Final Report

Green Crab, *Carcinus maenas*, Trapping Studies in the Harraseeket River, and Manipulative Field Trials to Determine Effects of Green Crabs on the Fate and Growth of Wild and Cultured Individuals of Soft-Shell Clams, *Mya arenaria* (May to November 2013)

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EXECUTIVE SUMMARY

In 2013, the Freeport Town Council approved funding a "Shellfish Restoration Project." The overarching goals of this field-based effort were to: 1) understand how trapping, netting, and fencing can reduce green crab predation on young-of-the-year clams (i.e., spat, "recruits," or 0-year class individuals); and, 2) understand how reduced crab predation correlates with increased spat survival.

Planned activities focused on three areas of study: 1) green crab trapping in the Harraseeket River at areas adjacent to and south of Weston Point (near Collins Cove) vs. areas north of Weston Point (at Porter Landing, Pettengill flat, and Sandy Beach) to collect information on the relationship between trap immersion time and catch-per-unit-effort (CPUE), how CPUE varied through time and by location, and how size-frequencies of male and female green crabs as well as sex ratios varied spatially and temporally; 2) the role of fenced vs. control vs. netted plots in enhancing 0-year class soft-shell clam individuals (Little River Flat); and 3) the effect of large-scale green crab fencing across an entire cove on enhancing wild soft-shell clam recruits (Recompence Flat).

Green crab trapping (using 18-inch diameter x 36-inches long wire traps) occurred from 27 May to 5 November, and involved a total of 15 clammers, seven of whom fished five to ten traps regularly over at least some of that period. A total of ca. 300 hauls (1 to 10 traps per haul) were recorded over the 162 days between May and November, with a total of 13,065 lbs. (ca. 6 metric tons) of green crabs harvested. Of that total, 11,715 crabs were measured and the sex of each determined. The average size (carapace width - CW) of crabs was 59.5 mm, and overall sex ratio (M:F) was 72% : 28%. Approximately 1% of females measured were ovigerous, and the last date than an egg-bearing female was trapped was 22 August.

At three of four locations south of Weston Point (upper and lower intertidal near Collins Cove, and the subtidal channel off Weston Point), catch-per-unit-effort (CPUE) was independent of time, averaging 8.8 lbs/trap. At the fourth location (lowest intertidal near Collins Cove), CPUE increased 100% from an average of 6.1 lbs/trap in June to 12.2

lbs/trap in August/September. At each of the three areas north of Weston Point, CPUE increased from June to September by an average of nearly 50% from 9.9 lbs/trap to 14.7 lbs/trap. Sex ratios were heavily skewed toward males during the earliest hauls (late May to mid-June) and, in six of the seven locations examined closely, the ratios fell significantly over time, with the greatest difference occurring at Pettengill flat where initial ratios were 89% : 11% that fell to 57% : 43% by late October/early November. The average CW of both male and female crabs in all locations decreased by about 4% over time.

A concerted effort over a 6-day period between 25-30 July showed that there was no relationship between CPUE and trap immersion (soak) time (1-day vs. 2-days vs. 3-days) at two intertidal areas and one subtidal area in the lower Harraseeket River. Similarly, in a larger area of the Harraseeket River from 27 May to 8 July 2013, no relationship was observed between CPUE and immersion time (1-day to 5-days).

Fenced plots at Little River Flat and the larger fence (ca. 2,100 ft) at Recompence Flat were not maintained after 1 September (ca. 5 weeks after the fences were initially installed - 27 July). By the time when the plots at Little River Flat and the larger intertidal area at Recompence Flat were sampled (16-17 November), the structural integrity of the fencing had been compromised making assessment of planned comparisons among experimental treatments weak at best. At Little River Flat, netted plots (plastic, flexible, 4.2 mm aperture) contained nearly 10x more 0-year class clams (ca. 90 individuals /m^2) than unnetted, fenced, or control plots (9.5 individuals/m^2). Average size of all clams was 2.7 mm. A resource survey conducted at the upper, mid, and lower intertidal (near the remains of the fencing) at Recompence Flat on 17 November contained soft-shell clams in only 5% of the samples. No commercial size clams were found anywhere except the upper intertidal, a trend observed at Spar Cove in June 2013 during another survey of the intertidal flats.

An experiment to determine the interactive effects of clam size (8 mm, 14 mm, and 19 mm) and predator exclusion (none, one-layer of netting, two-layers of netting) on the fate and growth of hatchery-reared soft-shell clam individuals (reared at the Downeast Institute for Applied Marine Research & Education, Beals, Maine) was conducted from 18 August to 16-

17 November near the mid-intertidal zone at Little River Flat and Recompence Flat, respectively. Survival of all sizes of clams in unprotected experimental units was zero at Recompence Flat and less than 2% at Little River Flat. For clams protected with netting, no difference in survival rate was observed in units at Little River Flat where nearly 56% of clams survived, but at Recompence, survival in the doubly-netted units was 54% compared to 36% in units with one-layer of netting. Growth rates (amount of new shell added over the experimental period) at both sites was remarkably similar (ca. 14.5 mm) and independent of initial clam size or predator exclusion treatment.

A fourth experiment occurred at Little River Flat during 2013 that, although not part of the Freeport Shellfish Restoration Project, provides valuable insight on future directions for research to enhance wild clam populations. On 28 April 2013, the second year of a 2-year study funded by Maine Sea Grant (PI's = Dr. William Ambrose, Bates College; Dr. Brian Beal, University of Maine at Machais) was initiated at three tidal levels (upper, mid, and lower zones). The experiment was concerned with variable growth rate of juvenile soft-shell clams across the tidal gradient. At each tidal height, experimental units containing juvenile clams were placed in the mud. One-third of all units at each tidal height were protected with a single layer of plastic mesh netting, while the remaining two-thirds were protected with two kinds of double-layered netting. Units were retrieved in the fall (15 November) and the contents washed through a 0.5 mm sieve. In one of the double-layered treatments, and independent of tidal height, an average of 1,800 wild clam recruits per m^2 was observed (ca. 165 recruits/ft^2). These results suggests two important things for future activities: 1) timing of the large- and small-scale experiments at Little River did not coincide with the major settlement event(s) for clams in that area (netting, fenced plots, and other experiments designed to examine factors affecting wild clam recruitment should be initiated in the spring [late April/early May]); and 2) there is tremendous capacity remaining in the system to counteract the effects of predators such as green crabs if there is interest in employing (and maintaining regularly) netting or other deterrent measures to enhance survival of cultured clam seed and/or to enhance recruitment of wild clam individuals in protected plots.

INTRODUCTION

The Town of Freeport, Maine has identified its soft-shell clam resources as a vital economic engine to help sustain and grow the town's wealth; that is, clamming is a local industry that provides jobs to its citizens, both directly and indirectly, that benefits the local economy. During the past five years, the fifty-three (53) licensed commercial clammers in Freeport have harvested more soft-shell clams from the 36-miles of shoreline than clammers in any other coastal town in Maine (DMR, 2013). Dockside revenues from clamming in Freeport alone in 2012 was nearly 1/10th of the value from the entire state of Maine (Fig. I-1).

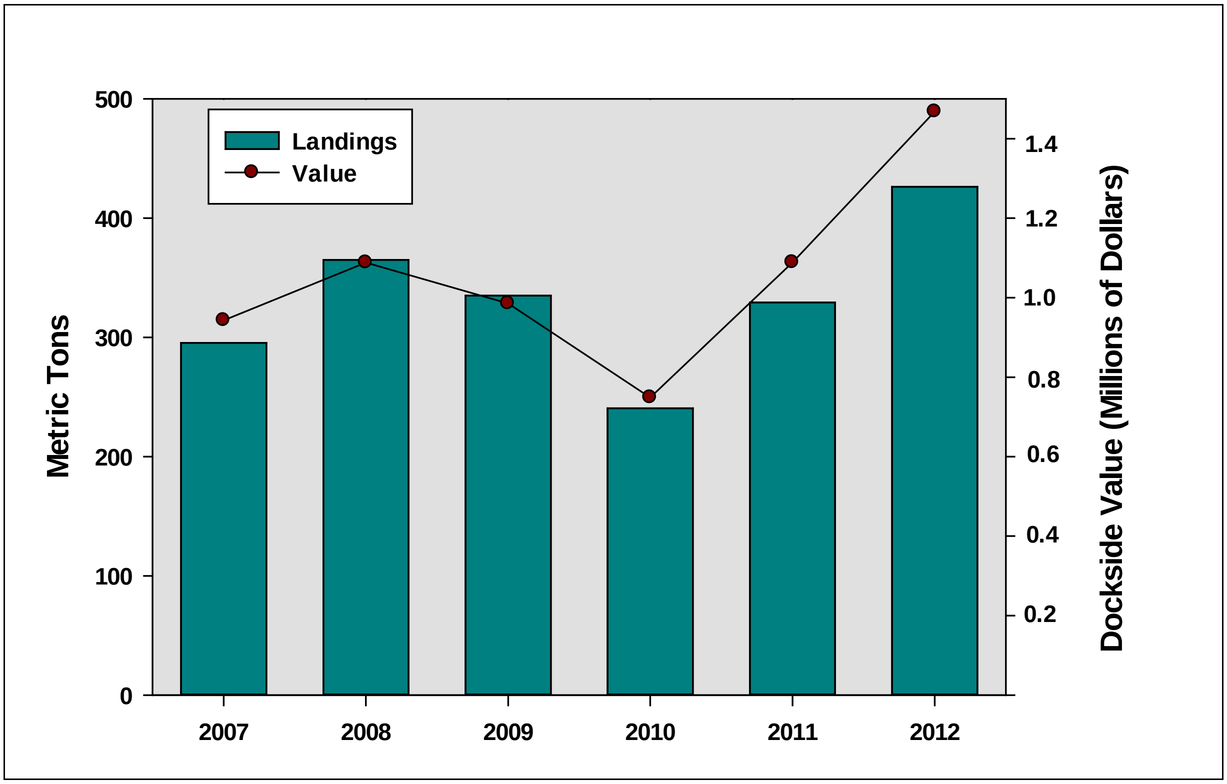

Figure I-1. Soft-shell clam landings and their dockside value by commercial harvesters in Freeport, Maine from 2007- 2012 (DMR, 2013)

The apparent boom in commercial landings is predicted to be short-lived, however. A gloomy forecast has state of Maine shellfish managers predicting dramatic drops in the commercial harvest in the coming years to levels that will not sustain more than a handful of clammers (http://www.pressherald.com/news/Survey-to-gauge-Maines-green-crab-population-.html). The relatively sudden problem has occurred at the same time that dramatic increases in population numbers of the invasive, European green crab, *Carcinus maenas*, have been observed (Whitlow and Grabowski, 2012). The increase in green crab numbers is associated with recent ocean warming trends (de Rivera et al., 2007), but also could be a result of adaptation to cold-temperature regimes in the northern part of its range (Audet et al., 2003; Roman, 2006).

Clammers and local stewardship officials in Freeport and other coastal towns in Casco Bay, including Brunswick, Harpswell, West Bath, and Yarmouth, have noticed during the past few years that commercial densities of soft-shell clams have shifted from the mid- and lower intertidal to the upper shore where the harvest now occurs almost exclusively (Heinig, 2013; R. Tozier, Chebeauge Island shellfish warden, pers. comm; Clint Goodenow, Freeport clammer, pers. comm.; B. Beal, pers. obs.; http://bangordailynews.com/2013/07/09/environment/as-green-crab-invasion-takes-toll-on-maine-clams-researchers-worry-that-lobsters-are-next-victim/). Because clams along the upper shore grow more slowly than at lower tidal levels (Beal et al., 2001), and are significantly older than individuals lower on the shore (Powers et al. 2006), clammers now are benefitting from a cumulative subsidy of years of commercial inactivity at upper shore levels. Because natural recruitment of *Mya* is highly variability throughout its range (Hunt et al., 2003; Bowen and Hunt, 2009; Vassiliev et al. 2010; Morse and Hunt, 2013), at current exploitation rates, it is unclear how long soft-shell clams in Freeport and other southern Maine communities will remain a viable commercial industry.

In 2013, using only local municipal funds, the town of Freeport initiated an historic pilot-scale shellfish management program (Shellfish Restoration Project) to examine the dynamics of green crab populations in the Harraseeket River, and to study the effects of predation on wild clam populations. Specifically, the Town Council approved a plan to quantify population numbers of green crabs at selected intertidal and subtidal sites, and to examine effects of green crab fencing, netting, and trapping on soft-shell clam recruitment. The Council identified several Project Outcomes, to:

1. Understand how trapping, netting and fencing reduces green crab predation in intertidal shellfish habitats;
2. Understand how reduced crab predation correlates with increased spat survival;
3. Identify regional opportunities to collaborate with other towns to address declining clam yields; and,
4. Identify and apply for state/federal grants to continue to enhance the health of the shellfish beds.

This report covers the following activities in 2013:

I. Resource survey at Spar Cove (27 June);
II. Field Experiments at Little River flat to understand the interactive effects of fencing, netting, and trapping on soft-shell clam recruitment (0-year class individuals) (27 July to 16 November);
III. Field Experiments at Little River flat and Recompence flat to follow the fate of three separate sizes of cultured soft-shell clam juveniles in three different predator exclusion treatments (18 August to 16-17 November);
IV. Large-scale, green crab fencing study at Recompence flat (27 July to 17 November);
V. Large-scale, green crab trapping study in the Harraseeket River to examine dynamics of crab populations (27 May to 5 November); and,
VI. Field Experiment at Little River flat (funded through the Maine Sea Grant Program) to examine effects of tidal height and predator exclusion on soft-shell clam recruitment (28 April to 15 November).

METHODS AND MATERIALS

Resource Survey

Spar Cove - 27 June 2013

Five benthic cores (0.0182 m^2) were taken randomly along four 50 m transects placed approximately 25 m apart at each of three intertidal heights (low, mid, and upper) at Spar Cove (Fig. 1).

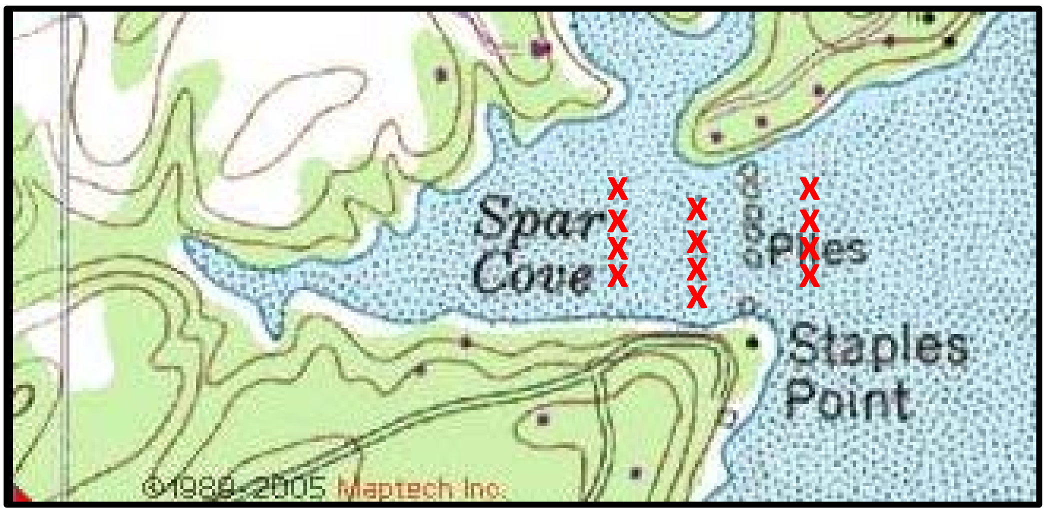

Figure 1. Chart of Spar Cove with approximate position of 50 m transects at the Low, Mid, and High intertidal. Five benthic samples (0.0182 m^2) were taken along each of four transects per tidal height (N = 60).

Samples were placed separately into labeled, plastic bags and washed through a 1 millimeter (mm) sieve. All living soft-shell clams (*Mya arenaria*), hard clams (*Mercenaria mercenaria*), and green crabs (*Carcinus maenas*) from each sample were enumerated and measured to the nearest 0.01 mm using digital calipers (for clams, shell length [SL] – greatest anterior-posterior distance; for crabs, carapace width [CW] – greatest distance between the fifth lateral spines).

To determine differences in density within and between tidal heights, analysis of variance (ANOVA) was performed on the square root-transformed number of individuals of each species per core sample using the following linear model:

$Y_{ijk} = \mu + A_i + B(A)_{j(i)} + e_{k(ij)}$;   Where:

Y_{ijk} = number of soft-shell clams, hard clams, or green crabs per sample;
μ = true mean;
A_i = tidal height (factor is fixed, i = 1 to 3);
B_j = transect (factor is random, j = 1 to 4); and,
e_k = sampling error (difference from sample-to-sample within a transect).

A priori contrasts were used to separate means across tidal heights based on recent observations from clammers regarding commercial clam populations. These observations suggested that commercial densities of soft-shell clams were limited to upper intertidal areas due to green crab foraging behavior. They hypothesized that crabs began foraging on clams closest to deeper water, then, following the contours of the intertidal, continued to prey on clams at mid tidal levels. Upper shore clams are better insulated from green crab attack because: 1) sediments there are more difficult to burrow into during periods when the tide is out; and 2) green crabs are more susceptible to predation from gulls and other birds along the upper shore at low tide (C. Coffin, Maine Clammer's Association, pers. comm.).

A decision rule (Type I error rate, or α) of 0.05 was used to determine significance for this and subsequent statistical tests.

Field Experiment I & II

To determine effects of different methods of green crab deterrence on density of 0-year class individuals of soft-shell clams, two field experiments were initiated near the upper mid-intertidal at Little River flat (Fig. 2) on 27-28 July 2013. In Experiment I, traditional green crab fencing (sensu Smith et al., 1955; Fig. 3a,b) was deployed. Six fenced plots (30-ft x 30-ft, or 900 ft^2, or 83.6 m^2; Fig. 4) and six control plots of a similar size (corners marked with wooden stakes) were established (N = 12). To determine whether crabs were able to somehow move through the fencing, and whether a green crab trap would provide sufficient protection for newly settled clams in non-fenced areas, a baited (cracked, commercial size soft-shell clams) trap (Acer; Fig. 5) was placed within three of the fenced and control plots.

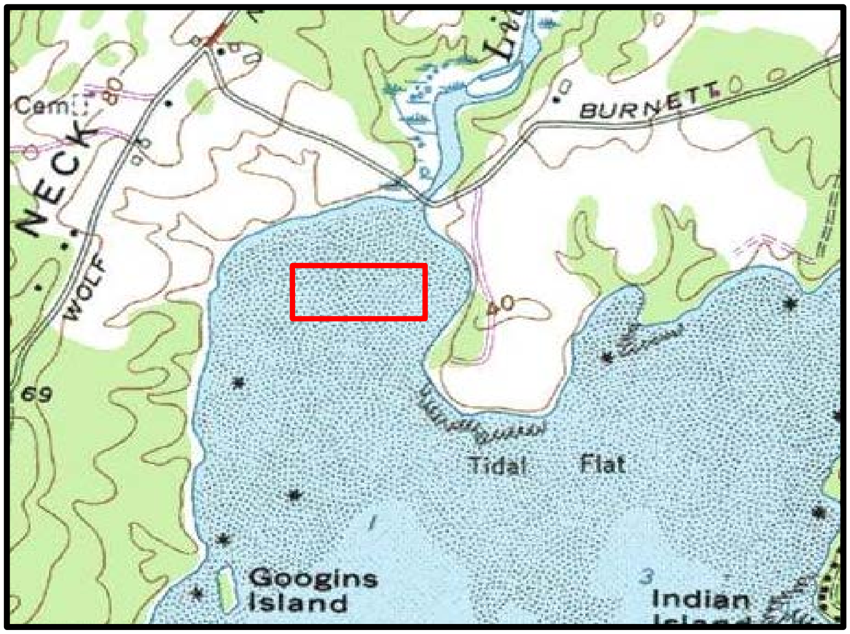

Figure 2. Chart of Little River flat with approximate position of Experiment I & II (initiated on 27-28 July; sampled 16 November 2013).

For Experiment II, ten 22-ft x 14-ft black, flexible plastic (polypropylene) nets (4.2 mm aperture; product OV-7100, Industrial Netting, http://www.industrialnetting.com/pdf/050-900-REV.pdf) were established by walking the periphery of each into the soft mud to secure each in place. Affixed to the underside of each net was an arrangement of five sytrofoam floats in a quincunx pattern – similar to the pattern of five dots on a die. Flotation was used so that netting would not be buried by sedimentary events from storms or winds (Beal & Kraus, 2002). The arrangement of the twelve large plots and the ten netted plots was completely random within the space used at Little River (Figs. 2 & 6).

Figure 3a. Photo of green crab fence used at Sam's Cove, Bremen, Maine (1960). Photo credit: NOAA Central Library Historical Fisheries Collection. Siphon holes at left – inside the fenced area; No siphon holes outside the fence (right side).
http://www.photolib.noaa.gov/htmls/fizh2043.htm

Figure 3b. Photo of green crab fence used at Cumming's Beach, Jonesport, Maine (1954). Photo credit: NOAA Central Library Historical Fisheries Collection. Juvenile seed clams from Western Beach (Scarborough) were transplanted within the fenced plot. http://www.photolib.noaa.gov/htmls/fizh2047.htm

Figure 4. Green crab exclusion fence (30-ft x 30-ft, or 83.6 m^2) at Little River, Freeport, ME on 27 July 2013.

Figure 5. Green crab trap (Acer; ca 18-inches diameter x 36-inches long) used at Little River, Freeport, ME in fenced and control plots.

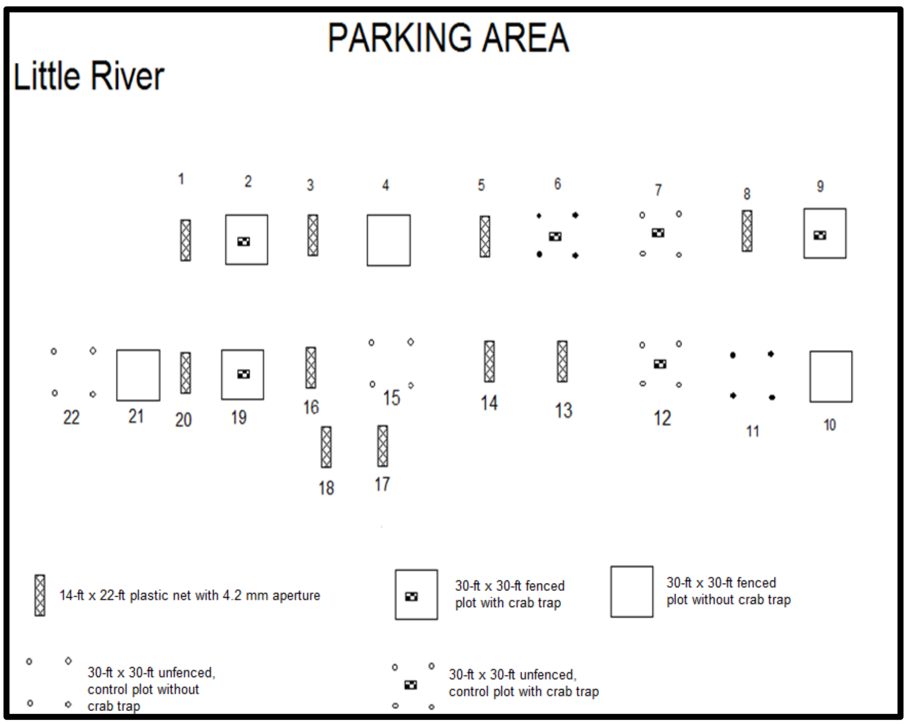

Figure 6. Schematic of the relative position of each replicate of fenced and control plots (with and without green crab traps; Experiment I) and netted plots (Experiment II) at Little River, Freeport, ME on 27 July 2013.

To establish initial densities of juvenile soft-shell clams in each of the 22 experimental plots, five benthic cores (0.0081 m^2) were taken haphazardly in each to a depth of 10 cm (N = 110), and the contents of each sample washed separately through a 0.5 mm sieve. All individuals of *Mya arenaria* were enumerated and the SL measured to the nearest 0.01 mm.

The experimental design called for the crab traps to be baited and hauled from each of the three fenced and control plots weekly, for the contents of each trap to be weighed to the nearest 0.1 kg, and for CW and gender measurements to be taken on each live green crab.

On 16 November 2013, five core samples (0.0182 m^2) were taken haphazardly to a depth of 15 cm from twenty of the twenty-two plots (Figure 6; N = 100). Samples were treated as described above.

Analysis of variance (ANOVA) on the square root-transformed number of juveniles per sample and size (SL) of clams was used to determine differences in mean soft-shell clam abundance and shell lengths, respectively, between the treatments in Experiment I and II using the following linear model:

$Y_{ij} = \mu + A_i + e_{j(i)}$, where:

Y_{ij} = Dependent variable (number of clams per core; mean SL of clams per core);
Ai = Treatment (i = 1 to 6; factor is fixed; Fenced with crab trap; Fenced without crab trap; Control with crab trap; Control without crab trap; Netted plot; Plot that was netted, but netting accidentally removed at time prior to sampling); and,
$e_{j(i)}$ = Sampling error (inherent variation from sample-to-sample within a given plot).

Field Experiment III

Although not originally intended, a third field experiment was developed to examine the fate of three different sizes of cultured juveniles of soft-shell clams ($\bar{x}_{SMALL}$ = 8.18 ± 0.45 mm, n = 30; $\bar{x}_{MEDIUM}$ = 14.19 ± 0.54 mm, n = 29; $\bar{x}_{LARGE}$ = 19.44 ± 0.87 mm, n = 30) arrayed in three different levels of predator exclusion (none; experimental units protected with a piece of flexible netting – 4.2 mm aperture [as described above]; units doubly protected with an extruded piece of plastic netting [VEXAR, 6.4 mm aperture] that sat directly on the unit, with a piece of flexible netting (4.2 mm aperture) used to secure the VEXAR in place (Figs. 7a,b; 8). The experiment was completely factorial with each of the three levels of clam size combined with each of the three levels of predator exclusion to yield nine separate treatments (n = 5 replicates/treatment). Experimental units were 15 cm diameter by 15 cm deep plastic horticultural pots (after Beal, 2006). On 18 August 2013, units were dug into the flat at Little River and Recompence (Freeport, Maine) near the mid intertidal and filled with ambient sediments (no care was taken to remove any existing fauna from the units prior to the start of the experiment). Units were spaced approximately one meter apart in a 9 x 5 matrix, and treatments were randomly assigned a position within the matrix.

On 16 and 17 November (after 90 and 91 days), units were removed from Little River and Recompence flat, respectively, and placed into separately labeled plastic bags. The contents of each experimental unit were washed through a 0.5 mm sieve within 48 hours. All living and dead clams were enumerated. To estimate growth rate for each live clam, an initial and final SL was recorded using digital calipers to the nearest 0.01 mm. Initial SL was measured using a disturbance line that appears in both valves of each cultured animal when it is transferred to sediments (i.e., hatchery mark, sensu Beal et al. 1999; Fig. 9).

ANOVA was used to examine the interactive effects of clam size and predator exclusion on mean survival and absolute growth (final SL – initial SL) at both locations using the following linear model:

$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{k(ij)}$, where:

Y_{ijk} = dependent variable (survival, absolute growth);
μ = true mean;
A_i = Clam Size (factor is fixed; i = 1 to 3 – Small, Medium, Large);
B_j = Predator Exclusion (factor is fixed; j = 1 to 3 – None, Flexible Netting, Flexible & Extruded Netting); and,
$e_{k(ij)}$ = Experimental Error (variability from unit to unit within a given treatment).

Absolute growth was used instead of relative growth because there was no relationship between absolute growth and initial clam size ($P = 0.1256$, $r^2 = 0.0065$, $n = 460$).

Figure 7. **a)** Open experimental unit; **b)** unit with flexible netting to deter predators.

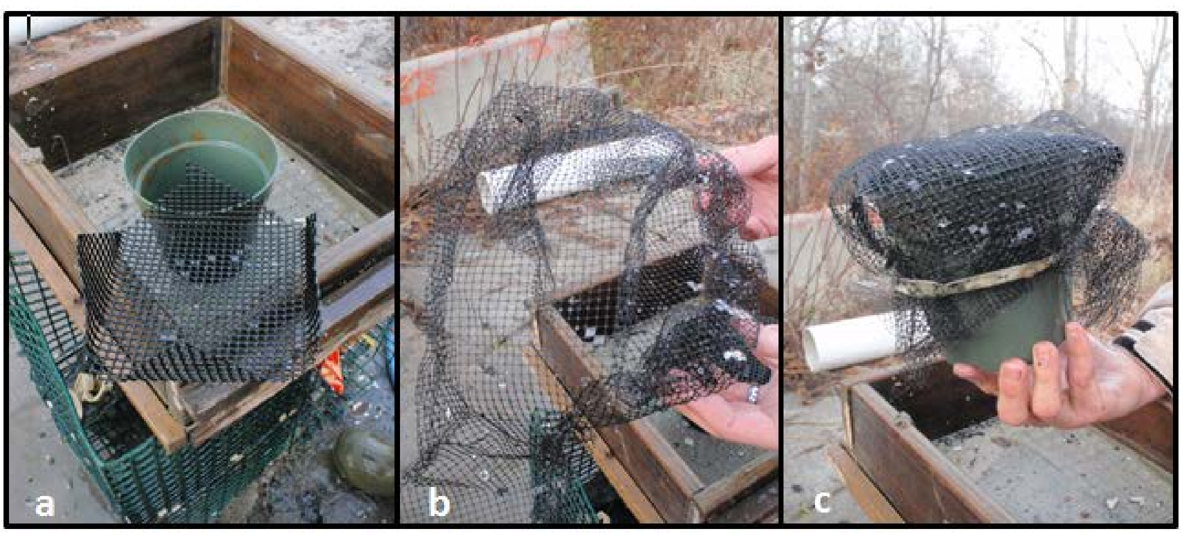

Figure 8. **a)** Experimental unit with extruded piece of VEXAR; **b)** flexible netting; **c)** unit with first layer of VEXAR, then covered with flexible netting to deter predators (i.e., double layer of netting).

Figure 9. Hatchery-reared soft-shell clam that has been growing in a mudflat during a seven-month period (May to November). The clear disturbance line on the left valve in the photograph was laid down at the time when the animal was placed in the sediments of an experimental unit.

Recompence – Green Crab Fencing Project

To deter green crabs from preying on wild soft-shell clams, an effort was made to erect a green crab fence along the mouth of Recompence Flat (Figs. 10, 11) on 27-28 July 2013. Fencing was constructed of wooden units (8, 10, or 12-ft in length) with polypropylene mesh (3/4-inch aperture) stretched over the top 18-inches of each unit (Fig. 12). A 6-inch wide piece of aluminum flashing was affixed to the top of each unit with roofing nails. Flashing was intended to keep crabs from crawling over the fence.

An Army Corps of Engineers permit (issued on 18 July 2013) was required before fencing could be installed. The permit required a 2-ft wide gap in the fence every 150 feet (total = 14 locations) and one 10-ft wide gap (located near the eastern side of the cove). With that stipulation, an effort was made to place one or green crab traps (Fig. 5) at each of the gaps.

Two quantitative inventories were undertaken to estimate juvenile soft-shell clam density and size-frequency distribution at Recompence flat. One occurred on 27 July 2013 using a benthic core (area = 0.008 m^2; n = 75). Samples were taken from the area where the fence was installed to the high tide mark. The other occurred on 17 November 2013 using a larger benthic coring device (area = 0.0182 m^2; n = 78). For the latter inventory, cores were taken along three transects (high, mid, and low – Fig. 13). Two cores were taken from thirteen regularly spaced blocks (16 m^2) along each transect. The contents of each sample were washed through a 0.5 mm sieve. All live soft-shell clams and hard clams were enumerated and measured (as described above).

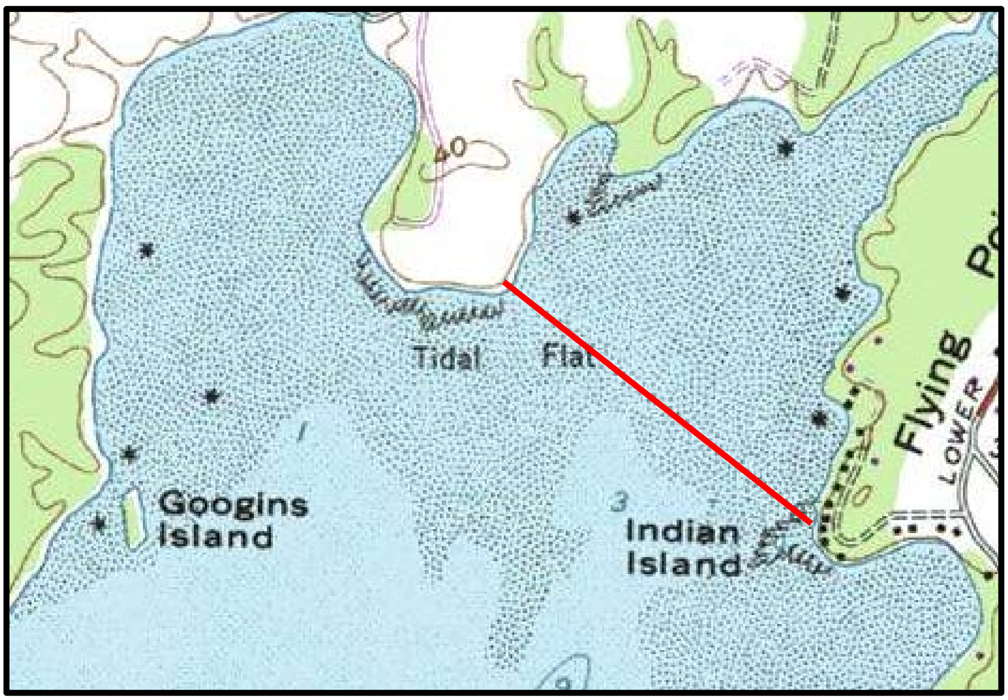

Figure 10. Approximate position of fencing erected at Recompence flat beginning 27-28 July 2013. The project was completed on/near 6 August when the last section was installed on the Indian Island shore.

Figure 11. Clammers installing fencing at Recompence flat on 28 July 2013. Length of fencing was approximately 2,100 feet (640 m).

Figure 12. A 10-ft unit of fencing deployed at Recompence flat on 27- 28 July 2013. The photo to the right shows how the polypropylene mesh was stretched across and secured (staples) to the wooden frame.

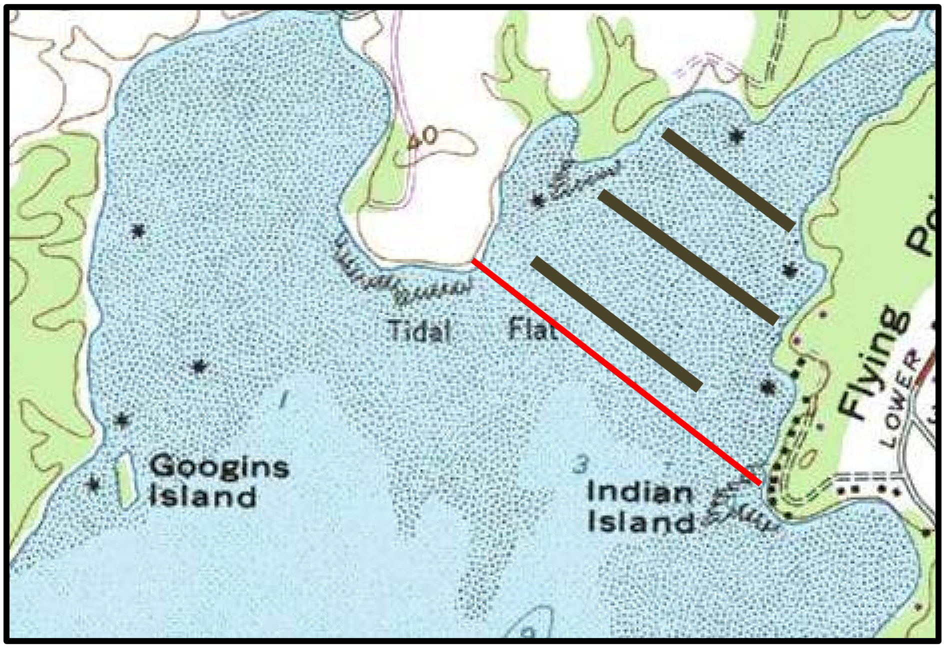

Figure 13. Approximate position of green crab fencing (red) and transects (black) along which benthic cores were taken on 17 November 2013 to estimate juvenile soft-shell clam numbers and size-frequency distribution (n = 26 core samples per transect).

Field Experiment IV

A field experiment unrelated to the Town of Freeport's study on green crabs and soft-shell clams was initiated at the upper, mid, and low intertidal at Little River flat, Freeport, Maine on 28 April 2013. The study was funded through the Maine Sea Grant College Program to two PI's (Dr. Will Ambrose, Bates College; Dr. Brian Beal, University of Maine at Machias) over two years to examine regional effects (southwestern vs. northeastern Maine) of intertidal height on soft-shell clam growth. Information about one aspect of the study is presented here concerning 0-year class individuals that recruited into experimental units.

The study used plastic horticultural plants (as described above) that were deployed in five blocks at each of three tidal heights. Within each block a 2 x 3 matrix of pots was established with two replicates of each of three predator exclusion treatments (i.e., 30 experimental units at each tidal height; N = 90). Twelve hatchery-reared soft-shell clams

($\bar{x}_{SL}$ = 13.4 ± 0.49 mm, n = 60) were added to the sediments within each experimental unit. Two of the treatments were similar to those used in Field Experiment III (i.e., one-third of the units at each tidal height were covered with a piece of flexible netting – aperture = 4.2 mm; one-third of the units were covered with a piece of VEXAR – aperture = 6.4 mm – and and a piece of flexible netting – see Figs. 7 and 8). No unprotected units were used. The remaining experimental units were covered with a piece of VEXAR plus a piece of heavy-duty flexible window screening (Phifer – TUFF; formerly called Pet Screen). In an attempt to keep the window screening from fouling, five adults of the common periwinkle, *Littorina littorea*, were added on top of the VEXAR and underneath the screening.

On 15 November 2013 (201 days), all experimental units from each tidal height were removed from the flat and the contents of each washed through a 0.5 mm sieve within 48 hours. All live clams (cultured and wild) were enumerated and their SL's measured to the nearest 0.01 mm using digital calipers. Data only from the number and size of wild clams is presented here.

Green Crab Trapping in the Harraseeket River

Immersion (soak) Time Study (25-30 July 2013)

To determine if catch-per-unit-effort (CPUE) was related to the time that traps were immersed (allowed to fish), a study was conducted at three sites in the Harraseeket River (lower intertidal at Spar Cove, subtidal channel to the east of Collins Cove off Weston Point, and an intertidal location along the Wolfe Neck shore (Fig. 14). Traps deployed at each site were allowed to fish either for one, two, or three days. Five Acer traps (Fig. 5) were baited once during high tide with live (cracked) soft-shell clams (ca. 1 pound – 0.45 kg/trap). When hauled, the contents of each trap were pooled and the total mass was taken to the nearest 0.1 pound using a digital scale. In addition, a random sample of approximately 10% of the pooled mass of the five traps was taken, and the carapace width and sex of each crab in the sample was recorded. Female crabs that were ovigerous were noted.

To determine whether catch-per-unit-effort (defined as the mass of crabs caught per five traps hauled) was affected by trap immersion (= soak) time, two methods were used. First, ANOVA was performed on the effect of immersion time on mean CPUE. Second, regression analysis was done to determine the relationship between CPUE and immersion time.

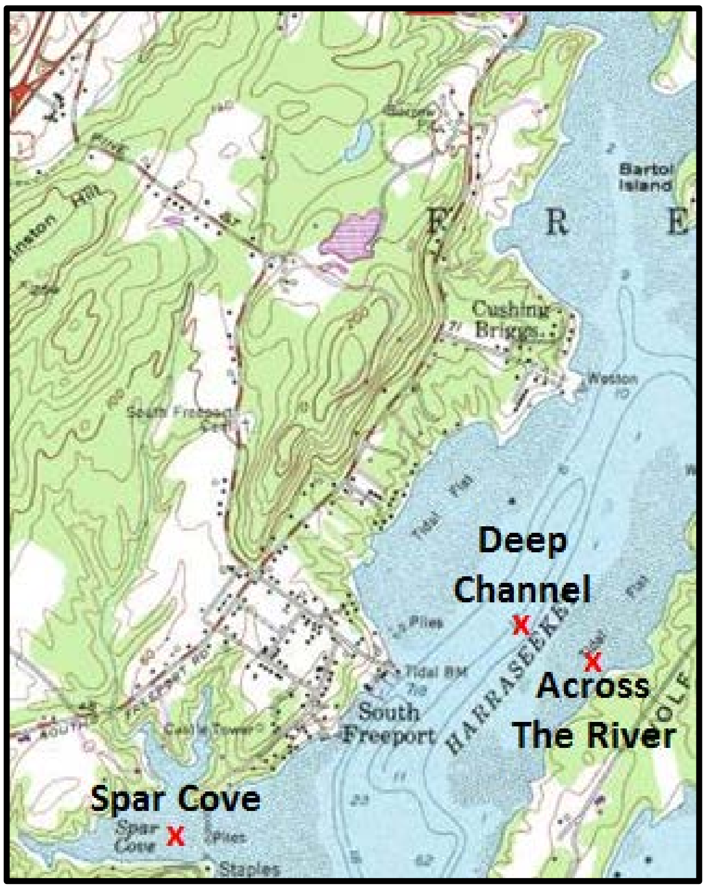

Figure 14. Approximate position of crab traps used in the soak time study (25-30 July 2013).

<u>Large-scale trapping study (27 May to 5 November 2013)</u>

A trapping study using Acer traps (Fig. 5) was conducted in the upper portion of the Harraseeket River during 2013 for approximately five months from the late spring to mid-fall. Initially, fishermen were issued and responsible for tending (deploying, hauling, baiting, collecting green crabs) five traps; however, some tended fewer than this and some a few more. Fishermen used live or frozen (cracked) soft-shell clams that were retained in a bait bag (ca. 1 pound of clams per bag) tied securely within each trap. When the five traps were hauled, all green crabs were pooled into a common container, and then the mass of all of the crabs recorded to the nearest 0.1 pound using a digital scale. A 10% (by weight) sub-sample from each pooled sample was taken and the CW and sex of each crab was recorded. Ovigerous females in a subsample were also noted.

From 27 May to 8 July, data on the location of the traps in the river was collected sporadically (i.e., it was not common for fishermen to record the exact location of their traps on the data sheets). During this period, a majority of the data sheets contained information about the number of traps fished and the number of days between hauling (soak times); however, after 9 July, this categorical data was recorded very infrequently.

Several fishermen tended gear regularly within the period between 27 May and 5 November 2013 to answer specific questions about green crab population dynamics in discrete locations. Seven areas (Fig. 15) – four below and three above Weston Point – were examined closely to discern how location affected: 1) catch-per-unit-effort; 2) size-frequency distribution of male and female green crabs; and 3) sex ratios.

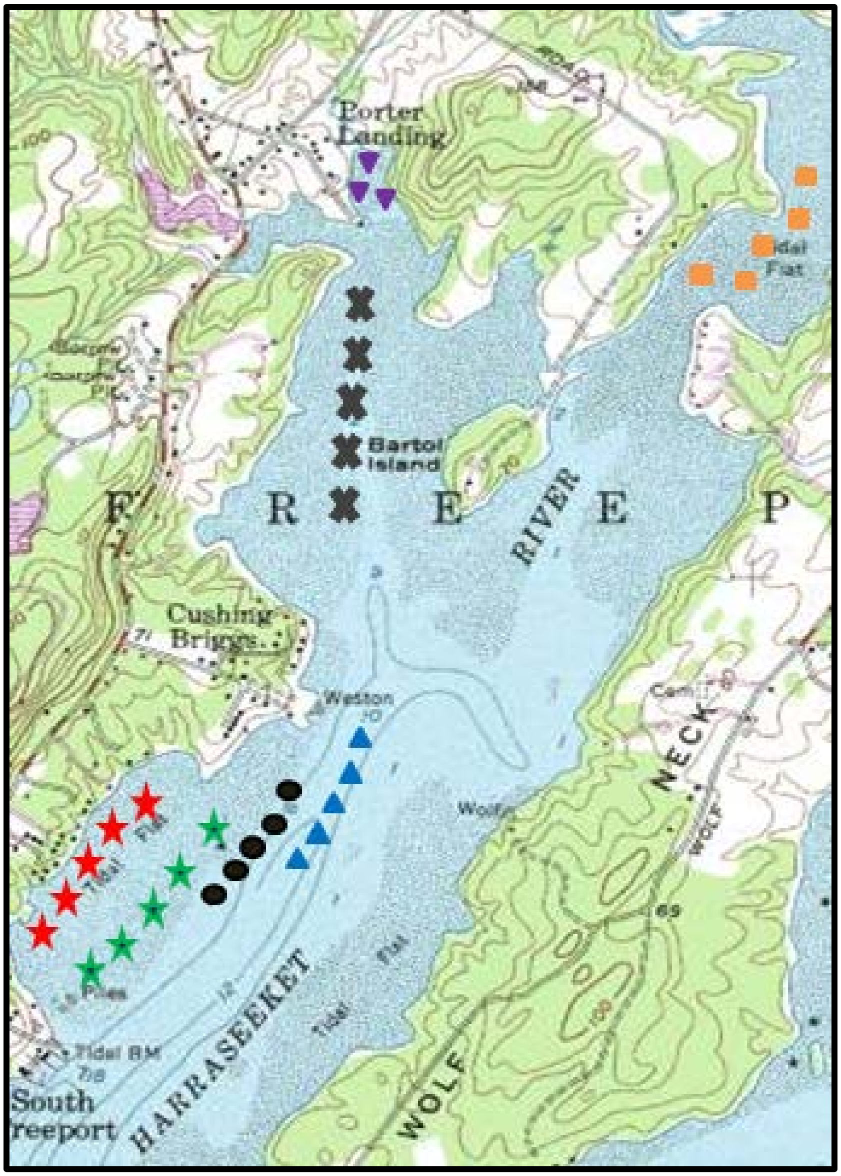

Figure 15. Chart of the upper Harraseeket River denoting discrete areas where seven clammers consistently fished green crab traps during the period from late May through early November 2013. Red stars = High intertidal (Collin's Cove); Green stars = Low intertidal (Collin's Cove); Black circles = Extreme low intertidal (Collin's Cove); Blue triangles = Channel off Weston Point (subtidal); Purple triangles = Intertidal (above Porter's Landing); Orange squares = Intertidal (Pettengill flat); Gray crosses = Intertidal (Sandy Beach). Number of icons per location may not be representative of the number of traps fished in a given location.

RESULTS

Resource Survey

Spar Cove - 27 June 2013

Soft-shell clams

Soft-shell clams occurred in samples only from the upper intertidal (mean density ± 95% confidence interval = 34.5 ± 19.56 individuals m^{-2}, or 3.2 ± 1.8 individuals ft^{-2}). This difference in mean density between tidal heights was statistically significant (Table 1).

The size distribution of soft-shell clams (Fig. 15) indicates that less than 5% of the clams in the upper intertidal transects were commercial in size (i.e., $\geq$ 50.8 mm SL, or 2-inches). The smallest clam in the samples was 8.7 mm SL. This clam had settled to the flat during the previous fall as it, and others less than 20 mm SL, had visible overwinter check marks in their valves. Median SL was 17.5 mm.

Table 1. ANOVA on the mean number of soft-shell clams across three tidal heights and four transects nested within each tidal height at Spar Cove on 27 June 2013 (n = 5; N = 60). Boldface P-values represent a statistically significant source of variation.

Source of variation	df	SS	MS	F	Pr > F
Tidal Height	2	5.3007	2.6504	6.14	**0.0208**
Upper vs. Mid & Low	1	5.3007	5.3007	12.29	**0.0067**
Mid vs. Low	1	0.0000	0.0000	0.00	1.0000
Transect(Tidal Height)	9	3.8827	0.4314	2.89	**0.0082**
Upper Transects	3	3.8827	1.2942	8.67	**0.0001**
Mid Transects	3	0.0000	0.0000	0.00	1.0000
Low Transects	3	0.0000	0.0000	0.00	1.0000
Sampling Error	48	7.1662	0.1493		
Total	59	16.3496			

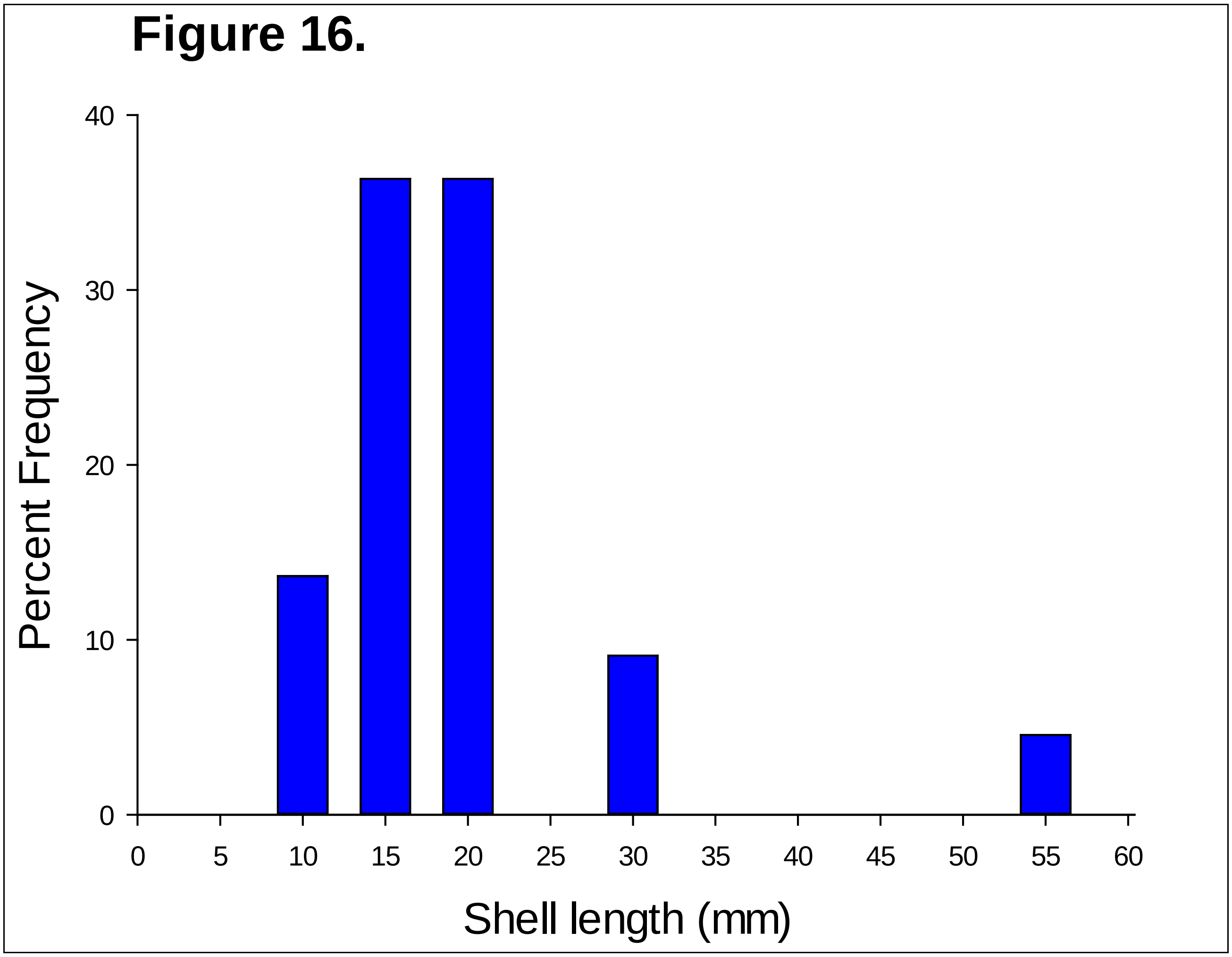

Figure 16. Size-frequency distribution of soft-shell clams occurring in upper intertidal core samples at Spar Cove on 27 June 2013. Approximately 95% of the clams were sub-legal (i.e., $\leq$ 50.8 mm SL, or 2-inches). N =22.

Hard clams

Hard clams occurred only in mid- and low intertidal transects, but at very low densities (e.g., 0.2 ± 0.19 individuals m^{-2} at the mid intertidal; 0.15 ± 0.17 individuals m^{-2} at the low intertidal). There was no statistical difference in mean density between tidal heights (Table 2). A total of four individuals were sampled from mid intertidal cores (minimum SL = 5.26 mm; maximum SL = 48.04 mm) and three from low intertidal cores (minimum SL = 15.15 mm; maximum SL = 45.98 mm).

Table 2. ANOVA on the mean number of hard clams across three tidal heights and four transects nested within each tidal height at Spar Cove on 27 June 2013 (n = 5; N = 60).

Source of variation	df	SS	MS	F	Pr > F
Tidal Height	2	0.4333	0.2167	2.05	0.1843
Upper vs. Mid & Low	1	0.4083	0.4083	3.87	0.0808
Mid vs. Low	1	0.0250	0.0250	0.24	0.6381
Transect(Tidal Height)	9	0.9500	0.4314	2.05	0.1843
Sampling Error	48	4.8000	0.1000		
Total	59	6.1833			

Green crabs

A total of four green crabs occurred in four of the twenty samples from the mid intertidal (0.2 ± 0.19 individuals m^{-2}; CW for each crab = 8.38 mm, 10.18 mm, 10.54 mm, and 13.73 mm) and in one sample from the low intertidal (0.05 ± 0.10 individuals m^{-2}; 15.86 mm). These differences in density between tidal heights were not statistically significant (P = 0.2857).

Field Experiment I & II

Initial sampling of the benthos – 27 July 2013

None of the cores (N = 110) contained live soft-shell clams.

Management of fenced and netted areas and on-going trapping (27 July to 16 November)

Although some details remain unclear as to why, it was clear that maintenance of the six fenced areas at Little River ceased around 1 September, approximately one month after the experiment was initiated. Unfortunately, this lack of maintenance, along with continued erosion due to tidal currents through the late summer and fall, resulted in breeches near the sediment surface in all six fenced plots. These gaps in the fencing were large enough so that by 12 October 2013 green crabs of most sizes could enter the plots (see Fig. 17 a,b). By the

16 November sampling, most of the fences had completely collapsed (Fig 18), and their effectiveness as a deterrence to crabs of any size was entirely compromised. In addition, collection of data from traps did not occur according to the experimental design. Between 27 July and 16 November, when the experiment ceased, sixteen weeks occurred. However, traps were hauled, re-baited, and data on total crab weight/trap, crab size and gender were collected less than 50% of the time (Table 3). Also, crab traps that were supposed to be in a specific (i.e., fixed) fenced or control plot throughout the entire experiment (see Fig. 6), were not found on three occasions in the specific, intended replicate plot (Table 4). As a result, it was not possible to correlate clam recruit numbers to specific treatments.

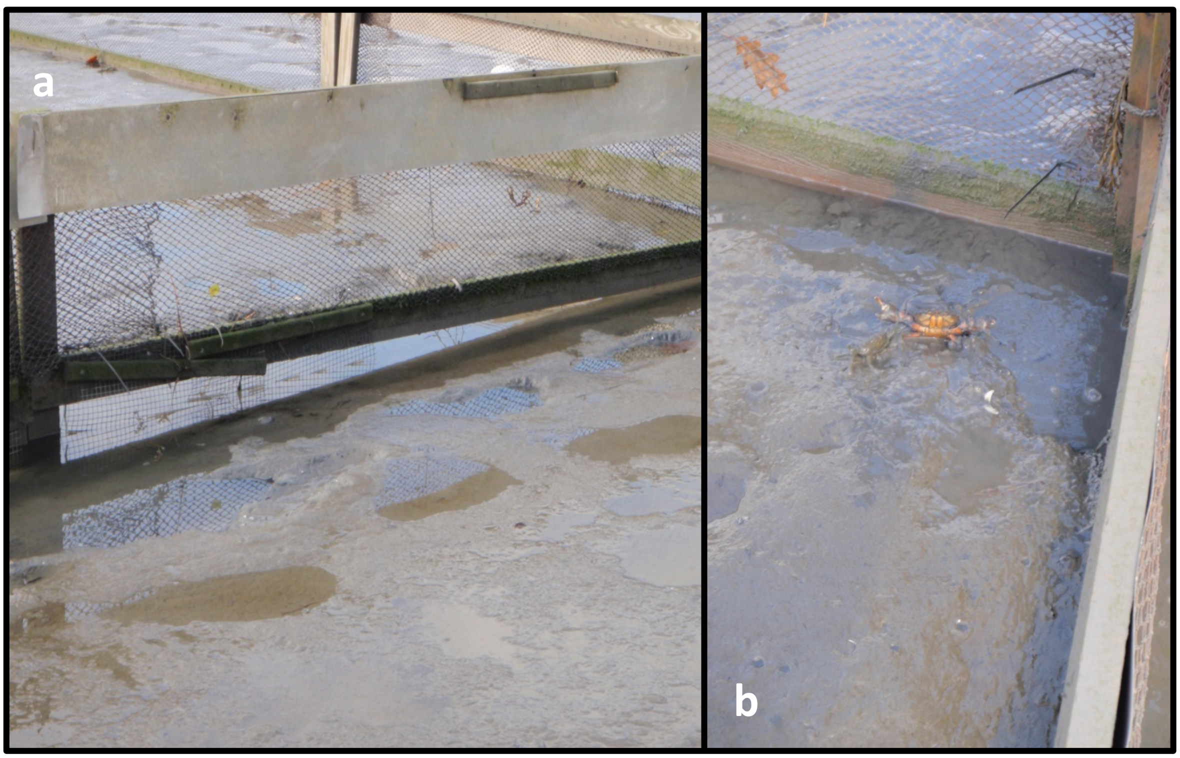

Figure 17. a) Photograph showing large breech near the sediment surface in one of the fenced plots at Little River flat, Freeport, Maine on 12 October 2013. **b)** Evidence that breeched fences were populated by green crabs. The photo shows a large (ca. 55-60 mm CW) male with chelipeds extended and a smaller female (adjacent, and to the immediate left of the male).

Table 3. Dates when green crab traps (N = 6) were scheduled to be hauled, re-baited, and data retrieved at Little River flat for Experiment I (27 July to 16 August 2013) versus when traps were actually hauled and data collected.

Week	Scheduled haul date	Were traps hauled and data collected?
Week I	28 July	Yes
Week II	4 August	No
Week III	11 August	No
Week IV	18 August	No
Week V	25 August	No
Week VI	1 September	No
Week VII	8 September	No
Week VIII	15 September	No
Week IX	22 September	No
Week X	29 September	No
Week XI	6 October	Yes
Week XII	13 October	Yes
Week XIII	20 October	Yes
Week XIV	27 October	No
Week XV	3 November	Yes
Week XVI	10 November	Yes

Netted plots required regular maintenance; however, this activity did not occur, either. By 16 November two nets (#'s 17 & 18; see Fig. 6) had disappeared, and it was not possible to determine the position they had been. Four nets (#'s 13, 14, 16, 20) had disappeared, but it was possible to determine where they had been based on an outline on the sediment surface in the area where each of the nets had been deployed (Fig. 19a), and four nets (#'s 1, 3, 5, 8) were intact (Fig. 19b). Five core samples were taken from each of the four plots where nets had disappeared (N = 20), and from the plots where nets had remained intact (N = 20).

0-Year class soft-shell clams

Mean density of clams in fenced and control plots (with and without green crab traps), as well as netted plots in which the nets had disappeared, was 0.175 ± 0.1283 individuals core^{-1} (n = 16; 9.5 ± 6.97 individuals m^{-2}). The density of clams in the four netted (intact) plots was nearly an order of magnitude greater (1.7 ± 3.59 individuals core^{-1}, or 92.3 ± 194.7 individuals m^{-2}). This difference in mean density between the four netted plots and the sixteen other plots was statistically significant (P = 0.0086; Table 5; Fig. 20).

Figure 18. Photograph showing nearly complete collapse of the one of the six fences at Little River flat, Freeport, Maine on 16 November 2013. Notice that most of the fences in the background encountered a similar fate.

Clams occurring in benthic cores ranged in size from 1.57 mm to 6.65 mm SL (n = 48). Approximately 65% of the clams were smaller than 3 mm SL; Fig. 21). Mean clam size (SL = 2.68 ± 0.37 mm, n = 23) did not vary significantly across treatments (P = 0.8714), and clam size-frequency distribution was independent of treatment (P = 0.5118, Fisher's Exact Test, df = 15).

<u>Green crab trapping (Experiment I)</u>

Because traps were not maintained in the specific plot throughout the course of the experimental period as intended (Fig, 6; Table 4), it was not possible to determine whether fencing reduced green crab density. Instead, the data were used to ask whether mean weight per trap, mean carapace width, and sex ratios varied significantly through time. Neither mean weight per trap (9.86 ± 2.3 pounds, or 4.48 ± 1.05 kg, n = 38) nor mean carapace width (49.43 ± 1.73 mm, n = 40) varied significantly across sampling dates (P = 0.5698 and P = 0.9055, respectively; Fig. 22). Sex ratios of crabs varied significantly from July (56%:44% = M:F) to the other sampling dates (4 in October and 2 in November) when the ratio was reversed, with females dominating (38%:62%; Table 6; Fig. 23).

Table 4. Brief account of position within the experimental matrix (Fig. 6) where green crab traps were noted on a particular date. (Note that the position of each trap was correct on 28 July 2013.)

Date	**Plot number**	**Treatment**	**Replicate**
28 July	2	Fenced Plot	a
	6	Control Plot	a
	7	Control Plot	b
	9	Fenced Plot	b
	12	Control Plot	c
	19	Fenced Plot	c
29 October	Between plot 8 & 9	No treatment	
&	9	Fenced Plot	a?
10 November	10	Fenced Plot	b?
	South of plot 10	No treatment	
	21	Fenced Plot	c?
	Between plot 21 & 22	No treatment	
16 November	Between plot 7 & 8	No treatment	
	4	Fenced plot	a?
	10	Fenced plot	b?
	South of plot 11	No treatment	
	21	Fenced plot	c?
	Between plot 19 & 20	No treatment	

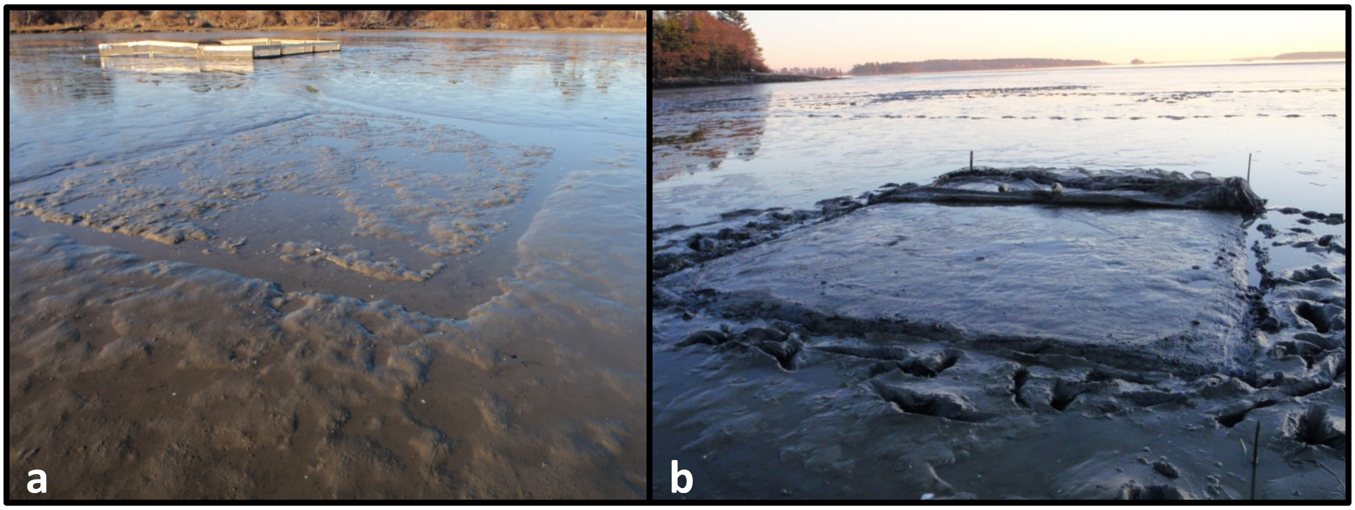

Figure 19. a) Area at Little River flat, Freeport, Maine, where a 22-ft x 14-ft piece of flexible netting had been deployed, but the netting was lost due to wind and/or storm events. It is likely that this net, and three similar nets, was lost within two weeks of when the photograph was taken (16 November 2013). Five benthic cores were taken in each of the four previously-netted plots, **b)** A netted plot (intact) with the netting peeled back prior to taking five benthic cores.

Table 5. ANOVA on the mean number of soft-shell clams sampled from fenced and control plots with and without crab traps (Experiment I) and from netted and unnetted plots (Experiment II) at Little River flat, Freeport, Maine on 16 November 2013. Boldface P-values indicate statistical significance. (n = 5)

Source of variation	df	SS	MS	F	Pr > F
Treatment	5	10.9603	2.1921	2.07	0.1299
Netting vs. Rest	1	9.8578	9.8578	9.32	**0.0086**
Net gone vs. Rest	1	0.2785	0.2875	0.26	0.6171
Fence vs. Control	1	0.4414	0.4414	0.42	0.0808
Fence (with vs. without trap)	1	0.1535	0.1535	0.15	0.7089
Control (with vs. w/o trap)	1	0.0333	0.0333	0.03	0.8616
Replicate(Treatment)	14	14.8069	1.0576	6.72	<**0.0001**
Sampling Error	80	12.5992	0.1575		
Total	99	38.3664			

Figure 20.

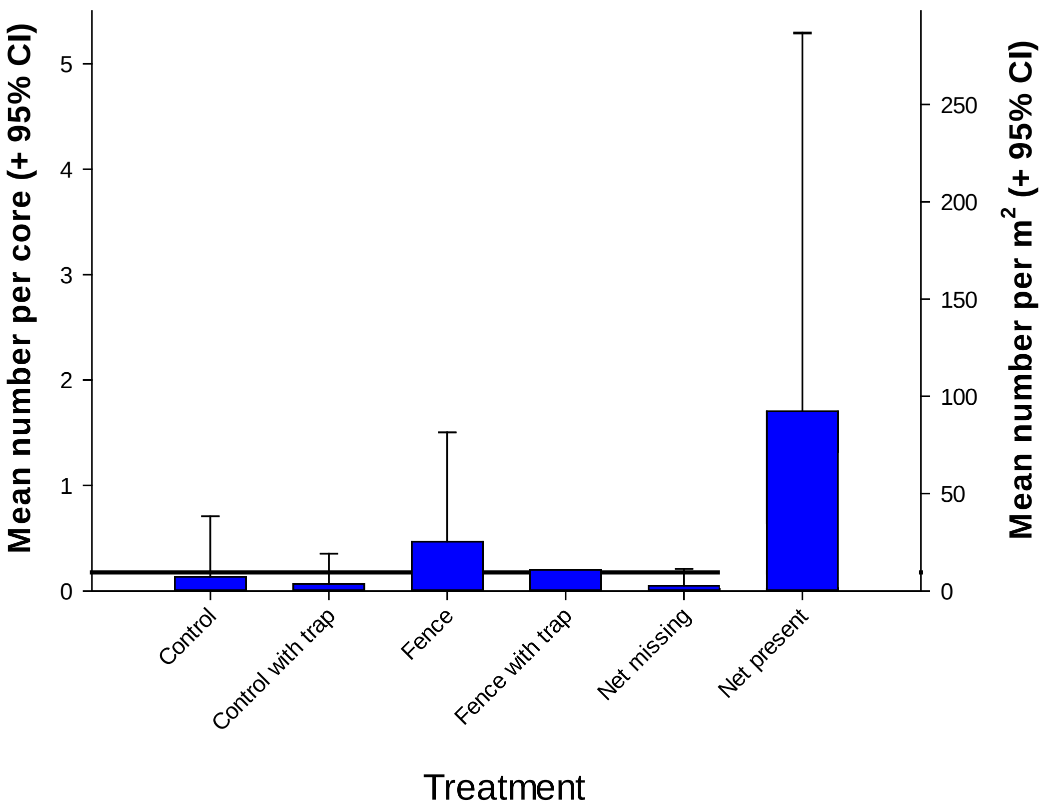

Figure 20. Mean number of soft-shell clam juveniles that occurred in benthic cores in Experiment I & II at Little River flat, Freeport, Maine on 16 November 2013. The black, horizontal reference line through five of the treatments is the overall mean for those treatments (0.175 individuals per core, or 9.5 individuals m^{-2}). The mean clam number in the fully netted plots was nearly an order of magnitude greater (1.7 individuals per core, or 92.3 individuals m^{-2}) than the mean of the other five treatments.

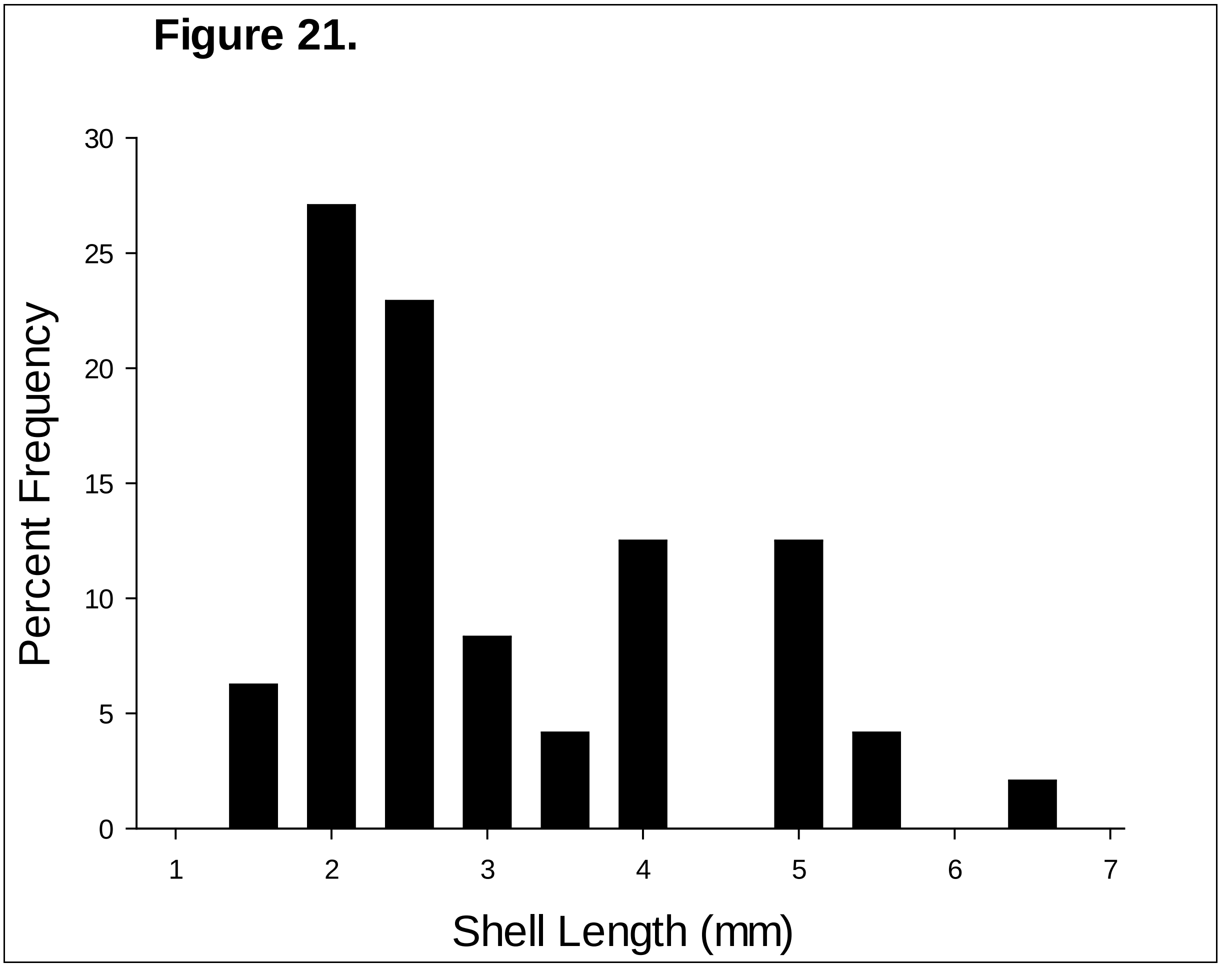

Figure 21. Size-frequency distribution of clams that occurred in benthic cores from Experiment I & II from Little River Flat, Freeport, Maine on 16 November 2013. No statistical difference in mean size (P = 0.8714) or in size distribution (P = 0.5118) occurred between treatments.

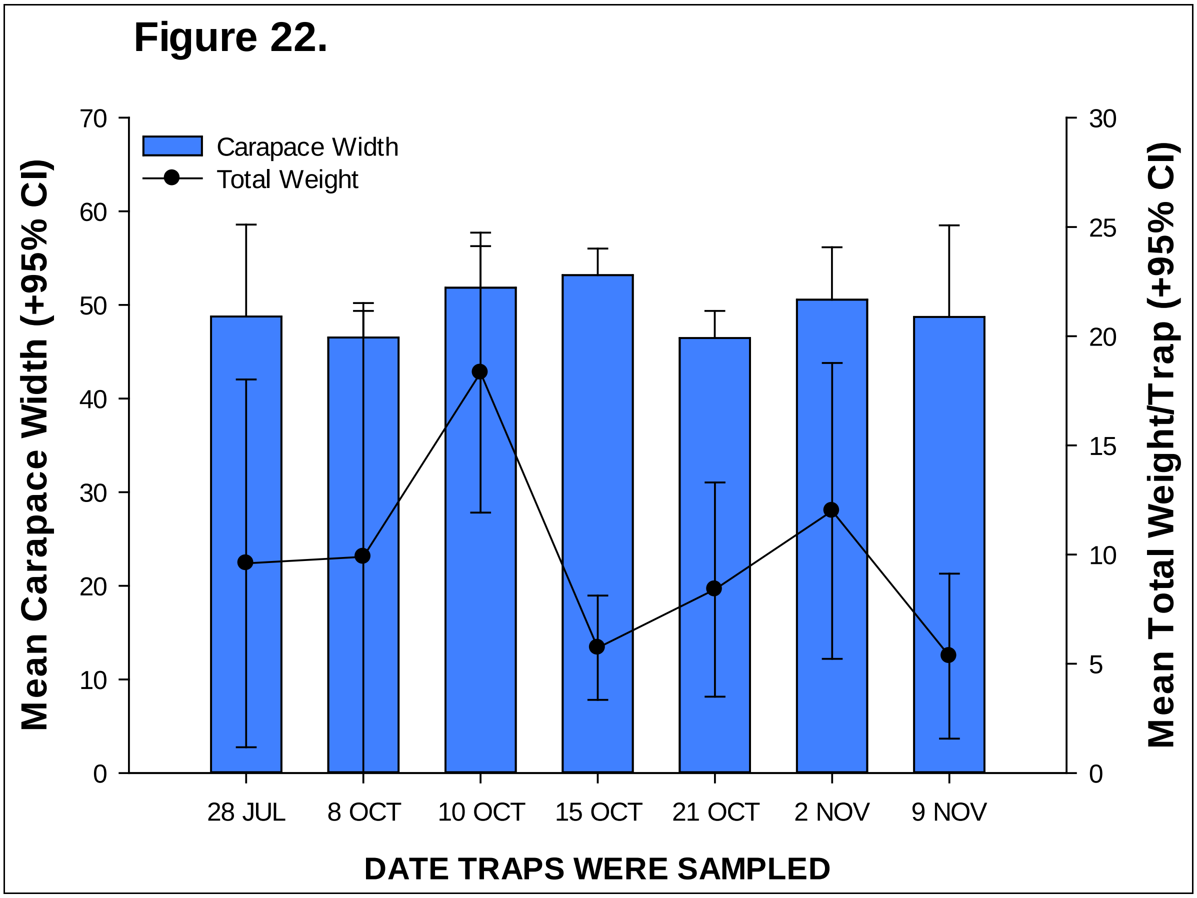

Figure 22. Mean carapace width (mm) of green crabs (bars) and mean total weight (pounds) of crabs from traps deployed for Experiment I at Little River Flat, Freeport, Maine during July to November 2013. No statistical difference in mean carapace width (P = 0.9055) or in mean total weight per trap (P = 0.5698) were detected over time.

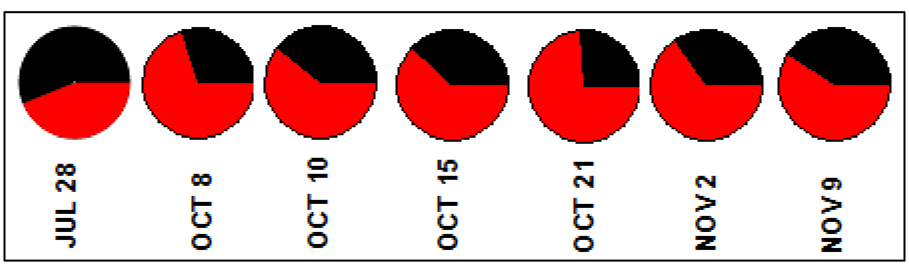

Figure 23. Sex ratios (black:red = male:female) of green crabs on each sampling date at Little River flat, Freeport, Maine in 2013. Ratios reversed through time with females becoming more dominant numerically. (See Table 6 for analysis of variance results.)

Table 6. ANOVA on the angular-transformed mean sex ratios of green crabs from traps at Little River flat, Freeport, Maine that were sampled on seven occasions between 28 July and 9 November (Table 3). On five occasions, all six traps were hauled. On two occasions, only five of the traps were hauled (N = 40). Boldface P-values indicate statistical significance.

Source of variation	df	SS	MS	F	Pr > F
Sampling Date	6	1199.76	199.96	4.83	**0.0012**
July vs. Rest	1	816.62	816.62	19.73	<**0.0001**
October vs. November	1	51.12	51.12	1.23	0.2745
2 Nov. vs. 9 Nov.	1	36.33	36.33	0.88	0.3557
Sampling Error	33	1366.18	41.40		
Total	39	2565.94			

Table 7. ANOVA on the angular-transformed mean percent survival of cultured individuals of *Mya arenaria* in experimental units at Little River flat, Freeport, Maine from 18 August to 16 November 2013 (90 days). Boldface P-values indicate statistical significance (n = 5).

Source of variation	df	SS	MS	F	Pr > F
Clam Size	2	2407.05	1203.53	3.45	**0.0424**
Small vs. Medium & Large	1	2210.87	2210.87	6.35	**0.0163**
Medium vs. Large	1	196.18	196.18	0.56	0.4579
Predator Exclusion	2	20782.06	10391.03	29.83	<**0.0001**
Open vs. Netted	1	20704.39	20704.39	59.43	<**0.0001**
Flexible vs. VEXAR	1	77.67	77.67	0.22	0.6396
Clam Size x Exclusion	4	1559.16	389.79	1.12	0.3628
Experimental Error	36	12541.74	348.38		
Total	44	37290.01			

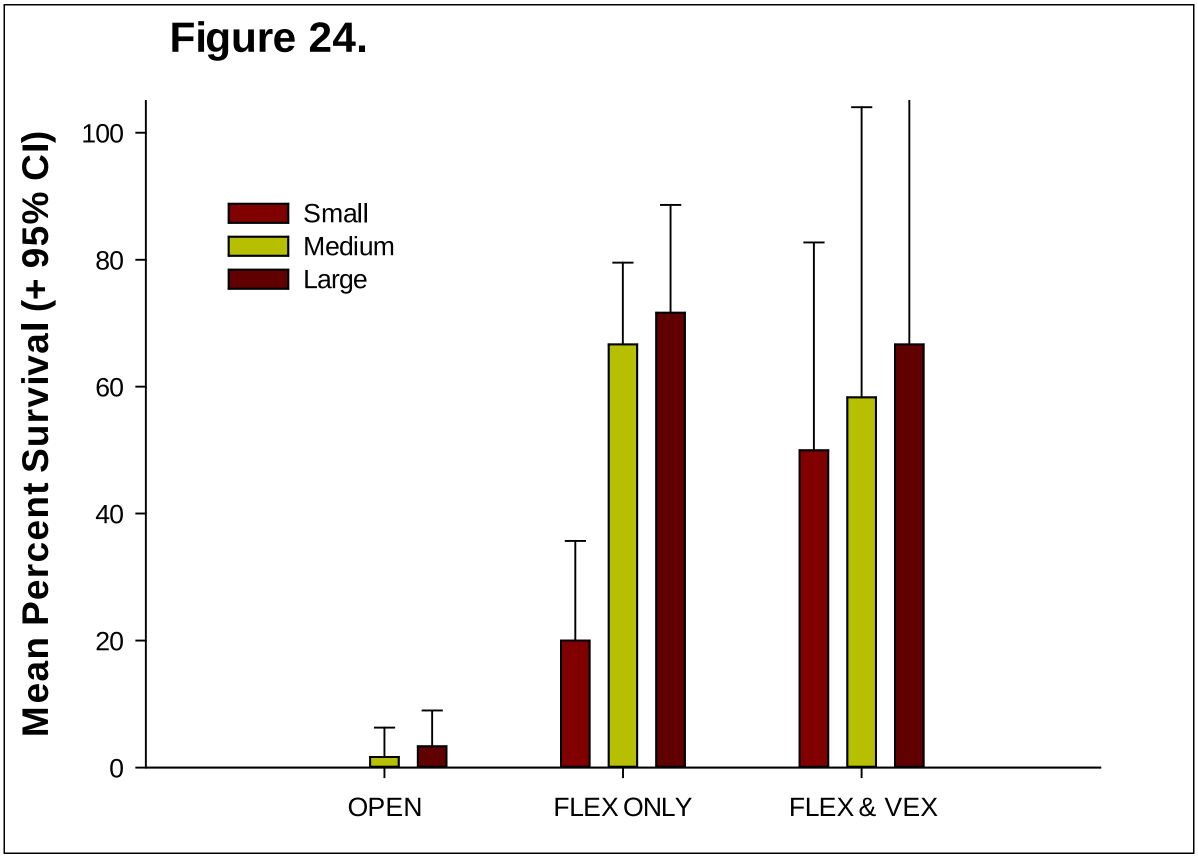

Figure 24. Mean percent survival (+ 95% confidence interval) of cultured clam juveniles in experimental units near the mid intertidal at Little River flat from 18 August to 16 November 2013 (90 days). Small, Medium, and Large refer to initial clam size (see text for specifics). Open, Flex only, and Flex & Vex refer to predator exclusion treatments (see Figs. 7 & 8). Both clam size and predator exclusion explained a significant amount of variation in clam survival (Table 7).

Field Experiment III

Clam Survival

Clam survival at Little River varied directly with clam size and with predator exclusion treatment (Table 7; Fig. 24). For example, small clam survival pooled over all predator exclusion treatments (23.3 ± 14.6%, n = 15) was nearly 50% lower than the combined survival of the medium- and large-sized clams (44.7 ± 14.2%, n = 30). This difference was statistically significant (P = 0.0163; Table 7). Of the two main factors (clam size and predator exclusion), the exclusion treatment explained approximately 55% of the variation in clam survival (Table 7). Of the two a priori contrasts, the source of variation associated with the comparison of open vs. netted pots explained 99.6% of the variation in predator exclusion. Mean survival in open pots, pooled over all clam sizes, was only 1.7 ± 1.9% (n = 15), whereas survival in the units protected with netting was 55.6 ± 11.3% (n = 30). There was no statistical difference in mean percent survival between units protected with flexible netting vs. those doubly protected with the flexible netting plus the piece of VEXAR.

At Recompence, clam size was not statistically significant (P = 0.2417; Table 8; Fig. 25); however, small clam survival (22.7 ± 17.3%, n = 15) was about 32% less than survival of medium and large clams (33.6 ± 12.8%, n = 30). Once again, predator exclusion treatment explained the majority of the variation in clam survival (56.8%, Table 8). No clams survived in open units where green crabs and other predators were allowed unrestricted access to their prey (Fig. 25). The open vs. netted contrast explained most (91.2%) of the variation in the predator exclusion source of variation (0% vs. 45.5 ± 11.7%, n = 30); however, survival in the doubly protected units (Flexible netting plus VEXAR) was approximately 53% higher

Table 8. ANOVA on the angular-transformed mean percent survival of cultured individuals of *Mya arenaria* in experimental units at Recompence flat, Freeport, Maine from 18 August to 17 November 2013 (91 days). Boldface P-values indicate statistical significance (n = 5).

Source of variation	df	SS	MS	F	Pr > F
Clam Size	2	1010.49	505.25	1.48	0.2417
Small vs. Medium & Large	1	937.20	937.20	2.74	0.1065
Medium vs. Large	1	73.29	73.29	0.21	0.6462
Predator Exclusion	2	18704.44	9352.22	27.35	<**0.0001**
Open vs. Netted	1	17055.99	17055.99	49.88	<**0.0001**
Flexible vs. VEXAR	1	1648.45	1648.45	4.82	**0.0346**
Clam Size x Exclusion	4	893.23	223.31	0.65	0.6285
Experimental Error	36	12310.05	341.95		
Total	44	32918.21			

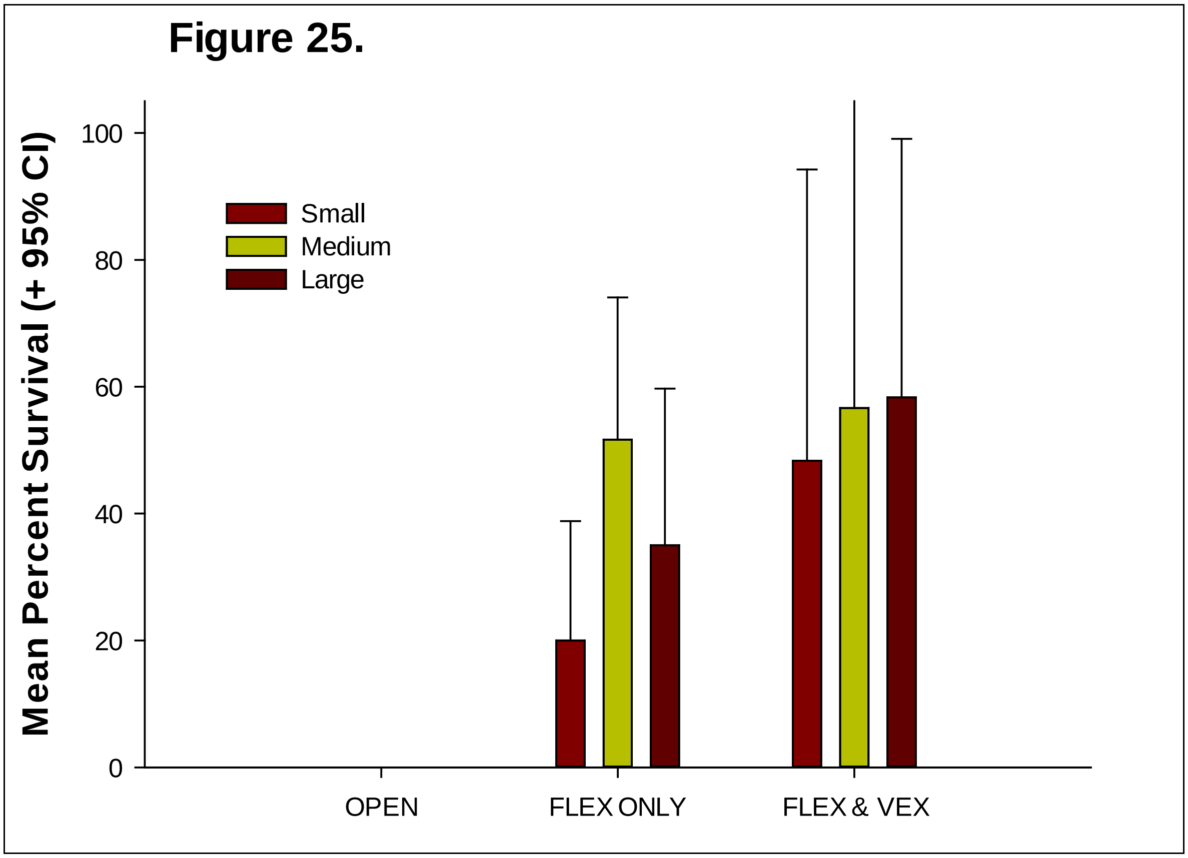

Figure 25. Mean percent survival (+ 95% confidence interval) of cultured clam juveniles in experimental units near the mid intertidal at Recompence flat from 18 August to 17 November 2013 (91 days). Small, Medium, and Large refer to initial clam size (see text for specifics). Open, Flex only, and Flex & Vex refer to predator exclusion treatments (see Figs. 7 & 8). Both clam size and predator exclusion explained a significant amount of variation in clam survival (Table 7).

than in the units protected with the single piece of flexible netting (35.5 ± 12.9% vs. 54.4 ± 19.9%; P = 0.0346, Table 8).

<u>Clam Growth</u>

At Little River, neither clam size (P = 0.3218) nor predator exclusion treatment (P = 0.7502) had a significant effect on mean clam growth (Fig. 26). Clams of the three size classes added, on average, 14.9 ± 1.6 mm (n = 31) of new shell material over the 90-day period.

Similar results occurred at Recompence. No significant effects on absolute growth were observed due either to initial clam size (P = 0.7382) or predator exclusion (P = 0.7161). Mean absolute growth pooled over the nine treatments was 14.1 ± 1.8 mm (n = 28; Fig. 27).

Wild Soft-Shell Clam Recruits

Wild clams juveniles recruited into experimental units at both intertidal locations. At Little River, no effect of either main factor (clam size – P = 0.1291; predator exclusion – P = 0.6020) was observed on mean number of juvenile wild clams ($\bar{x}$ = 1.13 ± 0.58 individuals core^{-1}, or 61.95 ± 31.87 individuals m^{-2}, n = 45). Similarly, no significant difference in mean SL occurred due to either main factor (clam size – P = 0.1406; predator exclusion – P = 0.7088; mean SL = 3.6 ± 0.86 mm, n = 20). In addition, no differences in size-frequency distribution of juvenile clams were observed due to either initial clam size or predator exclusion (Fisher's Exact Test, df = 6, P = 0.5879 and 0.6822, respectively). Approximately 63% of clams were less than 3 mm SL.

Wild clam recruitment at Recompence flat was not influenced by either clam size (P = 0.2271) or predator exclusion (P = 0.5339). Overall mean number per unit was 0.89 ± 0.47 individuals (48.8 ± 25.8 individuals m^{-2}; n = 45). Predator exclusion treatment had a significant effect on mean clam size (P = 0.0373). Mean SL in open units and those protected with flexible netting was 4.3 ± 1.7 mm (n = 9) and 3.7 ± 0.8 mm (n = 8), respectively. Significantly larger individuals occurred in units protected by flexible netting and VEXAR ($\bar{x}_{SL}$ = 13.9 ± 10.0 mm, n = 7). Distribution of juvenile clam sizes was affected by predator exclusion treatment (P = 0.0089, df = 4, Fisher's Exact Test), but not by initial clam size (P = 0.6782).

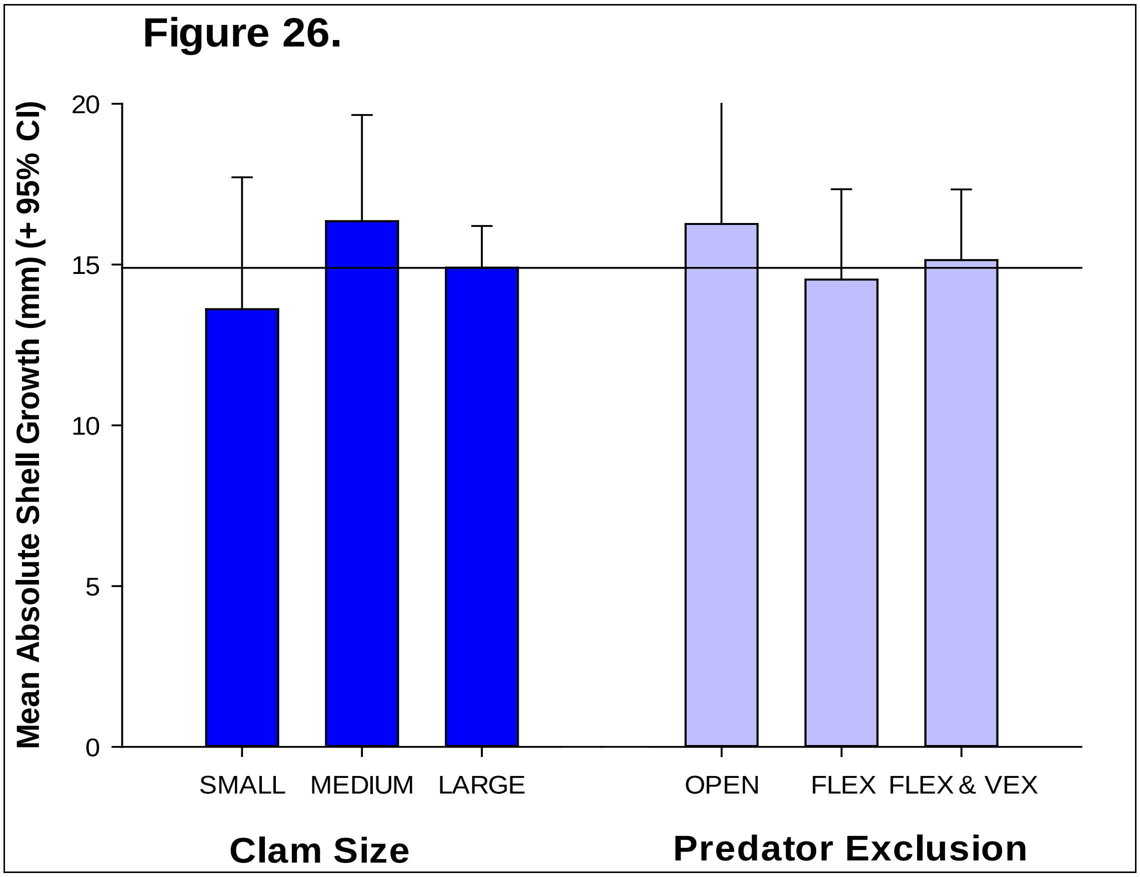

Figure 26. Mean absolute shell growth (+ 95% confidence interval) of cultured clam juveniles in experimental units near the mid intertidal at Little River flat from 18 August to 16 November 2013 (90 days). Small, Medium, and Large refer to initial clam size (see text for specifics). Open, Flex only, and Flex & Vex refer to predator exclusion treatments (see Figs. 7 & 8). Neither clam size nor predator exclusion explained a significant amount of variation in absolute clam growth. Reference line = overall mean absolute growth (mm) (i.e., Final SL – Initial SL).

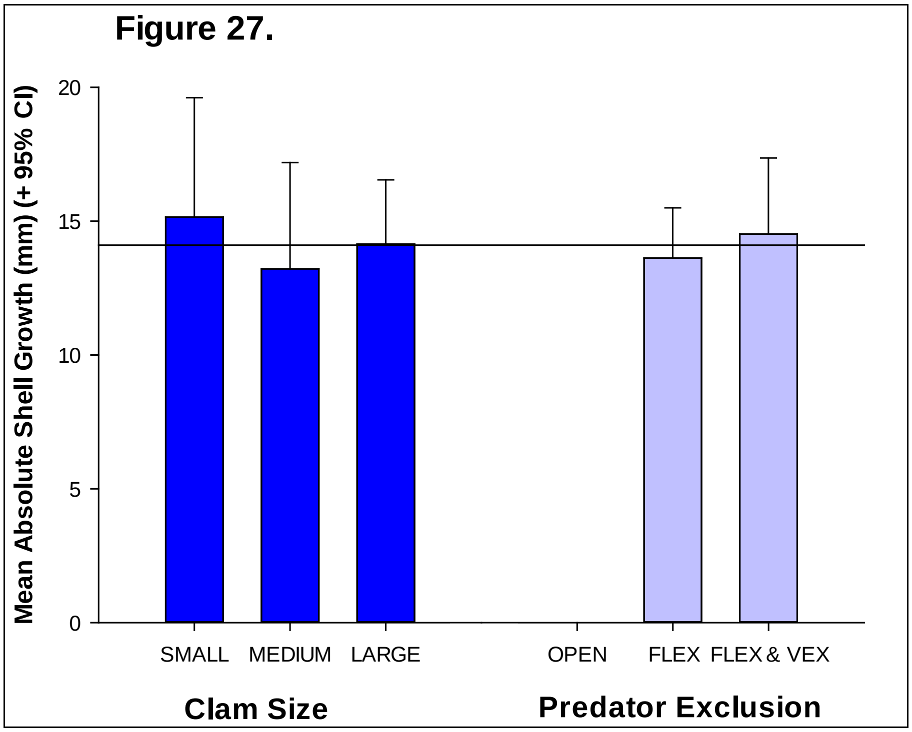

Figure 27. Mean absolute shell growth (+ 95% confidence interval) of cultured clam juveniles in experimental units near the mid intertidal at Recompence flat from 18 August to 16 November 2013 (90 days). Small, Medium, and Large refer to initial clam size (see text for specifics). Open, Flex only, and Flex & Vex refer to predator exclusion treatments (see Figs. 7 & 8). Neither clam size nor predator exclusion explained a significant amount of variation in absolute clam growth. Reference line = overall mean absolute growth (mm) (i.e., Final SL – Initial SL).

<u>Green crabs</u>

Juveniles of *Carcinus maenas* were found in experimental units at both experimental locations on 16 and 17 November. At Little River, mean number varied significantly with both initial clam size and predator exclusion (Table 9; Fig. 28). Nearly twice as many crabs were found in units with large vs. medium size clams (1.80 ± 0.84 vs. 0.93 ± 0.44 individuals per unit, n = 15), and more than three times as many crabs occurred in protected vs. open units at the end of the (0.47 ± 0.35 vs. 1.63 ± 0.45 individuals per unit, n = 15 and 30, respectively. Crab size varied significantly with predator exclusion treatment (P = 0.0013). Specifically, crabs were nearly 50% larger in netted (8.37 ± 0.75 mm, n = 25) vs. open units (5.63 ± 2.3 mm, n = 6) (P = 0.0064). Crabs ranged in size from 3.6 mm to 15.3

mm (Fig. 28). Size distribution of crabs was independent of predator exclusion treatment (P = 0.0816, df = 4, Fisher's Exact Test) and experimental clam size (P = 0.3028, df = 4, Fisher's Exact Test).

Table 9. ANOVA on the square root-transformed mean number of green crab juveniles in experimental units at Little River flat, Freeport, Maine from 18 August to 16 November 2013 (90 days). Boldface P-values indicate statistical significance (n = 5).

Source of variation	df	SS	MS	F	Pr > F
Clam Size	2	6.9778	3.4888	3.38	**0.0453**
Small vs. Medium & Large	1	1.3444	1.3444	1.30	0.1065
Medium vs. Large	1	5.6333	5.6333	5.45	**0.0252**
Predator Exclusion	2	15.2444	7.6222	7.38	**0.0021**
Open vs. Netted	1	13.6111	13.6111	13.17	**0.0009**
Flexible vs. VEXAR	1	1.6333	1.6333	1.58	0.2168
Clam Size x Exclusion	4	2.8888	0.7222	0.70	0.5978
Experimental Error	36	37.2000	1.0333		
Total	44	62.3111			

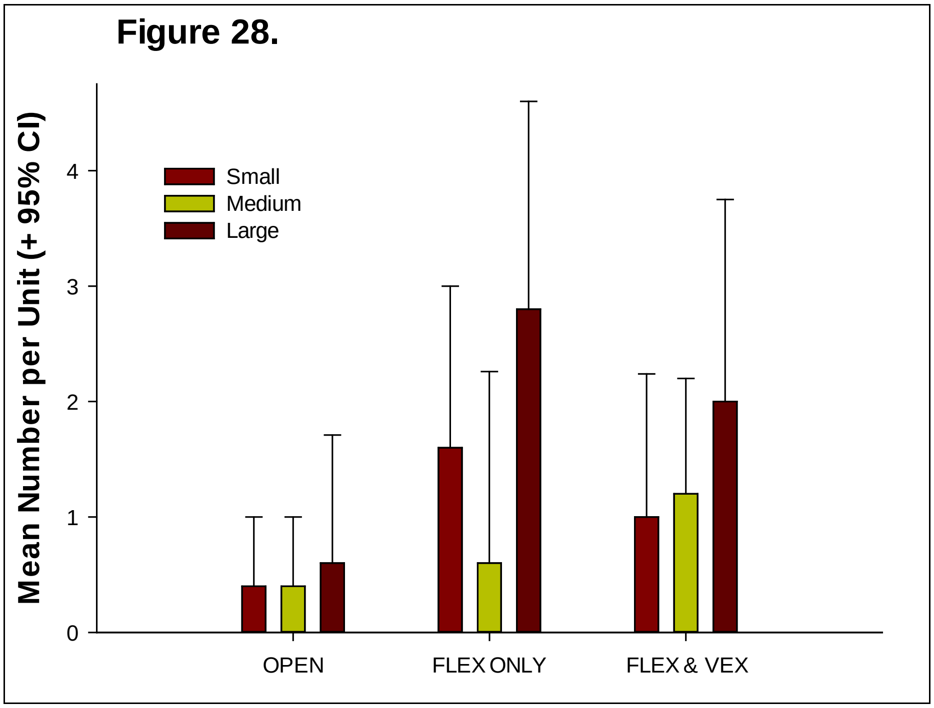

Figure 28. Mean number of juvenile green crabs in experimental units at Little River flat on 16 November 2013 (n = 5). See Table 9 for ANOVA.

At Recompence flat, green crab abundance averaged 0.51 ± 0.22 individuals per unit (n = 45), with no significant amount of overall variability in mean number explained by either main factor (clam size: P = 0.7357; predator exclusion: P = 0.0695). Approximately 2.5 times as many crabs were found in units doubly protected with flexible netting and VEXAR vs. those protected with the single piece of flexible netting (0.87 ± 0.51 vs. 0.33 ± 0.27 individuals per unit, n = 15); however, this was not statistically significant (P = 0.0571). Crab size did not vary significantly with either of the main factors (clam size: P = 0.9324; predator exclusion: P = 0.4968), and averaged 9.01 ± 4.38 mm (n = 23; Fig. 29). In addition, crab size distribution was independent of either main factor (Fisher's Exact Test, df = 4; clam size: P = 0.6534; predator exclusion: P = 0.8623).

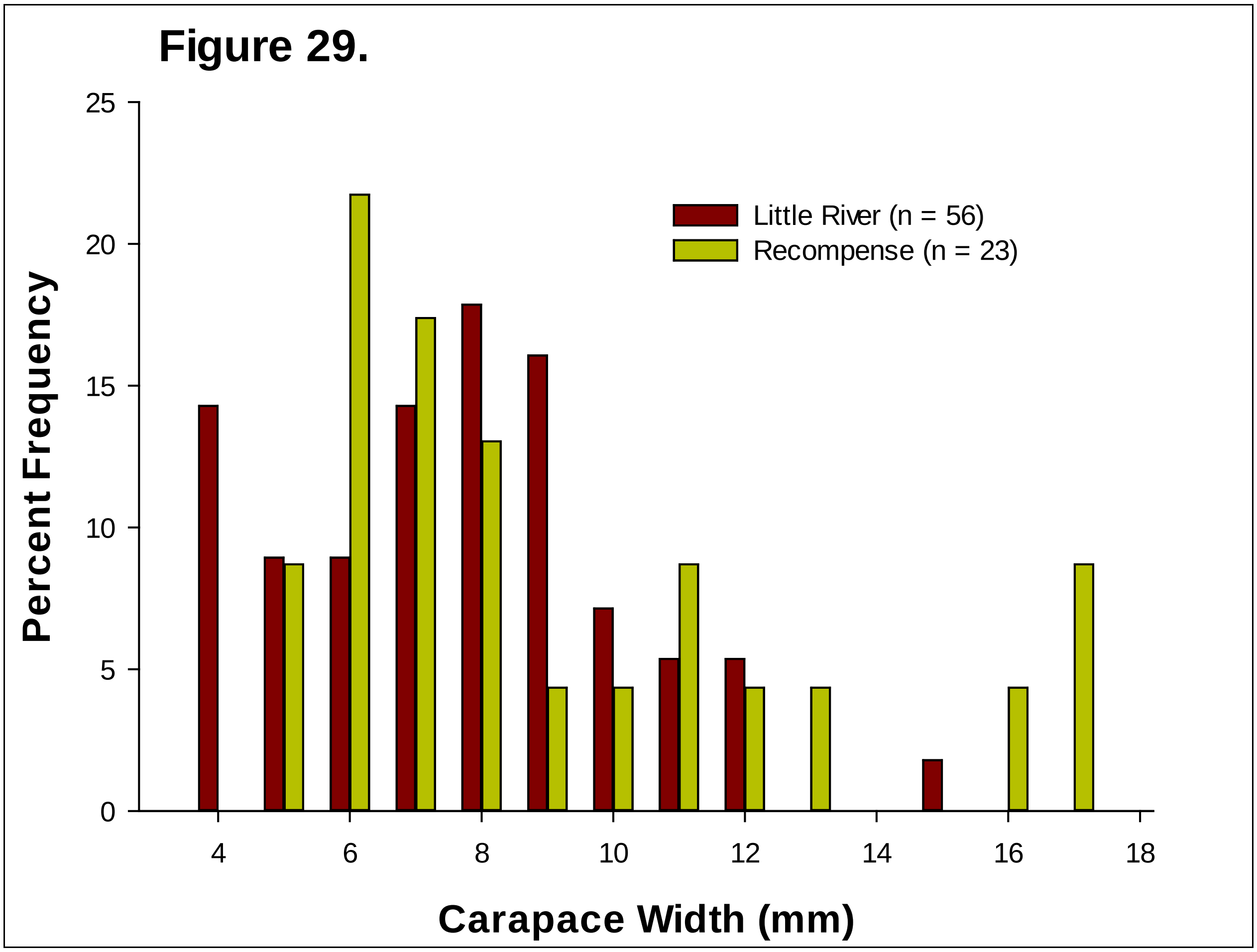

Figure 29. Size distribution of juvenile green crabs in experimental units at Little River and Recompence flat on 16-17 November 2013.

<u>**Recompence – Green Crab Fencing Project**</u>

One soft-shell clam (SL = 25.4 mm) occurred in the 75 samples taken on 27 July. It came from a core sampled near the upper intertidal. No hard clams were encountered in any of the samples.

On 17 November, soft-shell clams occurred in two of 26 cores sampled from the mid and upper intertidal (7.6%), but none occurred in low tide samples. No significant differences in mean soft-shell clam density occurred from block-to-block between tidal heights (F = 1.06; df = 2, 36; P = 0.3572) or between blocks within a given tidal height (F = 0.92; df = 36, 39;

P = 0.6025). Overall soft-shell clam density was 0.078 ± 0.079 individuals $core^{-1}$ (4.22 ± 4.35 individuals m^{-2}; 0.39 ± 0.40 individuals ft^{-2}, n = 78). This density is not significantly different from zero (T = 1.93; df = 77; P = 0.0573). The size distribution was bi-modal, with 0-year class juveniles occurring in the two core samples from the mid intertidal (core #2 = 3.04 mm; core # 26 = 2.06 mm) and adults occurring in the two core samples from the upper intertidal (core #1 = 66.74 mm and 77.15 mm; core #4 = 76.27 mm and 74.43 mm).

For hard clams, no discernible pattern in abundance was observed between tidal heights (F = 1.63, df = 2, 36; P = 0.2090) or from block-to-block within tidal heights (F = 0.76; df = 36, 39; P = 0.7922). Hard clams were four times more abundant that soft-shell clams. Mean density over all samples was 0.308 ± 0.137 individuals $core^{-1}$ (16.9 ± 7.5 individuals m^{-2}; 1.57 ± 0.70 individuals ft^{-2}, n = 78). This density was significantly different from zero (T = 4.48; df = 77; P < 0.0001). Mean hard clam SL (42.3 ± 11.1 mm, minimum = 2.21 mm, maximum = 93.8 mm) did not vary significantly across tidal heights (F = 1.32; df = 2, 21; P = 0.2896). Approximately 58% of hard clams were less than a SL of 50.8 mm (i.e., 2-inches; Fig. 30).

The lack of soft-shell clams at Recompence flat may be related to the ineffectiveness of the large (ca. 2,000 ft) green crab fence (Fig. 31). Similar to the maintenance schedule that occurred with the fenced plots at Little River, six to eight weeks after the fence at Recompence flat had been installed, routine care and upkeep was abandoned. On two occasions (18 August and 12 October 2013), the PI observed pieces of fencing along the shore at several places around Recompence Cove. In addition, it is not clear that the green crab traps that were deployed both outside and inside the fenced area were hauled and baited regularly. It is also unclear if any data was taken on the weight, CW, or sex of green crabs from traps at Recompence. If so, that data was not made available to the PI and that information does not appear in this report.

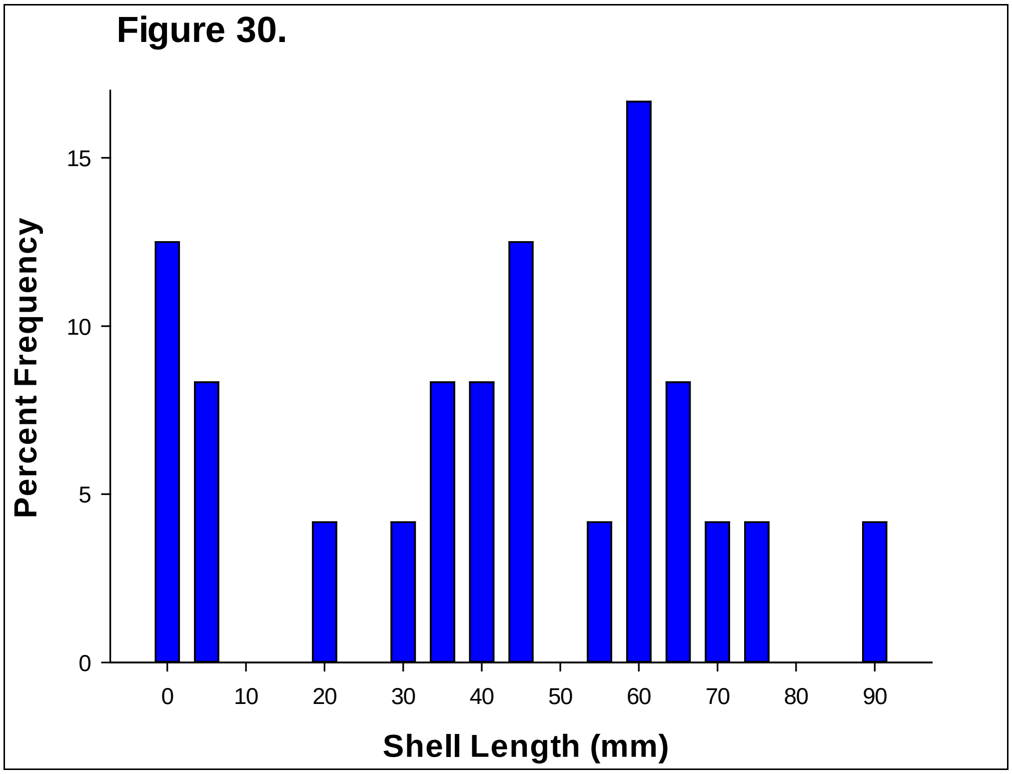

Figure 30. Size distribution of juvenile hard clams from core samples taken at Recompence flat on 17 November 2013.

Figure 31. Green crab fencing at Recompence flat on 17 November 2013.

Field Experiment IV

Wild clams were found in experimental units at each tidal height and in all three exclusion treatments; however, abundance varied significantly only with the latter (Table 10; Fig. 32). Significantly more soft-shell clams recruited and survived into experimental units covered with the VEXAR and TUFF screening (Fig. 32). Of the number of wild clams that occurred in experimental units at the end of the experimental period, nearly 80% were found in units protected with both the VEXAR and TUFF screening. Size of wild clams ranged in SL from 3.09 to 46.01 mm. Based on growth rates of cultured clams at Little River over the 201-day period (data not presented here), animals greater than 25 mm should not be considered 0-year class individuals. Therefore the percentage of wild clams in the experimental units that likely were 2013 recruits (i.e., animals < 25 mm) was 88.84% (Fig. 33). Mean SL of wild clams was 13.32 ± 0.73 mm (n = 466).

Table 10. ANOVA on the square root-transformed mean number of wild soft-shell clam juveniles in experimental units at Little River flat, Freeport, Maine from 28 April to 15 November 2013 (201 days). Boldface P-values indicate statistical significance (n = 5).

Source of variation	df	SS	MS	F	Pr > F
Tidal Height	2	27.653	13.827	0.96	0.3915
Upper vs. Mid & Low	1	8.630	8.630	0.60	0.4433
Mid vs. Low	1	20.756	20.756	1.45	0.2371
Predator Exclusion	2	94.916	47.458	3.30	**0.0481**
Flexible vs. VEXAR & TUFF	1	1.350	1.350	0.09	0.7609
VEXAR vs. TUFF screening	1	92.669	92.669	6.45	**0.0155**
Tide Height x Exclusion	4	32.375	8.094	0.56	0.6906
Block(Tide, Exclusion)	36	517.018	14.362	1.70	0.0501
Experimental Error	41	345.819	8.435		
Total	85	1016.721			

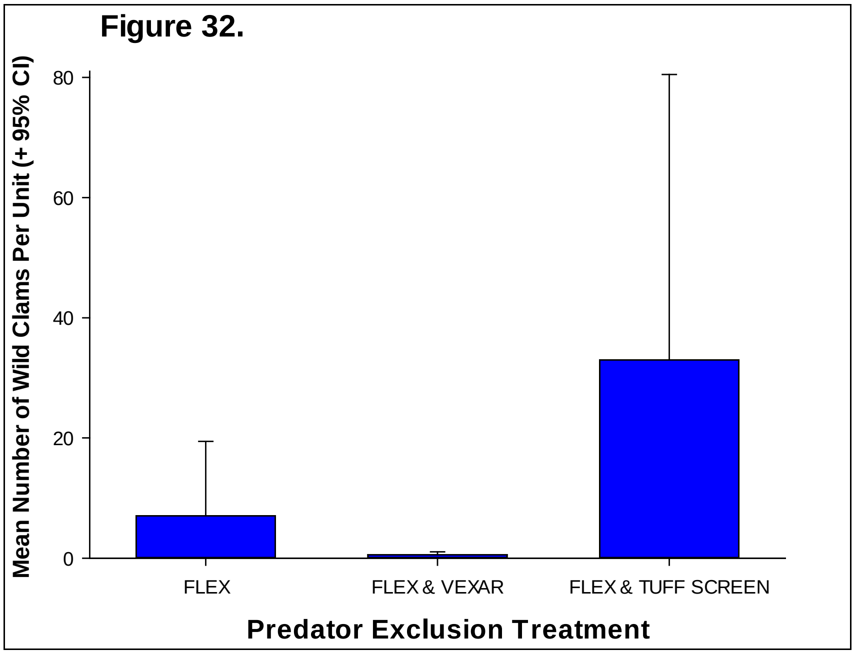

Figure 32. Mean number of wild soft-shell clams in experimental units from Experiment IV (28 April to 15 November 2013) at Little River flat (n = 28 for Flex and Flex & Vexar; n = 30 for Flex & TUFF screen).

The variability in wild clam numbers between experimental units within and between tidal heights and exclusion treatments was very high; nonetheless, the fact that in some cases hundreds of wild clams occurred in experimental units (Fig. 34) indicates the efficacy of the use of netting to deter predators to enhance wild clam recruitment and subsequent survival. Overall mean number of wild clams in the Flex & TUFF screening treatment was 32.9 ± 47.5 individuals per unit (ca. 1,807.6 ind. m^{-2}, or 167.9 ind. ft^{-2}).

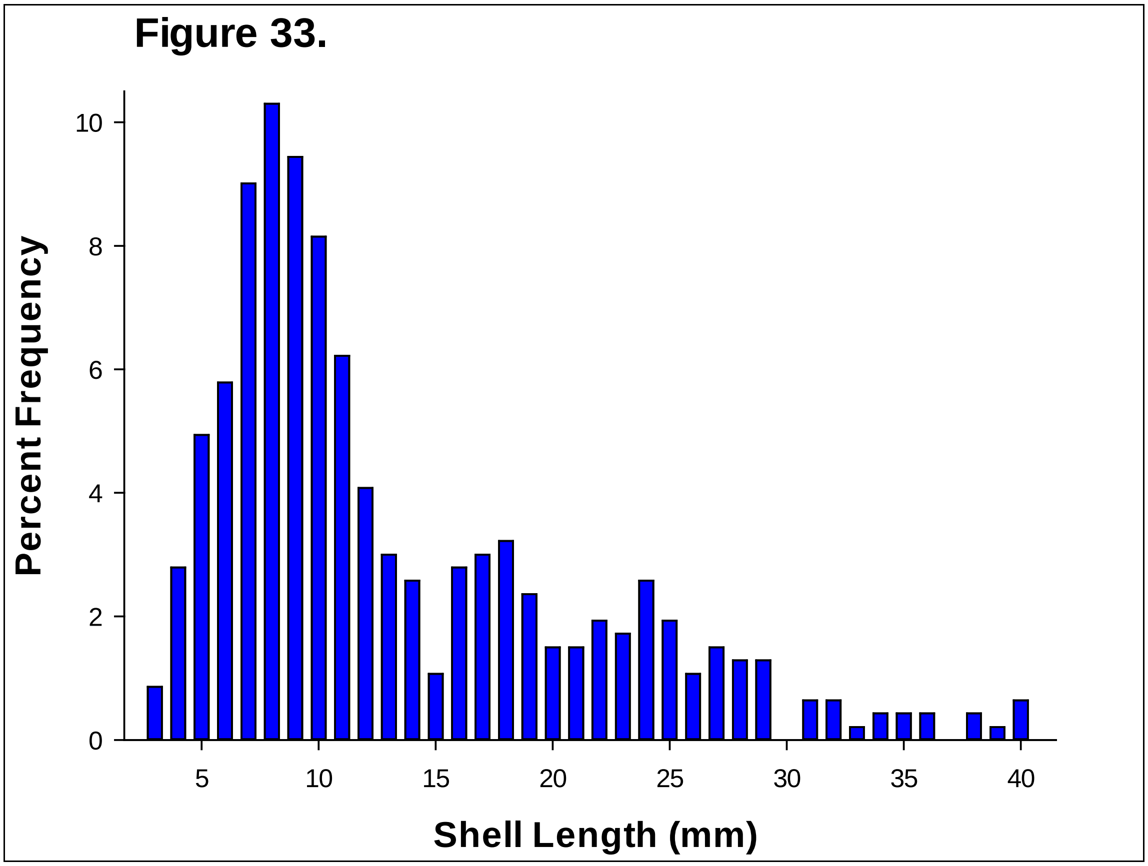

Figure 33. Size-frequency distribution of wild soft-shell clams in all experimental units (upper , mid, low intertidal) at Little River flat on 15 November 2013. (n = 466)

Figure 34. An example of an experimental unit with wild clams from Experiment IV at Little River (28 April to 14 November 2013). In this instance, a total of 695 live wild clams occurred in the unit (38,100 individuals m^{-2}, or 3,540 individuals ft^{-2}). (Average SL = 8.09 mm, range = 3.09 mm to 13.83 mm.)

Green Crab Trapping in the Harraseeket River

Immersion (soak) Time Study (25-30 July 2013)

Although mean catch mass of crabs from the five traps fished near the mouth of Spar Cove (mean = 38.6 ± 5.9 lbs, or 17.5 ± 2.7 kg, n = 11) was approximately 70% greater than that from the other two locations in the Harraseeket River (22.5 ± 2.7 lbs, or 10.2 ± 1.2 kg, n = 23), no significant differences were observed in mean CPUE across the different immersion times (P = 0.6049) and no significant relationship was observed between CPUE and immersion time (r^2 = 0.0317; df = 1, 32; P = 0.3134; Fig. 35).

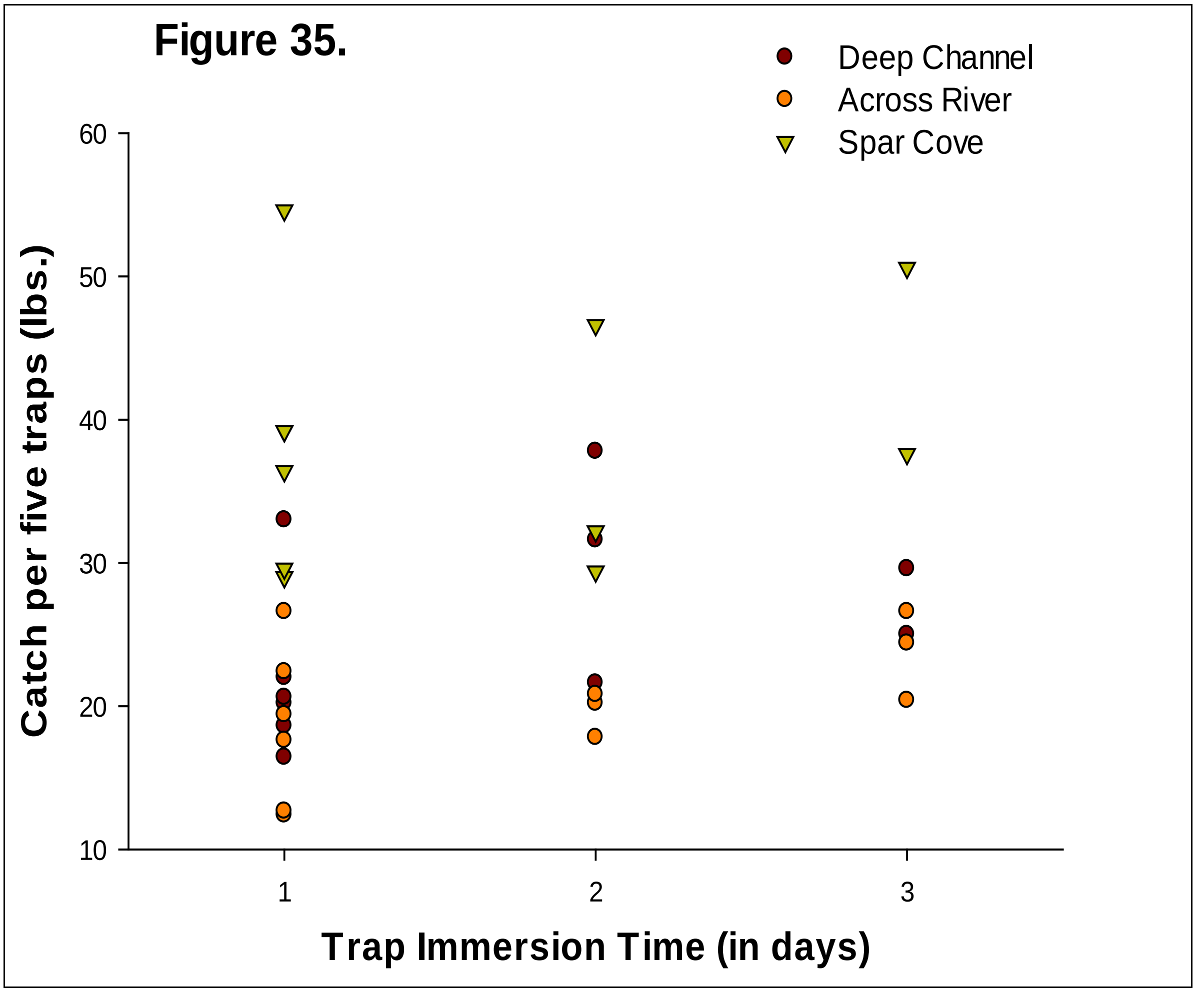

Figure 35. Relationship between catch (in pounds) from five Acer traps and immersion (soak) time at two intertidal (Spar Cove and Across River) and one subtidal (Deep Channel) locations in the Harraseeket River (25-30 July 2013). ANOVA demonstrated no significant effect of immersion time on mean catch-per-unit-effort and regression analysis indicated no relationship between catch and immersion time.

Mean carapace width varied significantly across location, with crabs in the Deep Channel being nearly 50% larger than those from Spar Cove and nearly 25% larger than those from Across the River ($\bar{x}_{Deep}$ = 67.2 ± 3.3 mm, n = 12; $\bar{x}_{Across}$ = 54.1 ± 4.2, n = 11; $\bar{x}_{Spar}$ = 45.2 ± 2.4 mm; $P < 0.001$). This difference was likely due to differences in the mean proportion of males to females in the catches from each location ($P = 0.007$). For example, 88.5 ± 6.2% (n = 12) of the crabs in the Deep Channel were males whereas this ratio was smaller for the combined mean (because they were not significantly different) of the other two sites (70.8 ± 5.7% (n = 22).

Large-scale trapping study (27 May to 5 November 2013)

From 27 May to 5 November, 300 separate landings from 1-10 traps/haul occurred yielding 13,065.3 pounds (5,938.8 kg, or nearly 6 metric tons). This is a conservative figure because several data sheets were excluded from the analysis because no date or number of traps hauled had been recorded. The average catch per trap was 10.28 ± 0.74 pounds (n = 295), or 4.67 ± 0.34 kg. Mean CW was 59.5 ± 0.7 mm (n = 300). A total of 11,715 green crabs were measured and sexed (♂ = 8,396, ♀ = 3,319; ratio ♂:♀ = 71.7%:28.3%).

Because data was recorded only infrequently after 8 July about number of days between hauls (immersion time), it was only possible to examine the relationship between immersion time and catch-per-unit-effort (mass/trap) using data from 27 May to 8 July 2013. During that interval, there was no relationship between CPUE and immersion time (regression analysis; $r^2 = 0.000004$; F = 0.001; df = 1, 61; P = 0.9880; Fig. 36).

Catch-per-unit-effort varied little from the beginning of the trapping study until early September. Then, catches appeared to increase, but accompanying this was larger variation in catch between individuals (Fig. 37). ANOVA indicated a significant difference in mean CPUE over time ($P < 0.0001$).

Sex ratios also varied significantly through time (ANOVA: $P < 0.001$; Fig. 38). A linear regression model (date as the independent variable) explained 33.2% of the variation in the sex ratio (F = 17.93; df = 1, 36; $P < 0.001$) suggesting that proportionately more males were taken earlier in the year.

Overall, 3,319 females were sampled from traps during the study. Only 34 (1.02%) were ovigerous (size range = 33 mm to 74 mm CW). Mean carapace width of ovigerous females was approximately 7% larger than non-ovigerous females (52.4 ± 3.3 mm vs. 49.2 ± 0.3 mm; T = 2.27, df = 3,317, P = 0.023). No ovigerous females were caught after 22 August, and 70% were trapped on or before 26 June. Non-ovigerous females (size range = 20 mm to 82 mm) were significantly smaller (by approximately 20%) than males (mean CW = 61.2 ± 0.3 mm, n = 8,396) over the entire study period (T = 53.83, df = 11,679, P < 0.0001). Size-frequency distribution of all females was approximately normal whereas for males, the distribution was skewed to the left (Fig. 40).

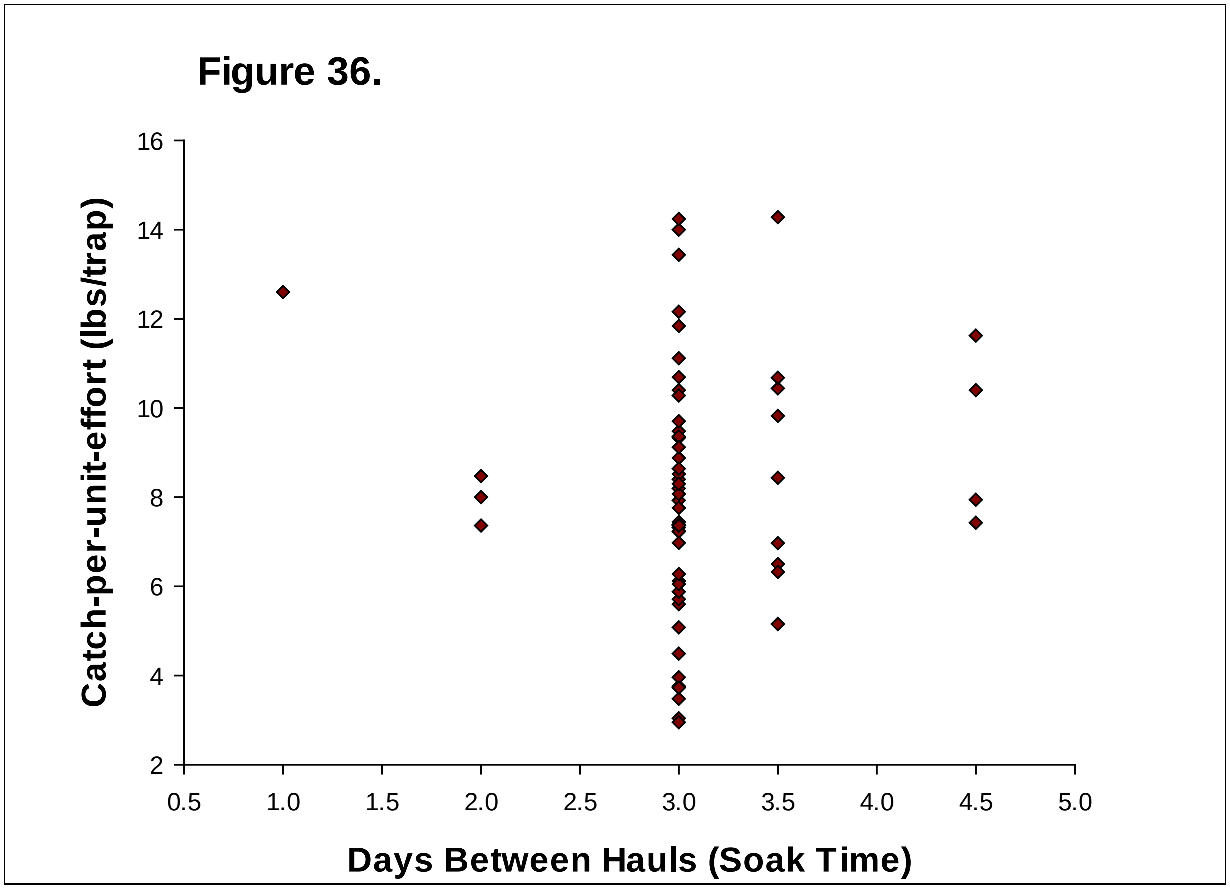

Figure 36. Relationship between catch-per-unit-effort and immersion (soak) time from crab traps in the Upper Harraseeket River from 27 May to 8 July 2013. Regression analysis demonstrated the lack of a significant relationship between the two variables.

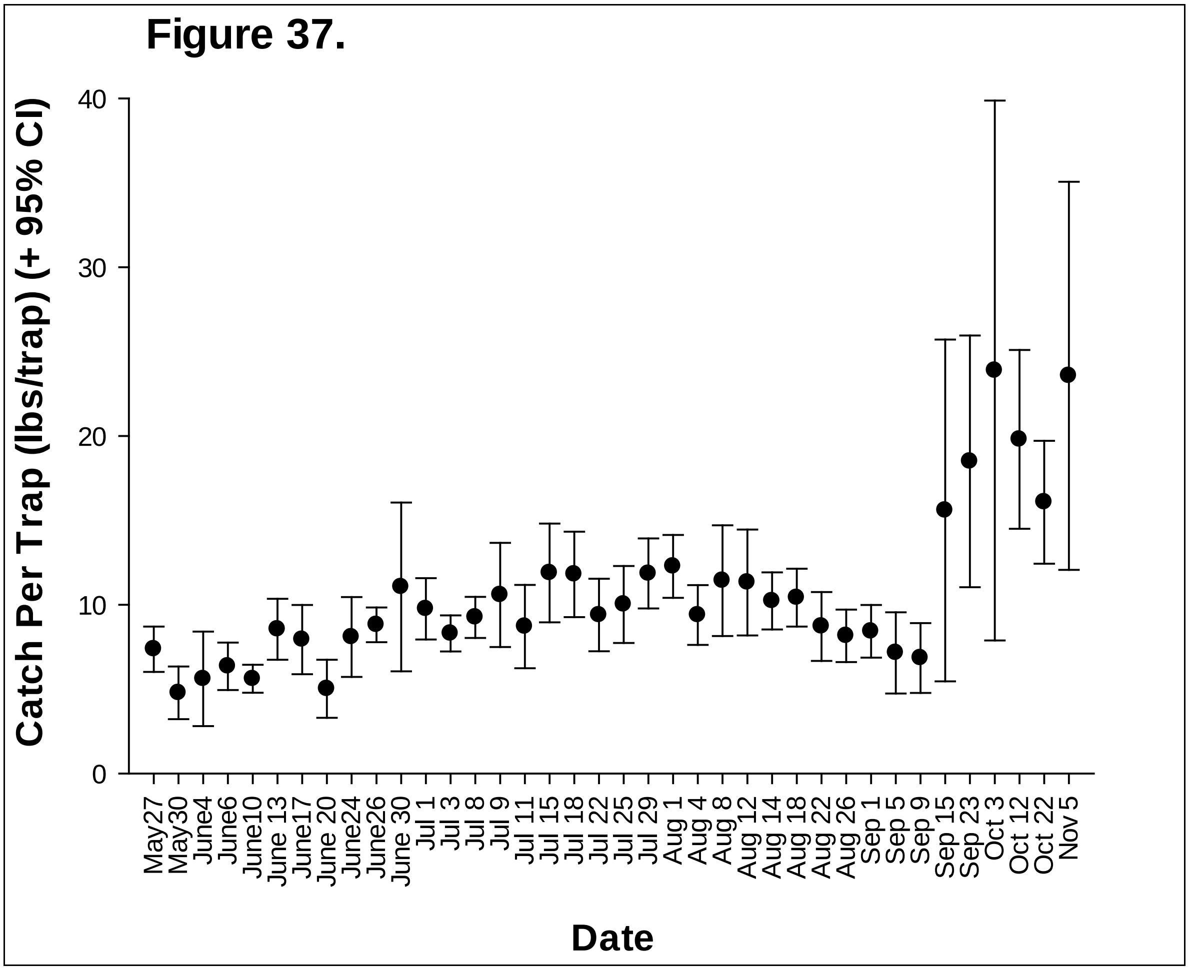

Figure 37. Relationship between catch-per-unit-effort and haul date from crab traps in the Upper Harraseeket River from 27 May to 5 November 2013. ANOVA indicated a difference in mean CPUE over time (P < 0.0001).

Figure 38.

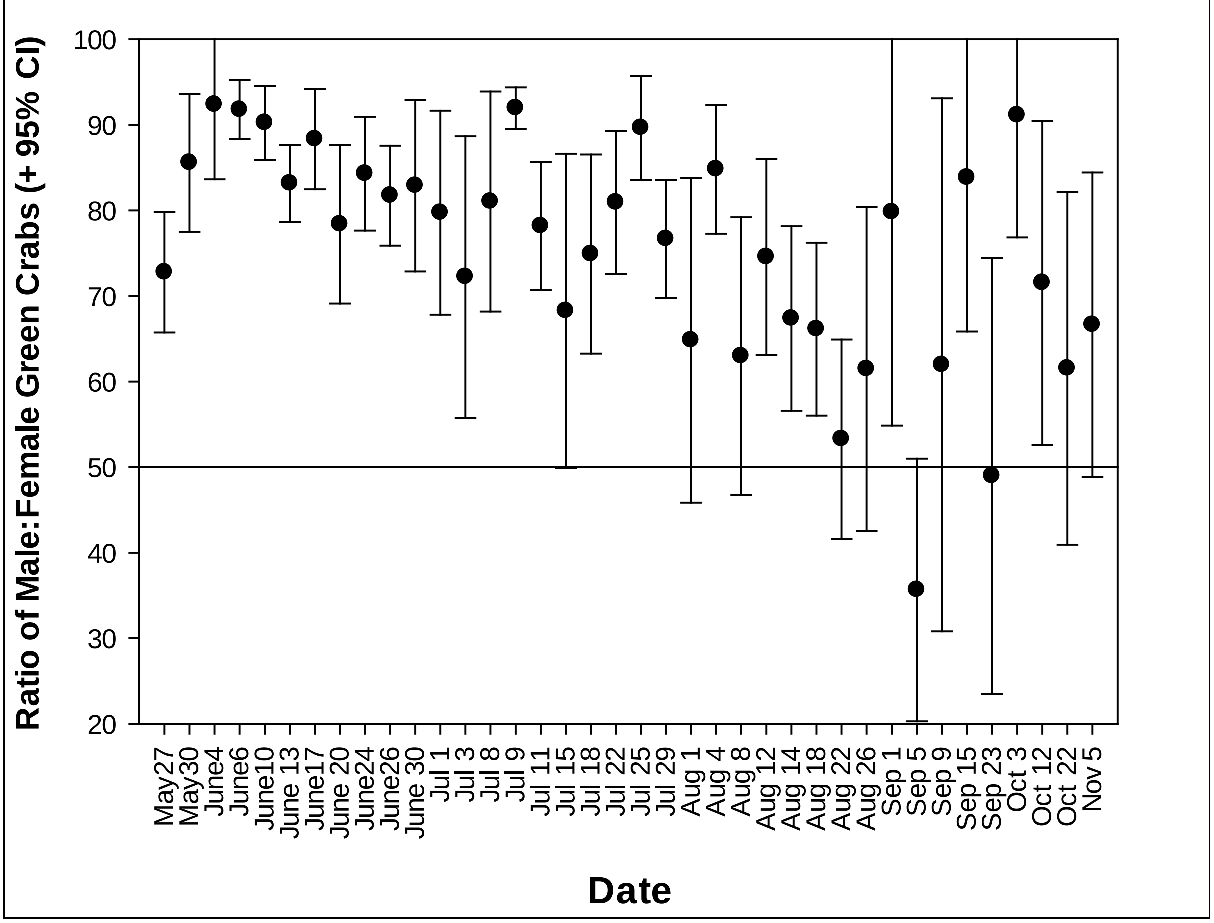

Figure 37. Mean sex ratio of green crabs from crab traps deployed in the Upper Harraseeket River from 27 May to 5 November 2013. (Reference line indicates 50:50 ratio. ANOVA indicated a difference in mean ratio over time ($P < 0.0001$), and a regression analysis demonstrated that females became proportionately more numerous in the catch from the beginning to the end of the study.

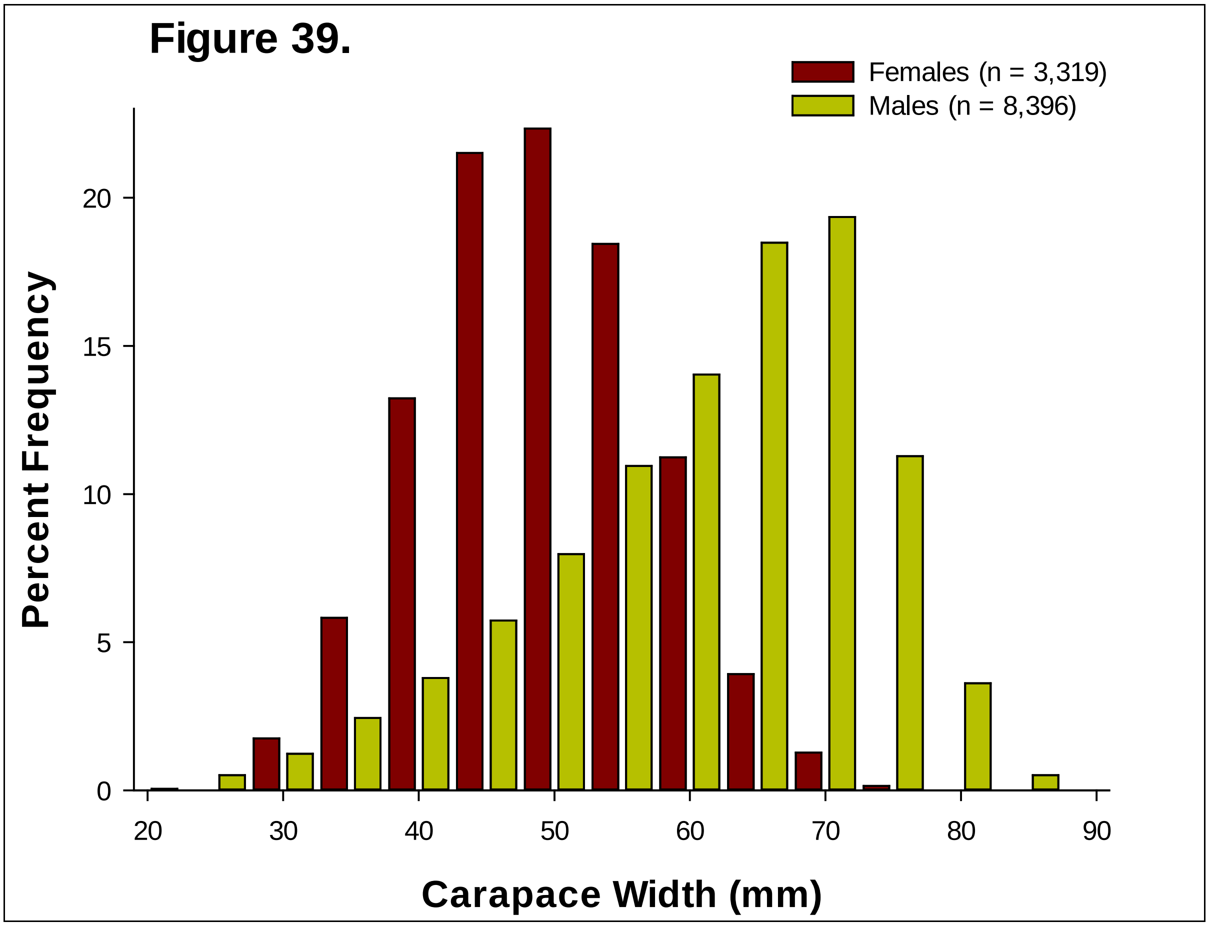

Figure 39. Size frequency distribution of female and male green crabs in the Upper Harraseeket River from 27 May to 5 November 2013.

Differences in mean CW and size-frequency distribution was assessed between the first four (27 May to 6 June) vs. last four (3 October to 5 November) sampling dates (Fig. 40). Mean CW of females increased 10.8% whereas the increase in mean CW for males was 21.3%. For both sexes, size-frequency distributions differed significantly between the two time periods (df = 4, P < 0.0001, G-test of independence).

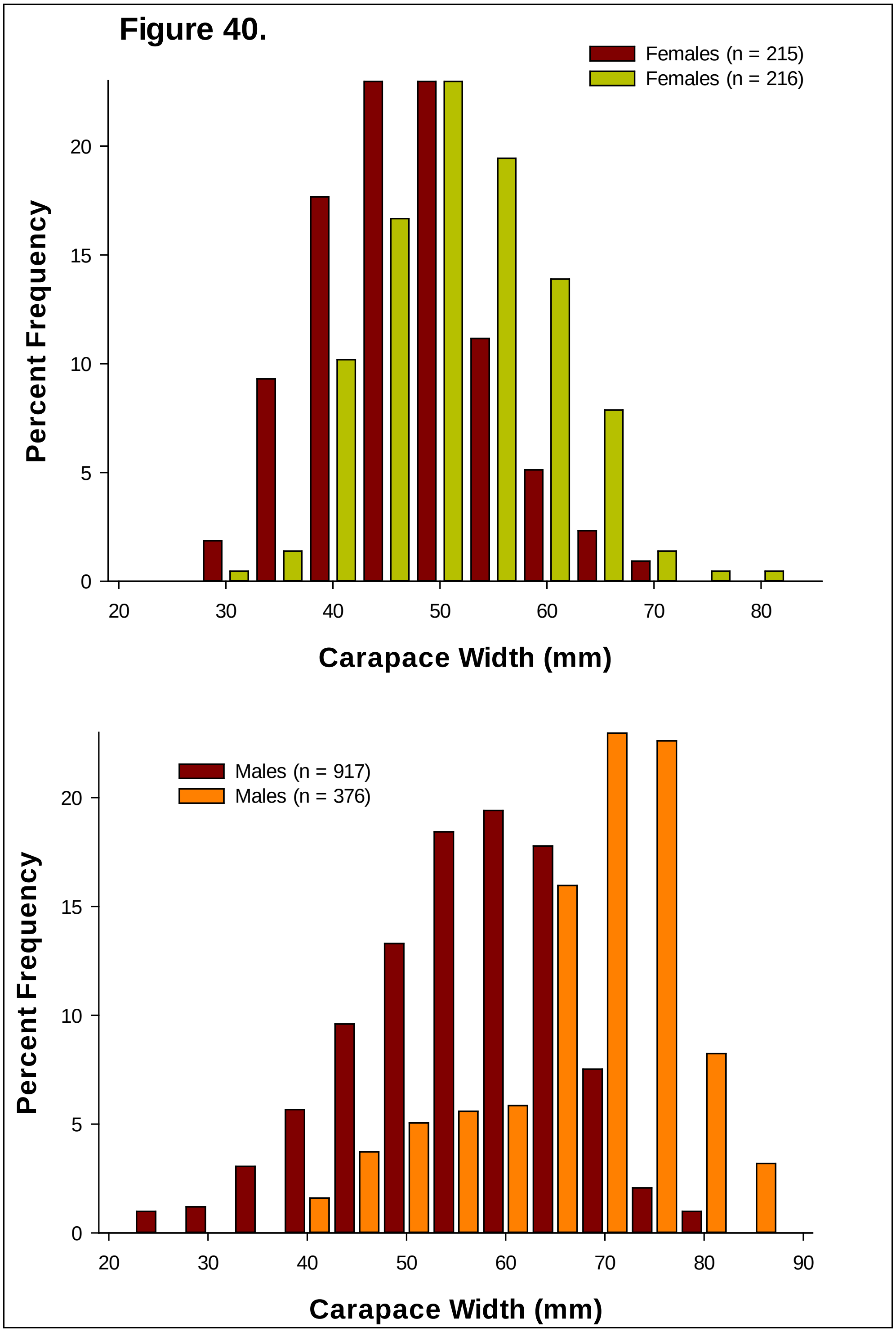

Figure 40. Size frequency distribution of females (top) and males (bottom) over time. Red bars = 27 May to 6 June; Green and Orange bars = 3 October to 5 November. In both distributions, sizes vary significantly between dates ($P < 0.001$).

Collins Cove – Weston Point area

In the upper intertidal at Collins Cove, green crab size-frequency distributions varied significantly for both sexes through time (Males: G = 76.4, df = 12, P <0.0001; Females: G = 31.2, df = 12, P = 0.0018; Fig. 41). From June to September, both female and male size-frequencies tended to become more skewed towards individuals smaller than 40 mm (Fig. 41). This trend also was observed for mean CL of each sex through time. (Females: mean CL decreased 4.5% from June through September – 47.9 ± 1.2 mm [n=114] to 45.8 ± 1.2 mm [n=205]; Males: mean CL decreased 13.1% from 56.3 ± 1.2 mm [n=366] to 48.9 ± 2.2 mm [n=170]). Sex ratios (M:F) changed through time from a high, initially, of ca. 80:20 in June to 48:52 by early September (Fig. 42). Total mass of crabs landed from 27 May to 9 September at this site was 1,589.4 lbs.

In the lower intertidal at Collins Cove, size-frequency distributions of males varied significantly through time (G = 66.8, df = 12, P < 0.0001), but not for females (G = 18.6, df = 12, P = 0.0997; Fig 43). Mean CL for males decreased 10% from June to September (65.0 ± 1.3 mm [n=168] to 58.5 ± 2.3 mm [n=123]). Mean CL for females did not change significant over the same time interval (June: 51.4 ± 2.8 mm [n=32]; September: 50.7 ± 1.5 mm [n=89]). Similar to the upper intertidal, sex ratio (M:F) declined significantly in the lower intertidal from June (83:17) to September (56:44) (Fig. 42). Analysis of covariance was used to compare the regression lines (proportion of males vs. time) for each intertidal location at Collins Cove. The lines were parallel (P = 0.6706), but the least-square mean sex ratio for the lower intertidal traps was ca. 17% higher than for the upper intertidal traps indicating a greater proportion, in general, of males along the lower vs. upper shore. Total mass of crabs landed in the lower intertidal was 1,261.4 lbs.

Two locations adjacent to the upper and lower intertidal at Collins Cove were fished sporadically during the period between 27 May and 1 September (extreme lower intertidal [= 610 lbs total] and the channel off Weston Point [= 1,965 lbs total] (Fig. 15). Catch-per-unit-effort did not vary through time for traps fished in the channel (P = 0.1340), but did for those in the extreme low intertidal (P = 0.04; Fig. 44). Size-frequency distribution of female green crabs changed through time at the extreme lower intertidal (G = 24.2, df = 12, P = 0.0191). Mean CL for females decreased by 4% from 56.3 ± 1.9 mm (n = 10) to 54.0 ± 2.4 mm (n = 24) from 20 June to 1 September. Male crabs sampled at the same location and over the same period of time tended to increase in size (G = 21.5, df = 12, P = 0.0431), with mean CL increasing by 2.4% from 62.9 ± 2.6 mm (n = 43) to 64.4 ± 4.9 mm (n = 27). Sex ratio did not vary significantly at the extreme lower intertidal (P = 0.2495), and averaged 77:12 (M:F). In the subtidal channel, the size distribution of female crabs did not vary significantly from 27 May to 22 August (G = 12.7, df = 8, P = 0.1213), but size distribution of males did vary significantly (G = 109.2, df = 8, P < 0.0001). Mean CL of females did not change significantly during the period (53.0 ± 1.8 mm, n = 87 vs. 53.9 ± 1.0 mm, n = 181), but mean CL of males did increase slightly (ca. 3.3%) from 62.3 ± 0.74 (n = 543) to 64.4 ± 1.0 mm (n = 427). Sex ratio in the subtidal traps decreased significantly from May to August (Y = 73.1 – 0.138X, r^2 = 0.144, P = 0.0060) from an average of 85.8% males in June to 73.3% males in the August samples.

To examine potential differences in green crab size-frequency distribution between locations, a narrow period of time (29 July to 1 August – 3 days) was chosen when traps from each of the four locations adjacent to Collins Cove were fished. A G-test of independence examined whether size-frequency distribution of male and female crabs was independent of location. For both sexes, crab distribution shifted toward larger individuals from the upper shore to the subtidal channel (Table 11).

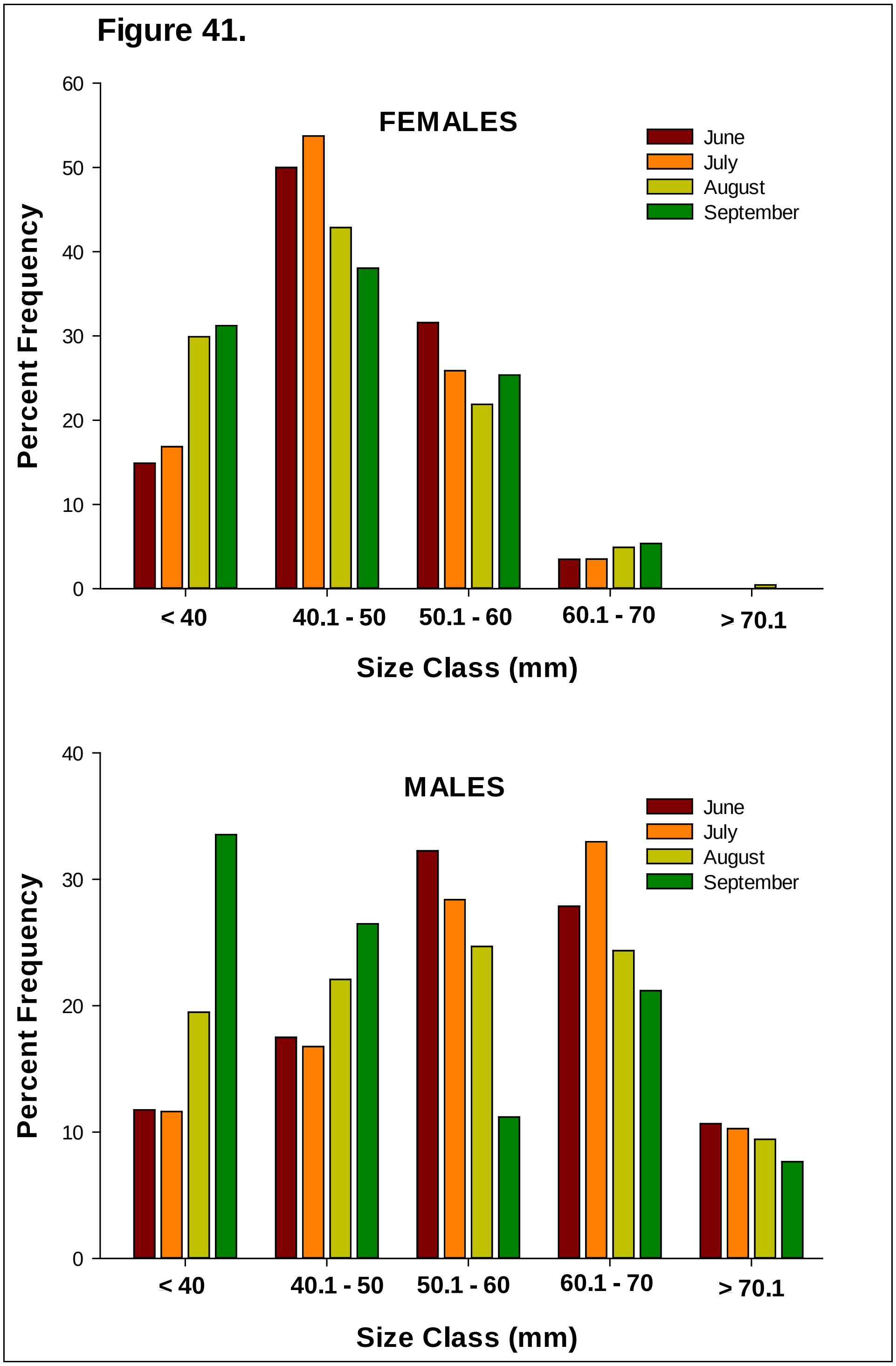

Figure 41. Size-frequency distribution of female and male green crabs from Collins Cove, Freeport, Maine from June through September 2013 in upper intertidal traps. Crabs of both sexes decreased in size through time, with proportionately smaller individuals in traps in September vs. June.

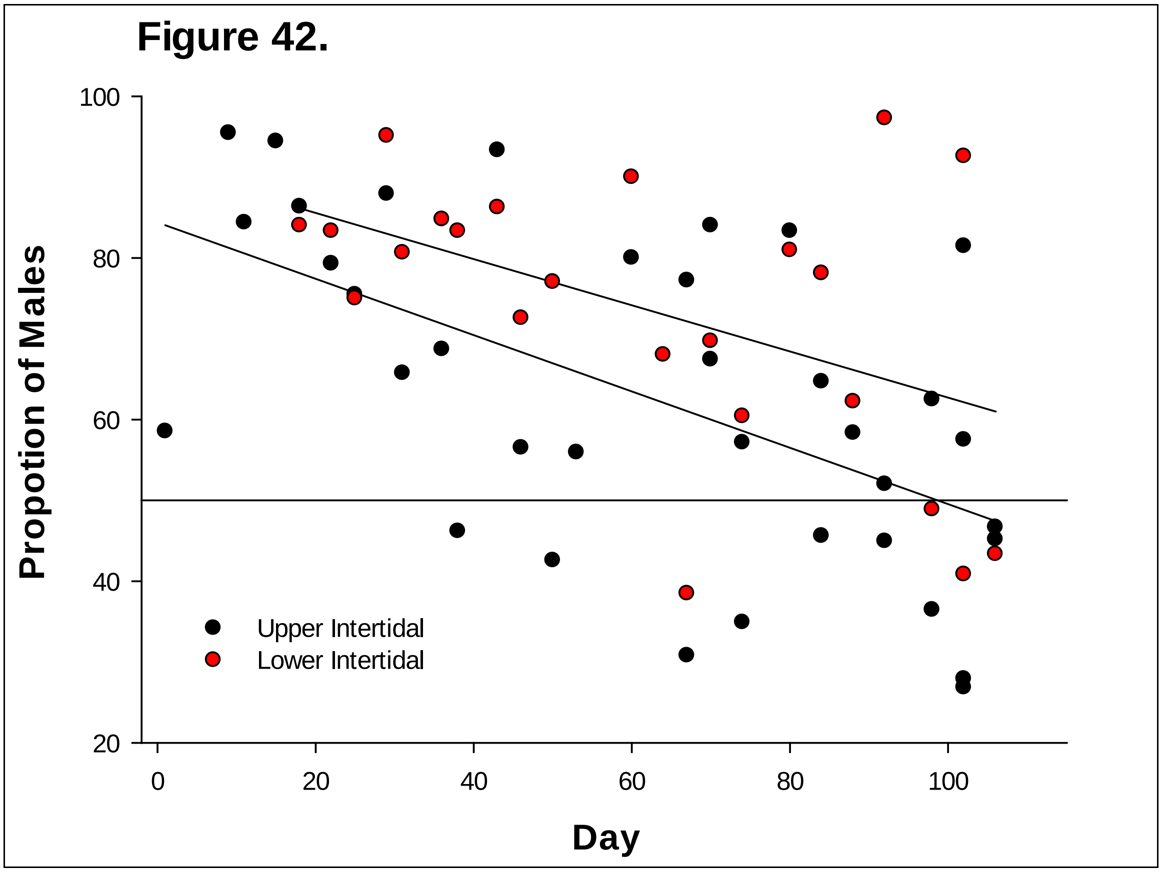

Figure 42. Proportion of males at Collins Cove through time (2013) from the upper and lower intertidal. (Day 1 = May 27; Day 106 = September 9). Regression analysis demonstrated the slopes of the two lines to be equal (P = 0.6706). Analysis of covariance showed that location was highly significant (P = 0.0152) suggesting that for any given date, the proportion of males in the catch was higher in the lower intertidal than upper intertidal traps.

Table 11. 5 x 4 G-test of independence examining size-frequency distribution of **a**) female, and **b**) male green crabs at four adjacent locations from the upper intertidal to the subtidal channel (Fig 15.) near Collins Cove during a 3-day period from 29 July to 1 August 2013. Five size (CL) categories were created (≤ 40.1 mm; 40.1 – 50 mm; 50.1 – 50 mm; 60.1 – 70 mm; and, > 70.1 mm). A priori contrasts are shown that examine changes in size-distributions sequentially from the upper shore to the subtidal channel.

a) Females

Test	df	G-statistic	P-value
Overall	12	23.3898	0.0246
Upper Intertidal vs. Other Locations	4	10.2964	0.0357
Low Intertidal vs. Extreme Low & Channel	3	9.5242	0.0231
Extreme Low Intertidal vs. Channel	3	3.5693	0.3119

b) Males

Test	df	G-statistic	P-value
Overall	12	69.7966	<0.0001
Upper Intertidal vs. Other Locations	4	27.9815	<0.0001
Low Intertidal vs. Extreme Low & Channel	4	33.8341	<0.0001
Extreme Low Intertidal vs. Channel	4	7.9810	0.0923

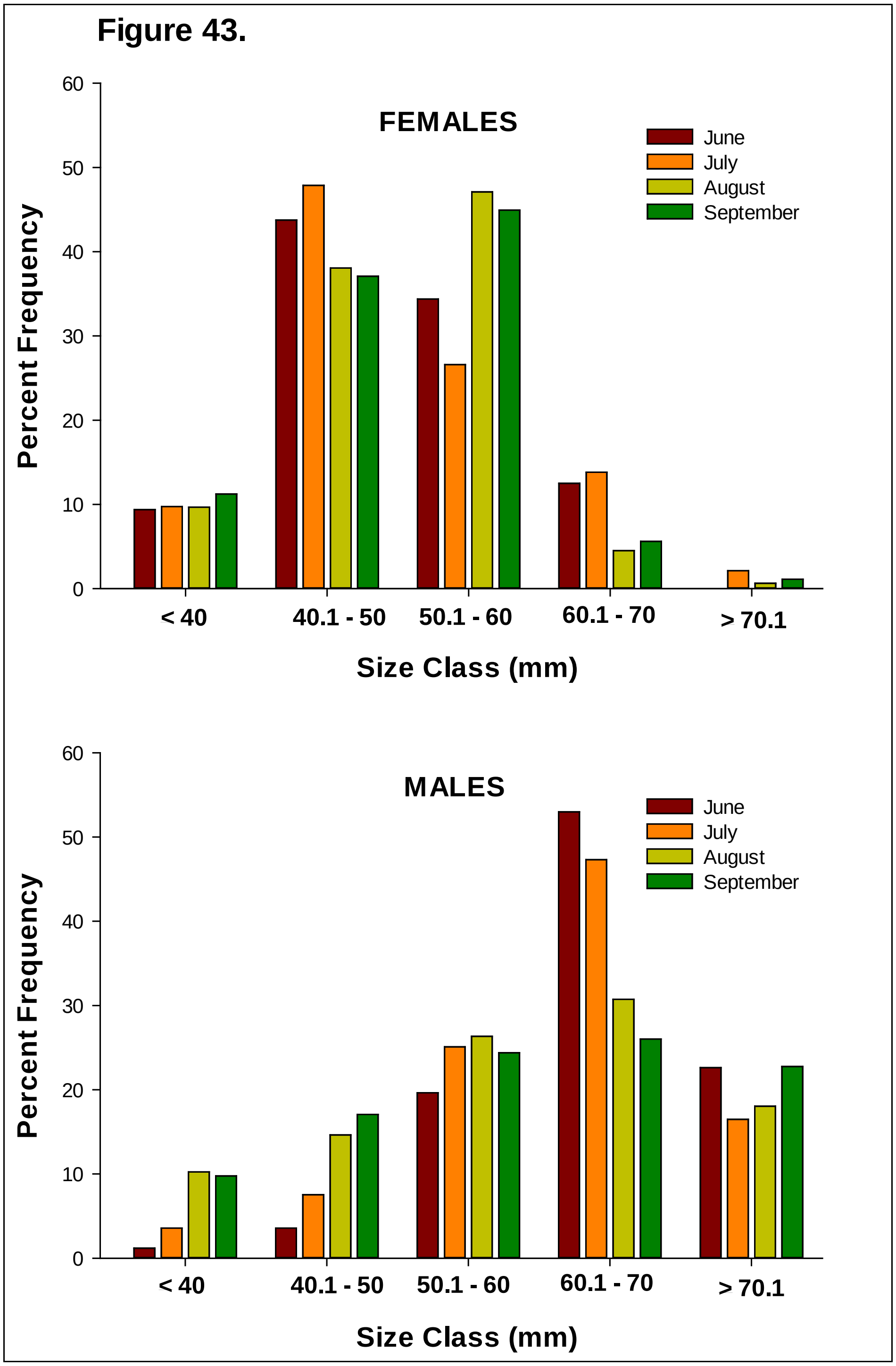

Figure 43. Size-frequency distribution of female and male green crabs from Collins Cove, Freeport, Maine from June through September 2013 in lower intertidal traps. Only male crab size-frequencies changed through time, with proportionately smaller individuals in traps sampled in September vs. June. Mean CL decreased ca. 10% over time.

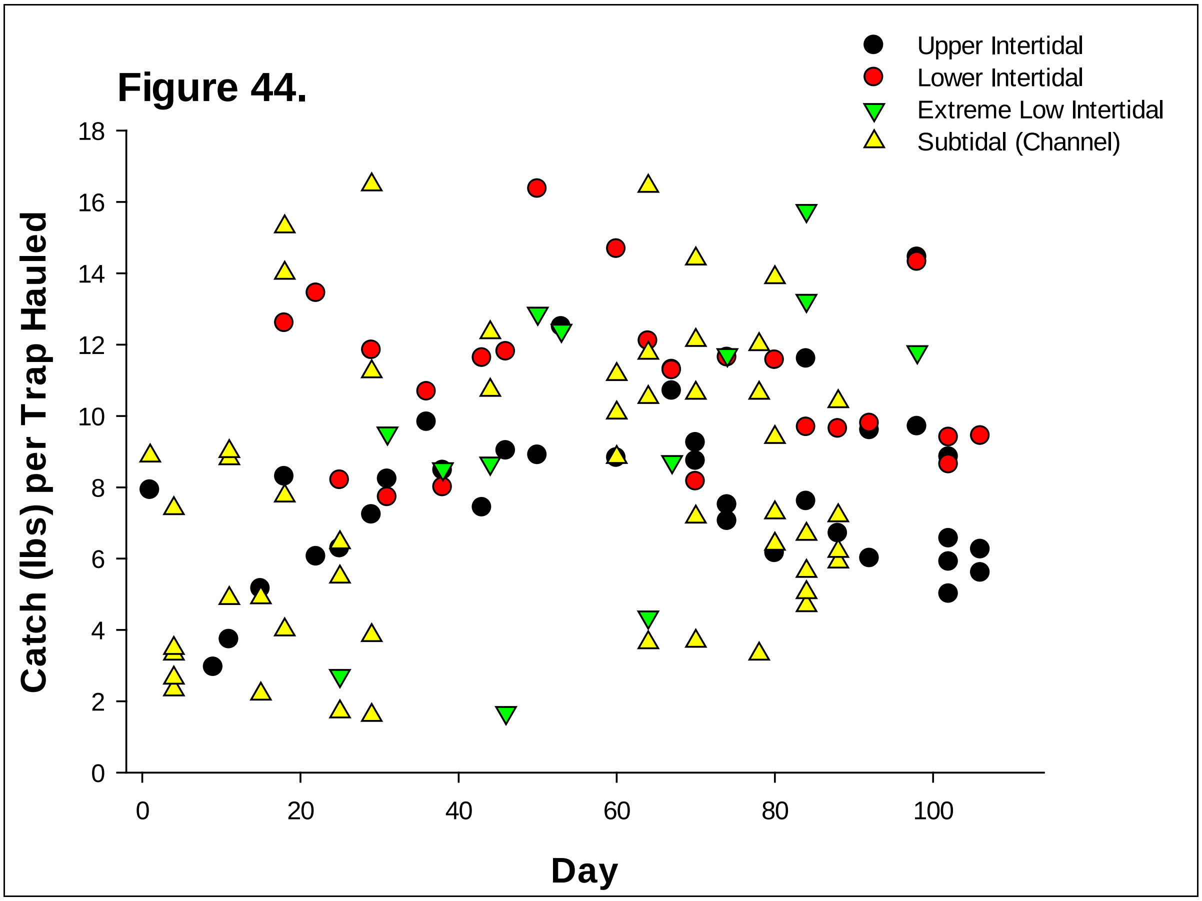

Figure 44. Catch-per-unit effort through time at four locations near Collins Cove (Upper Intertidal; Lower Intertidal; Extreme Lower Intertidal; Subtidal in the Channel near Weston Point) in the Harraseeket River, Freeport, Maine during 2013. Day 1 = May 27; Day 106 = September 9). Only traps fished in the extreme low intertidal showed a significant (positive) relationship between CPUE and day ($Y = 2.97 + 0.0199X$; $r^2 = 0.33$, $n = 13$, $P = 0.04$).

Upper Harraseeket (Porter Landing; Pettengill Flat; Sandy Beach)

Traps were fished consistently over relatively long periods of time at three locations in the Upper Harraseeket during 2013. At Porter Landing, traps were fished on 27 May followed by a 56-day hiatus (until 22 July), and then regularly from 29 July to 5 November (total pounds landed = 1,128.2 lbs). At Pettengill, traps were fished regularly from 4 June to 22 October (total pounds landed = 1730.4 lbs). Traps were hauled at Sandy Beach from 27 May to 29 July. For each of the three locations, catch-per-unit-effort increased significantly over time (Fig. 45). At Sandy Beach, mean catch per trap hauled in June was 7.2 ± 1.6 lbs (n = 15), and this increased in July by ca. 45% to 10.4 ± 6.3 lbs (n = 6) (total pounds landed = 835.6 lbs). At Porter Landing, the mean catch per trap hauled from May to September increased ca. 34% from 8.4 lbs (n = 1) to 11.2 ± 4.9 lbs (n = 8). The largest increase in mean catch per trap from May to September occurred at Pettingill (ca. 97%; from 10.3 ± 4.9 lbs [n=5] to 20.2 ± 8.8 [n=5]).

Size-frequency distribution for male and female green crabs did not vary through time at Sandy Beach (Females: G = 7.7, df = 3, P = 0.0525; Males: G = 7.1, df = 4, P = 0.1324), but did so at Porter Landing (Females: G = 26.7, df = 9, P = 0.0015; Males: G = 53.5, df = 12, P < 0.0001) and Pettengill (Females: G = 39.0, df = 12, P = 0.0001; Males: G = 43.3, df = 12, P < 0.0001). At the latter two locations, size proportionately increased through time for both sexes. For example, mean CL of female green crabs at Porter Landing increased 21% from 42.7 ± 3.6 mm (n = 22) to 51.6 ± 2.1 mm (n = 71) from May to November 2013, while mean CL of male crabs at Pettengill increased ca. 6% over the same period of time from 63.7 ± 1.3 mm (n = 193) to 67.3 ± 1.5 mm (n = 145).

Sex ratios at each location decreased significantly through time (Fig. 46). At Sandy Beach, sex ratio (M:F) averaged 86:14 in June and 73:27 in July. At Porter Landing, ratios were 84:16 in July and 72:28 in October/November. At Pettengill flat, the ratio fell from a high of 89:11 in June to 57:43 in October/November. Analysis of covariance demonstrated that the least square mean proportion of males (± SE) varied from 71.8 ± 4.2% at Sandy Beach, 83.3 ± 3.2% at Porter Landing, and 67.1 ± 2.9% at Pettengill.

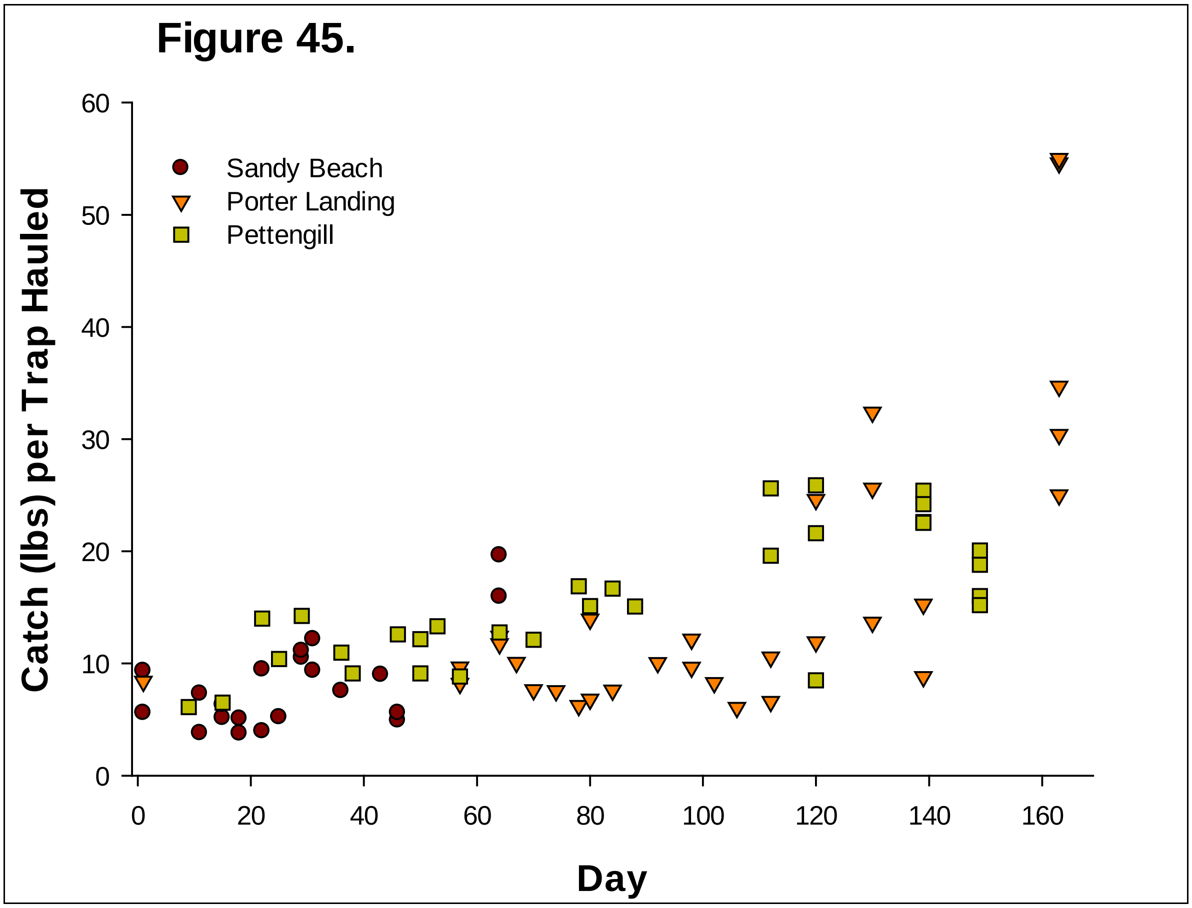

Figure H. Catch-per-unit-effort for three locations in the Upper Harraseeket River. Sandy Beach: $Y = 4.1 + 0.146X$, $r^2 = 0.392$, $n = 21$, $P = 0.0024$. Porter Landing: $Y = -7.5 + 0.229X$, $r^2 = 0.477$, $n = 31$, $P < 0.0001$; Pettengill: $Y = 7.6 + 0.094X$, $r^2 = 0.568$, $n = 31$, $P < 0.0001$.

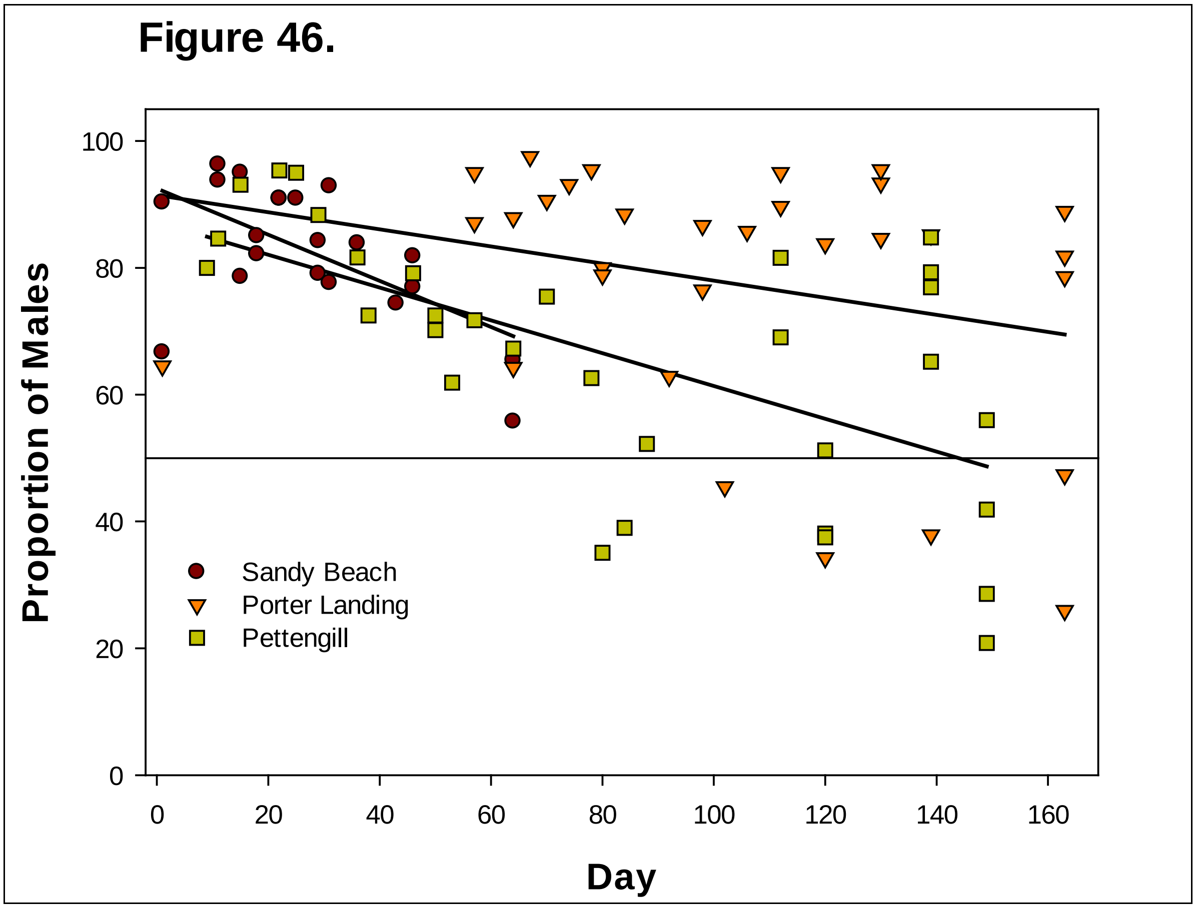

Figure 46. Proportion of male green crabs in traps hauled at Sandy Beach (n = 21), Porter Landing (n = 31) and Pettengill flat (n = 31) during 2013. Reference line = 50%. Analysis of regression lines indicated that the slopes were equal (P = 0.3437), and analysis of covariance demonstrated a difference in the least-square means (P = 0.0011).

Discussion

Results from the series of field-based activities in Freeport, Maine during 2013 can be summarized in one sentence. Green crabs have become the major predator of soft-shell clams in the Harraseeket River and adjacent intertidal areas extending to the east of Wolfe Neck, but it is possible to deter their predatory activities in small, routinely-maintained areas that will result in an enhancement of both wild and cultured soft-shell clam juveniles.

The larger-scale projects (Field Experiment I & II, Recompence Fencing Study) did not proceed as intended. In both cases, lack of routine maintenance (apparently due to funds originally budgeted to pay for labor costs for these activities that were cut from the final Shellfish Restoration budget) resulted in a loss of structural integrity of the field plots (Little River; Figs. 17-19) and the larger fence at Recompense flat (Fig. 31). In addition, routine trapping at Little River in both fenced and control plots was not carried out according to the experimental design. It remains unclear, however, if trap tending at Little River (which was completed once near the beginning of the study, but then did not occur again until 10 weeks later - Tables 3 & 4) did not occur regularly due to the lack of funds or due to miscommunication between the PI and staff at Resource Access International (RAI). In mid-April, when a workplan for activities at Little River was submitted to the Freeport Town Council, the following plan was presented and approved/accepted:

> **Little River**
>
> Experiment I and II (see Appendix A) will be initiated as soon as Army Corps of Engineer permits are received. Core samples will be taken at the beginning (May-June) and end (November) of the trial. In addition, staff from Resource Access Internation (RAI) will tend crab traps at least weekly that will be associated with Experiment I. Data on number and size of crab will be recorded (see Appendix A) as well as sex ratio and percent of females with eggs. RAI staff also will record levels of pH in sediments in the four treatments on a regular basis.

The data presented here show several important findings. First, as many clammers in Freeport have reported during the past two years, the data from the two resource surveys (27 June at Spar Cove; 17 November at Recompence flat) showed clearly that soft-shell clams are missing from mid- to low intertidal areas. That is, the resource is now limited to upper intertidal areas where clam growth is slower than in lower portions of the intertidal. This is significant because the resource is now limited to one-third the area that had been available to harvest, and the effort is now concentrated in a much smaller area of the intertidal than it had been a few years ago. Second, clams as large as 20 mm in shell length (SL) that are not protected by netting, fencing, or some other deterrent, will be consumed quickly. Results from Experiment III at Little River and Recompense flat over a short period of time from 18 August to 16-17 November (90-91 days) show unambiguously that survival rates of cultured seed clams of three discrete sizes (8 mm, 14 mm, and 19 mm) averaged less than 3% (Figs. 24-25). Third, netting (i.e., plastic, flexible with $1/6^{th}$-inch aperture [4.2 mm]) can enhance wild clam survival. Two independent sources of information support this claim. From Experiment I (Table 5; Fig. 20), the density of 0-year class (2013 clam 'recruits') individuals was nearly 10x greater in the netted plots compared to the plots without nets or in the "fenced" structures. In addition, Experiment IV showed that placing netting on flats earlier in the year than 26-27 July (i.e., end of April) can result, in some cases, in dramatically high densities of wild soft-shell clam recruits (Fig. 34). Fourth, trapping over a summer and fall can provide information about green crab abundance and population dynamics that can be used to make more efficient decisions about future attempts to capture crabs. For instance, one concerted effort to examine the effect of trap immersion time on catch showed that allowing traps to fish for three days provided no additional catch beyond that from traps allowed to fish for a single day (Fig. 35). Similar data by several fishermen in other areas of the Harraseeket River (Fig. 36) confirmed that result. Catch-per-unit-effort varied depending on whether traps were fished south or north of Weston Point. For example, in the area near Collins Cove, CPUE was relatively constant through time regardless whether traps were deployed in the upper or lower intertidal, or subtidally. However, in the three areas north of Weston Point (Porter Landing, Sandy Beach, and Pettengill flat) where traps were fished at regular intervals, CPUE actually increased significantly through time (Fig. 45). The latter could indicate that the clamming and/or other food resources are greater north of Weston Point compared to the Collins Cove area, or that there is better, more diverse habitat for crabs north of Weston Point, or that green crab predators (fish, gulls, other crustaceans) are more scarce north of Weston Point, or some combination of these or some other reason. Finally, regardless of location, female green crabs tended to increase proportionately faster through time than male crabs (Fig. 42, 46).

Green crabs have been singled out by some fishermen to be responsible for recent declines in population numbers of a variety of commercially important shellfish species in Maine, including sea scallops (*Placopecten magellanicus*) and blue mussels (*Mytilus edulis*) (http://bangordailynews.com/2013/07/09/environment/as-green-crab-invasion-takes-toll-on-maine-clams-researchers-worry-that-lobsters-are-next-victim/). Some scientific evidence exists to support these claims (Breen and Metaxas, 2008; Pickering and Quijón, 2011; Quinn et al., 2012; Wong et al., 2005). In addition, green crabs have been associated with the demise of populations of the vascular marine plant, *Zostera marina* (Malyshev and Quijon, 2011; Garbary et al. 2014). In addition, green crabs may be preying on juvenile lobsters, *Homarus americanus*, or outcompeting them for some food types (Williams et al. 2006; Haarr and Rochette, 2012; Mar Sigurdsson and Rochette, 2013). Results presented here indicate that green crabs control soft-shell clam populations on the intertidal flats studied, and that this is very similar to work conducted elsewhere on the interaction between *Carcinus* and *Mya* (Beal, 2006; Whitlow, 2010). Recent efforts in Freeport are also similar to historic accounts of these two species in Maine during the 1950's (Dow and Wallace, 1952; Glude, 1955; Welch, 1969).

Future efforts should focus on: 1) continuing to trap green crabs in discrete areas of the Harraseeket River to determine if trends (e.g., CPUE, frequency distributions of male and female crabs; sex ratios) observed in 2013 continue in future; 2) re-examine the effectiveness of fenced plots (similar in size to those used at Little River for Experiment I) vs. control plots on the abundance patterns of 0-year class clam recruits (with fencing properly maintained and plots positioned so that they are oriented with the corners facing net movement of tides/currents); 3) re-examine the use of netted plots to enhance wild recruits and protect cultured seed to determine whether these are cost-effective measures that communities or individuals could use to enhance existing stocks of clams; 4) examine the effect of using weathered clam shells in areas of low sediment pH in an attempt to buffer plots to determine if this effort will result in enhancing wild recruits to settle and grow; and 5) working directly with clammers to grow cultured seed (upwellers) for eventual planting in protected plots to enhance the wild stocks.

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