) indicated that 3.2% (12 of 370 individuals) were 2014 recruits (i.e., SL < 15 mm).

**Figure 21.** 1+ year class soft-shell clams that were pulled out of the sediments at the Potato Patch, South Thomaston, on 28 October 2014 when the net was removed from the plot. Clams forced their siphons through the aperture of the netting (4.2 mm) to communicate with the overlying water column, and some siphons were pinched.
Figure 22. 1+ year class individuals that were pulled out of the sediment within a netted plot at the Potato Patch on 28 October 2015 because the siphon of each was temporarily pinched in the aperture of the net. Mean SL of these 370 individuals was 25.1 ± 0.6 mm.
Figure 23. Size-frequency distribution of clams pulled up with a single net at the Potato Patch, South Thomaston, on 28 October 2014. Mean SL increased approximately 10 mm between early July and 28 October (15.2 ± 1.3 mm [n = 55] to 25.1 ± 0.6 mm [n = 370]).

There was no significant enhancement due to netting for clams of all sizes (P = 0.4244) although the mean density for the netted plots was nearly 2.5x greater ($\bar{x}_{SL} = 833.3 ± 1602.7$ vs. $339.9 ± 283.3$ ind. m$^{-2}$, or $77.4 ± 148.9$ vs. $31.6 ± 26.3$ ind. ft$^{-2}$; n = 5). Control plots contained both 0- and 1+ year class individuals whereas samples from netted plots contained only 1+ year class clams due to the high level of sediment on top of each net that did not allow this year’s clams to reach the protective netting. Density of 0-year class individuals sampled from the larger core in control plots was compared to the density of similar year class individuals sampled from the sediments lying on top of the netted plots. Mean density was no different between the two samples (P = 0.5761; $\bar{x}_{SL(top of nets)} = 172.7 ± 174.6$ ind. m$^{-2}$ [n = 5] vs. $\bar{x}_{SL(control plots)} = 115.1 ± 142.6$ ind. m$^{-2}$ [n = 10]).
Size-frequency distribution of clams from the larger cores (Fig. 24) shows that both 0- and 1+ year class clams were sampled in the control plots, whereas only 1+ year class clams were sampled from the netted plots due to the excessive sediment deposit occurring on top of all five nets.

![Size-frequency distribution of soft-shell clams on 28 October 2014 from the Potato Patch, South Thomaston, Maine.](image)

**Figure 24.** Size-frequency distribution of soft-shell clams on 28 October 2014 from the Potato Patch, South Thomaston, Maine.

### 3.23 Boothbay

#### 3.23 (a) Pleasant Cove – 29 October 2015

A total of two clams (5.68 mm and 6.09 mm) were sampled in the ten cores taken under the nets. Four clams (4.95 mm, 6.97 mm, 2.63 mm, 3.35 mm) were sampled in the control plots. There was no significant enhancement due to the presence of netting ($P = 0.3972$). Mean density in the netted plots was $10.9 \pm 18.6$ ind. m$^{-2}$ (1.0
\[ \pm 1.7 \text{ ind. ft}^{-2}, n = 5 \] compared with \[ 21.9 \pm 28.5 \text{ ind. m}^2 \] \( (2.0 \pm 2.6 \text{ ind. ft}^{-2}, n = 5) \) in the control plots.

3.23 (b) Cross River – 29 October 2015

No significant enhancement due to nets occurred \( (P = 0.4675) \). Mean density in netted plots was approximately 1.6x greater than in control plots; however, the variability between samples within a given treatment was quite large making the comparison not statistically significant \( (\bar{x}_{\text{Netting}} = 60.3 \pm 77.6 \text{ ind. m}^2, \text{ or } 5.6 \pm 7.2 \text{ ind. ft}^{-2}, n = 5 \) vs. \( \bar{x}_{\text{Controls}} = 38.4 \pm 18.6 \text{ ind. m}^2, \text{ or } 3.6 \pm 1.7 \text{ ind. ft}^{-2}, n = 5 \)).

Clams from control plots \( (n = 7) \) ranged in SL from 2.85 mm to 5.03 mm. Two clams from the 11 sampled in the netted plots were from the 1+ year class \( (16.6 \text{ mm, } 57.7 \text{ mm}) \), the remaining 9 ranged in SL from 1.92 mm to 12.67 mm. Among the 0-year class individuals, there was no significant difference in mean SL between netted and control plots \( (P = 0.2918) \).

4.0 Discussion

This study was designed to examine effects of deterring predators on survival and recruitment of 1+ and 0-year class soft-shell clams, respectively. It showed that deterrent netting is not a panacea for enhancing soft-shell clam abundance (Table 1). Netting was effective at enhancing recruitment at only one of six study sites \( (16.7\%) \). The best assessment of whether nets protected extant clams should have occurred at the two St. George River sites because initial densities of 1+ year class individuals was relatively high at both sites \( (\text{Barney’s Cove} – 1,326.8 \pm 680 \text{ ind. m}^2, \text{ Potato Patch} – 307.0 \pm 188.7 \text{ ind. m}^2) \). Unfortunately, siltation began almost

<table>
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<tr>
<th>County</th>
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<th>Site</th>
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<td>-</td>
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immediately after the experiment was initiated, and was so intense that sediment build-up on nets likely killed clams rather than protected them. For example, in October, densities of live clams in netted plots at Barney’s Cove was $43.9 \pm 61.8$ ind. m$^{-2}$, indicating a mortality rate of nearly 95%, whereas an 80% mortality rate occurred in the control plots. At the Potato Patch, initial clam densities were $307.0 \pm 188.7$ ind. m$^2$, and $833.3 \pm 1620.7$ ind. m$^{-2}$ in netted plots in October; however, this apparent increase was not statistically significant ($P = 0.421$) most likely because of the large variability between samples observed in the October sampling. In addition, no significant change in densities occurred between July and October in the control plots where $339.9 \pm 283.3$ ind. m$^{-2}$ were observed. The only site with relatively high initial clam densities where netting was not affected by siltation was Bob’s Cove in Jonesboro. There, initial clam density was $268.6 \pm 132.7$ ind. m$^{-2}$. In October, density in both netted and control plots for clams > 15 mm SL was exactly the same – $43.85 \pm 40.5$ ind. m$^{-2}$, an apparent mortality rate of nearly 85%. Although no predators were sampled in cores at Bob’s Cove, several large green crabs were observed under the nets (Fig. 25) before and on the October sampling date that could explain the results observed.

![Figure 25. A green crab under a net at Bob’s Cove, Jonesboro, on 15 September 2014.](image)
A single study cannot adequately examine all of the factors that led to the results observed here. Our comparative experimental approach at two intertidal flats in each of three communities across a wide geographic range of the Maine coast is a good first step that should be repeated in other years and at least in the same locations. The question about whether predator deterrent netting can increase local clam harvests has not entirely been examined in this study. There are several items that require attention if future investigations are to add to our knowledge base. These include:

- **The timing of net placement at each site requires careful consideration**

Nets were employed during the last day of June and the first two days of July 2014. For netting to be effective in protecting 0-year class individuals (recruits), they must be in place before soft-shell clam larvae begin to settle to intertidal flats. Clam recruitment in a given location is related directly to the timing of annual spawning. Spawning is temperature-dependent, and occurs when seawater temperatures exceed 50°F. Each spring, warming water follows the coast from south to north in an almost wave-like progression (Fig. 26), which suggests that the timing of clam spawning does as well. Larval development beginning with external fertilization of the gametes takes 14-23 days and depends on temperature. The warmer the water, the faster larval development occurs. Therefore, the fact that few 0-year class individuals were sampled from under nets at least at the two Boothbay sites may be due to the fact that nets were placed on the flat too late. If natural recruitment of clams to the flats occurred prior to the first week of July, and if netting acts to discourage predators, then one explanation for the lack of clams at the two Boothbay sites is that many of the small clams may have been consumed prior to net deployment. Other explanations may include but are not limited to: 1) general lack of large quantities of larval settling in either area; 2) a spawning failure in that region of the coast; 3) infaunal predators such as large polychaete and nemertean worms preyed on recruits under the netting (none of these were observed in the benthic cores, however); and/or 4) a combination of two or more of these models. Placing nets on flats during the first two weeks of May at any intertidal site in Maine would likely solve any problem with the timing of spawning and natural recruitment.

- **The buoyancy created by the Styrofoam floats could be increased**

Although netting performed well at the two sites in Jonesboro and Boothbay with respect to siltation and sediment build-up on top of the nets, the problem we observed at both sites in the St. George River may have been ameliorated with
Figure 26. Sea surface temperatures (2014) in the Gulf of Maine from a) 7 May, b) 29 May, and c) 8 June. Notice how seawater temperatures increase beyond 50°F first in the southwestern portion of Maine and then progress gradually north and east. Since clam spawning is related directly to seawater temperature, we suggest that clam recruitment is a process that occurs in a southwest to northeast fashion along the coast following seawater temperatures closely. Data from http://www.neracoos.org/datatools/realtime/SST.
additional flotation under the nets. It appeared that the buoyancy created by the Styrofoam floats at Barney’s Cove and Potato Patch was not enough to keep up with the level of sedimentation that occurred. The high rate of sediment build-up on all of the nets at both sites did not permit them to act in a fashion that would protect settling clam recruits. Adding more floats to nets, especially those in very soft mud, would likely solve this problem. In addition, it is possible to remove sediments from the top of nets by scraping off excess mud with a squeegee; however, doing so will likely remove 0-year class recruits from the plot.

- **Nets need to be routinely inspected for rips, tears, and the presence of green crabs**

Netting cannot perform its predator-deterrent function if it is ripped or torn. Nor, can it exclude predators effectively if sediments within the netted plot contain predators immediately prior to affixing it to the benthos. It is impossible to remove small green crabs (< 12 mm, or ½-inch) that are in the sediments in a plot that is to receive netting. It is more feasible to remove larger crabs, however, prior to net placement over a particular plot. In some instances, we have used garden rakes with tines that extend 5-8 cm into the sediments to extract crabs prior to net deployment over a certain plot. In addition, an edge of the net that lifts out of the sediments or a piece that gets ripped or torn will turn a predator-deterrent plot into a predator haven. Crabs that enter the plot through a rip or tear or an edge that lifts not only find a place with the potential for lots of food, they also become protected from their predators such as larger crabs, fish, or birds. If the edge of a net lifts, it can be re-seated fairly easily. If one or more crabs are observed underneath a net, then the net should be lifted (edges pulled out of the mud and the net rolled back exposing the plot) to allow access to remove the crab(s). If the net is torn in such a way that the ripped area can be pushed into the sediments making the larger plot completely protected, then that should be done; otherwise, if the rip or tear is too large, either the net should be completely replaced or the plot size shrunk to meet the size of a smaller, but whole, net. Routine inspection (at least on a weekly basis) is the best hedge against problems with nets.

Nets have been used with some success during the past two decades to protect cultured soft-shell clams from predators (Beal, 2005). Often, netted plots attract and then protect wild clam recruits. Further work to examine factors affecting the spatial and temporal variability of wild clam enhancement will lead to stronger, better-informed shellfish management options for communities.
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