NORTHEAST CONSORTIUM
Final Report

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Project Title: ***A Collaborative Effort to Examine New Strategies for Managing Closed Bottom Habitats for Sea Scallops***

Project Leader:
Dr. Brian F. Beal
University of Maine at Machias
9 O'Brien Avenue
Phone: 207.255.1314
Fax: 207.255.1390
e-mail: bbeal@maine.edu

Lead Institution:
Downeast Institute for Applied Marine Research & Education

Phone: 207.497.5769
Fax: 207.497.2264
e-mail : downeastinstitute@hotmail.com

Additional Key Project Participants:
Mr. Terry Stockwell,
ME DMR
State House Station 21
Augusta, Maine 04333
Phone 207.624.6562
e-mail: terry.stockwell@maine.gov

Mr. Christopher Bartlett,
ME Sea Grant/Cooperative Extension
Marine Technology Center
16 Deep Cove Road
Eastport, Maine 04631
Phone 207.853.2518
e-mail: cbartlett@maine.edu

Fishermen:
Maurice Alley (Beals, ME)
Preston Alley (Beals, ME)
Robert Alley, Jr. (Jonesport, ME)
Ernest Kelly, Jr. (Jonesport, ME)
Raymond Alley (Jonesport, ME)
Jeff Alley (Jonesport, ME)
Colon Alley (Jonesport, ME)

Executive Summary

Commercial populations of sea scallops, *Placopecten magellanicus*, are at or near record low catch levels in eastern Maine. Three independent field trials were conducted in the Jonesport-Beals region from May 2007 to May 2009 that focused on providing information for fishermen and fisheries managers about the efficacy of using closed bottom areas to enhance commercial populations of these bivalves.

The first trial was short-term, and conducted from May to June 2007. Two approximately 1 km^2 bottom areas were closed to all dragging and diving activities. Bottom plots (15 m x 15 m; n = 8) within each area were seeded at a density of 2.5 individuals/m^2 using legal and sub-legal size scallops dragged from an area in Englishman Bay, in Jonesport. One-half of the plots in each area received scallops that had been stored for ca. 7 hours in commercial fish totes (black, plastic units measuring 70 cm x 40 cm x 28 cm deep with holes in the bottom) on board two commercial draggers, while the other half of the plots received scallops that had been held in flow-through containers (modified Xactic box) for the same period of time. The fate of these scallops was followed for thirty days by SCUBA divers. Scallop recovery and survival in all plots in both areas was excellent and independent of handling treatment. In one of the two areas, mean number of scallops recovered on Day 30 from both handling treatments was not significantly different from the initial seeding density. Final recovery was lower at the other area where faster tidal currents occurred that tended to push scallops out of the marked bottom plots.

The second (2007-2008) and third (2008-2009) field trials involved collecting wild scallop spat (juveniles < 20 mm in shell height) using fine-mesh bags similar to those used successfully to collect small scallops of the same species in nearby Passamaquoddy Bay during the 1990's, and in the Northumberland Strait and surrounding areas of the Canadian Maritimes in the past decade. In addition, materials and methods of deploying spat bags were similar to those used successfully in Japan, Chile, and Northern Europe. The reason for attempting to collect wild spat was for the purposes of enhancing the bottom plots in both closed areas. A total of 1200 bags were deployed in late summer 2007 and 2008, and these were retrieved in the spring of 2008 and 2009, respectively. Each year, one half of the bags were placed on the eastern and western side of Great Wass Island, in the town of Beals. On each side of the island, one-half of the bags were deployed in shallow (< 20 m) and deep (> 30 m) water. Less than 40% of the gear was retrieved in both years. In May 2008, number of spat per bag averaged 2.8 ± 0.43 individuals (n = 460 bags). Recruitment was approximately 6.5x higher in May 2009 (18.6 ± 2.04 individuals per bag; n = 383 bags). In May 2008, scallop density per bag was significantly higher and scallop size was significantly greater on the western vs. eastern side of Great Wass Island. In May 2009, no significant difference in scallop density was observed between sides of the island, but scallop size remained higher on the western vs. eastern side. In both years, more scallops settled into bags deployed in deep vs. shallow water. These results are in stark comparison to the work of others in the Canadian Maritimes where > 3,000 spat have been collected in similar size bags.

These results suggest that enhancement of bottom plots is feasible using legal and sub-legal individuals; however, it remains to be seen whether dragging animals from open areas to seed into closed bottom areas is a sustainable activity. The discouraging results from spat collection trials suggest that commercial scallop populations are recruitment-limited and that, at least in the Jonesport-Beals area, other methods to collect wild spat or produce culture spat should be explored.

Project objectives

The objectives of the work are to: 1) determine method(s) of handling commercial quantities of sea scallops (both legal and sublegal sizes) to minimize mortality prior to deploying on bottom; 2) determine the most effective method(s) of deploying commercial quantities of sea scallops to bottom plots; 3) follow the fate of scallops deployed into bottom plots over a month after deployment; 4) determine sites that maximize numbers of wild scallop spat per spat collector; and 5) provide fishermen and resource managers with information that will enable them to decide whether the use of closed and enhanced bottom areas is a viable management tool.

Project scientific hypotheses

Handling experiments

Hypothesis 1: There is no difference in the fate of legal and sublegal sizes of sea scallops that are transported from collection sites damp/moist vs. wet/aerated.

Hypothesis 2: There is no difference in the fate of legal and sublegal sizes of sea scallops that are seeded in bottom plots from the surface of the water from a vessel vs. hand-seeded by divers into bottom plots.

The purpose of this experiment is to determine the best handling and transportation methods to minimize handling mortality prior to enhancement. We are unfamiliar with previous attempts to relocate commercial quantities of legal and sublegal size sea scallops. Scallops will be harvested (dragged) from several locations near Jonesport, Maine in April and May 2007 when seawater and air temperatures are usually below 10^{o}C. One-half of the animals will be placed carefully into dry, plastic fish totes filled to one-half capacity (20-22 kg) and then covered with a 3-4 inch layer of moist, nylon spat bags. The other half will be placed into specially designed, flow-through, aerated holding tanks (700-liter Xactic box—double wall polyethylene box with polyurethane foam insulation) retrofitted with shelves to hold scallops. We will estimate mean shell length and height of scallops from both handling treatments prior to deployment by measuring 50 individuals to the nearest 0.1 mm using Vernier calipers.

Because of fast currents, winds, and extreme tides, we had to abandon hypothesis #2 and have divers place transported sea scallops in bottom plots. That is, we decided not to deploy scallops into bottom plots via a broadcasting method from boats at the surface. We could not ensure that scallops would fall into the delineated bottom plots, and, since we repeatedly returned to these plots over a 30-day period to assess the fate and growth of the animals, we did not think that the method of broadcasting scallops from the surface would yield valuable information about how scallop density changed over time in the marked plots.

We added an additional sampling date (27 April 2008) for the bottom study and hired a diver to examine four of the eight plots at the Sheep Island site and one of the eight plots at the Moosabec Reach site. The purpose of this additional sampling was to learn about mortality and growth of the scallops that had been seeded into bottom plots approximately one year before.

Wild spat collection

Hypothesis 1: There is no difference in number of sea scallop spat per bag between shallow (< 20 m) and deep (> 30 m) locations (bottom types similar).

Hypothesis 2: There is no spatial or temporal difference in number of sea scallop spat per bag.

Hypothesis 3: There is no difference in number of sea scallop spat per bag or in size of scallop spat from the east to the west side of Great Wass Island.

Hypothesis 4: There is no difference in number of sea scallop spat per bag or in size of scallop spat from 2 meters from the bottom vs. 6 meters from the bottom.

Hypotheses 3 & 4 were added after the study was funded, and provide additional regional information about where sea scallop spat may be located and the arrangement of bags along discrete lines give us further information about where in the water column scallop spat may be located. The purpose of this field trial is to determine whether collecting wild sea scallop spat is a viable management option to use in conjunction with closed areas.

Results

Handling Experiments (bottom enhancement plots – Sheep Island and Moosabec Reach)

The 2007 Northeast Consortium project enabled us to engage in two activities. The first was to determine the best methods to collect, handle, transport, and deploy wild sea scallops into bottom plots in two closed areas. Those results are presented here. We eliminated one level of the factors in the first activity (deployment methods). We had proposed to seed scallops using divers who would distribute scallops into the bottom plots, and to drop scallops from a boat into the plots that we marked both at the surface and the bottom. However, because of high winds, stormy weather, and rapid currents, we decided to abandon that idea because it became clear that any attempt to seed from the surface would not accomplish our goals of being able to quantify scallop survival in marked bottom plots. Because many of the scallops seeded from the surface would have fallen outside the marked bottom plots, this method of distributing scallops would have led us to conclude that scallop migration from the plots was higher than it actually was (see below). The second activity was an attempt to collect wild spat using collection methods transferred from successful field trials in the Canadian Maritimes. Results of both efforts are presented here.

On 4 May 2007, we initiated a short-term (30-day) field experiment to examine how handling and transporting wild sea scallops collected using commercial drags affected their fate and growth. The study site was located near Sheep Island in Eastern Bay between Great Wass Island, town of Beals, and Kelley Point, town of Jonesport (44^{o} 31.10'N; 67^{o} 33.91'W). A similar study was initiated on 9 May 2007 between Perio Point, town of Beals, and the Coast Guard Station in town of Jonesport (Moosabec Reach – 44^{o} 31.52'N; 67^{o} 36.95'W; Fig. 1). Both sites were approximately 1-km^2. The bottom type at Sheep Island was sparse boulders and cobble with scattered individuals of *Agarum clathratum* and *Laminaria longicruris*. Few decapods were observed (rock crabs, *Cancer irroratus*, Jonah crabs, *C. borealis*, green crabs, *Carcinus maenas*, and American lobsters, *Homarus americanus*) during any of our visits to the site; however, this area is heavily fished for lobsters from June through November of each year. In addition, the site had been fished commercially by scallopers and urchin draggers/divers during the winter months (M. Alley, pers. obs.), which may explain the sparse macroalgae. On 3 May 2007, divers sampled 80 random 1-m^2 quadrats within the site, finding a density of 0.088 individuals m^{-2} ranging in size from 85-120 mm SH. Water depths at Sheep Island ranged from 3 to 6 meters at low tide. At the Moosabec Reach site, the bottom type was similarly mixed with some boulders, but was mostly flat ledge with juvenile mussels occupying the shallowest areas. Macroalgae was even more sparse at this site than at Sheep Island. Only green and rock crabs were observed during our visits to the site. Because the Beals-Jonesport bridge bisected the enhancement sites, current velocities at any particular bottom location were always significantly faster than those occurring at the Sheep Island site. On 8 May 2007, divers found 0.063 scallops m^{-2} ranging in size from 80-140 mm SH. The Moosabec Reach site also is heavily fished for scallops, urchins, and periwinkles, *Littorina littorea* (E. Kelley, Jr., pers. obs.). These sites were chosen based on three factors: 1) proximity to the fishing villages of Jonesport and Beals Island; 2) each was a traditional scalloping ground with a history of high scallop abundance, but with low abundances in recent years; and 3) both are easily enforced in terms of poaching and other violations of the closed management area rules.

Within each site, eight bottom plots (15 m x 15 m) were created approximately 3-5 days before collecting, transporting, and deploying seed. Plots were marked at each corner with cement filled cinder blocks. Polypropylene sink rope (15 m lengths) was used to connect each block so that divers could delineate the periphery and area within each plot. Two permanent transect lines (sink rope, 15 m in length with white, numbered, plastic paper markers tied into each at 1-m intervals) were affixed to two opposite bottom lines approximately 5 m from each cement block.

Wild scallops were collected using commercial scallop drags at an area in Englishman's Bay in Jonesport (44^{o} 36.17'N; 67^{o} 32.03'W). Scallops were held and transported on each of two draggers on 4 and 9 May 2007. One-half of the scallops were placed in a flow-through Exactic box ("Wet Storage") while the other half were kept in plastic fish totes with several holes in the bottom of each tote to allow seawater to drain out ("Dry Storage"). Totes were covered with a piece of blue plastic tarpaulin, and placed under the stern of each boat, out of direct sunlight. Seawater temperatures on these dates was 8^{o} C measured at the nearby Downeast Institute on Great Wass Island (44^{o} 28.83'N; 67^{o} 35.92'W). Air temperatures on these dates ranged from 7 to 12^{o} C. From time-to-time throughout the day, sea scallops in the totes were watered by pouring a 5-gallon bucket of seawater over them. Boats worked the collection site for approximately 6 hours on both days. At the end of the day, the scallops were transported directly to the enhancement site where divers distributed the scallops evenly throughout each of the eight bottom plots. Scallops from each handling treatment were randomly assigned to the bottom plots. Initial enhancement density at both sites was established at 2.5 m^{-2}, or approximately 30-40 times ambient densities. This density was chosen based on practical measures (the length of time needed to collect enough animals for the trials, but also based on results from Canadian efforts to enhance bottoms with smaller animals (see Hatcher et al. [1996], Wong et al., [2005]). Mean (± 95% CI) shell height (SH) of scallops transplanted into bottom plots at Sheep Island was 86.4 ± 1.97 mm (n = 189), and 85.9 ± 1.54 mm (n = 309) at Moosabec Reach (Fig. 2). On each collection date, 30 sea scallops from each handling treatment and representing the frequency of sizes transplanted to bottom plots were taken to the Downeast Institute and held in flowing ambient seawater for 30 days to assess their survival. This gave us a measure of predator-independent handling mortality.

We returned to each site on **Days 1, 2, 3, 5, 10, 20, and 30** after deployment. On each visit, divers collected data on sea scallop density in five 1-m^2 randomly selected quadrats along each transect line within each plot (5 quadrats per transect line x 2 transect lines per plot x 4 plots per handling treatment x 2 handling treatments = 80 samples per site per sampling date). On the last sampling date, all scallops within each quadrat were taken to the surface where the shell height of each was measured to the nearest 0.1 mm using Vernier calipers.

Results from the Sheep Island enhancement site were unambiguous (Fig. 3, Table 1). First, there was no effect due handling treatment and there was no effect to due sampling date. In fact, the mean density in the 80 quadrats on 2 June 2007 (2.5 ± 0.63 individuals m^{-2}) was not significantly different from the stocking density at the beginning of the experiment. In addition, none of the sixty sea scallops that were taken from the group that was placed in bottom plots at Sheep Island and held at the Downeast Institute in ambient seawater for the 30-day period died. The results provide strikingly clear evidence that 1) in low-flow areas, adult sea scallops generally tend to stay where they are transplanted for at least 30 days, and 2) moving scallops from wild beds to enhancement sites can be done easily using plastic fish totes in which the animals are stored dry, but moistened with seawater from time-to-time.

Figure 1. Location of the two closed areas near the towns of Beals and Jonesport, Maine.

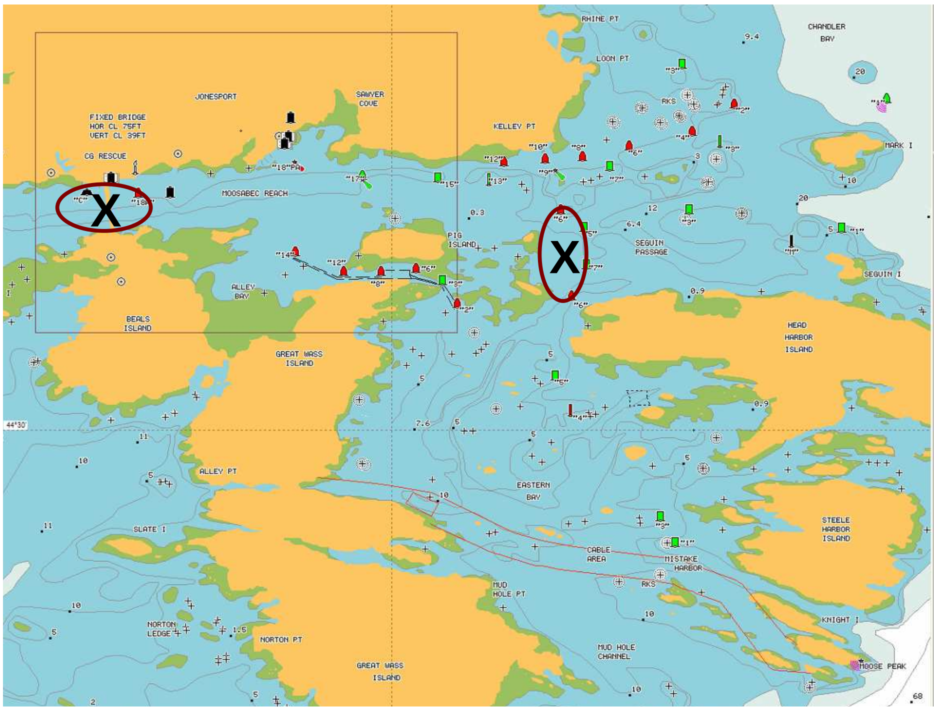


Figure 2. Size-frequency distribution and mean size of sea scallops used in the field experiment at Sheep Island (n = 189), and Moosabec Reach (n = 309).

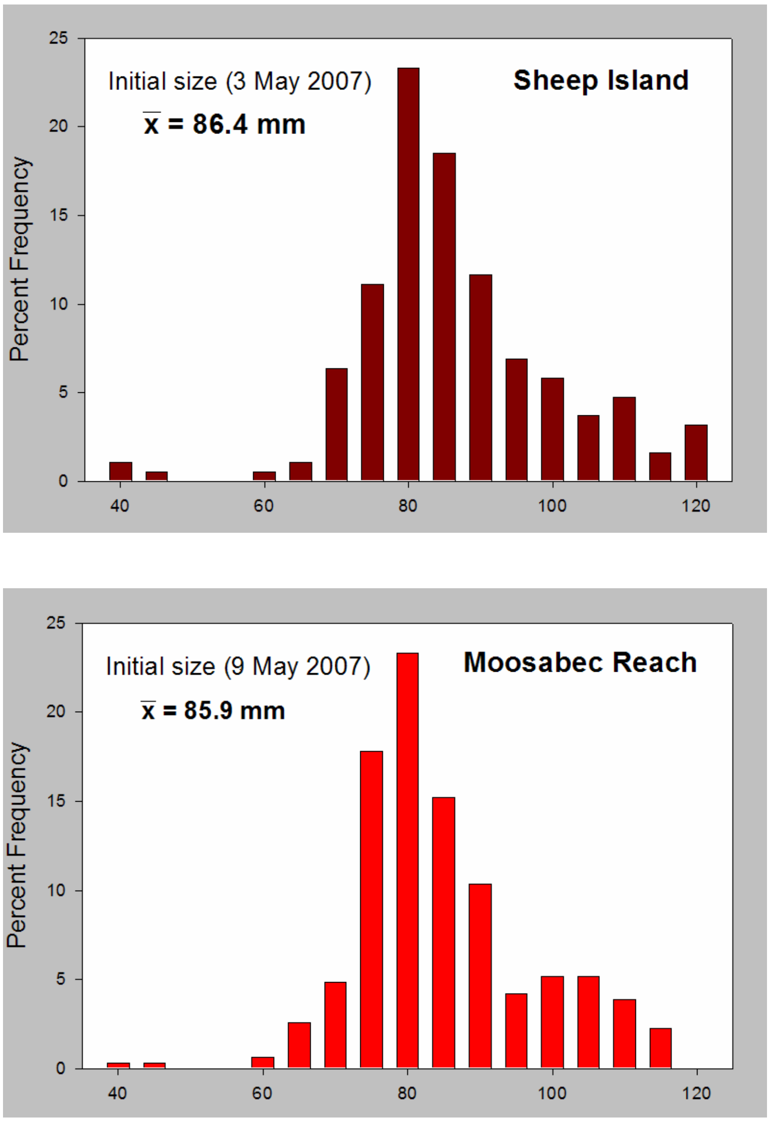


Figure 3. Fate of sea scallops, *Placopecten magellanicus*, seeded at a density of 2.5 m^{-2} in bottom plots at the Sheep Island enhancement site from 4 May to 2 June 2007.

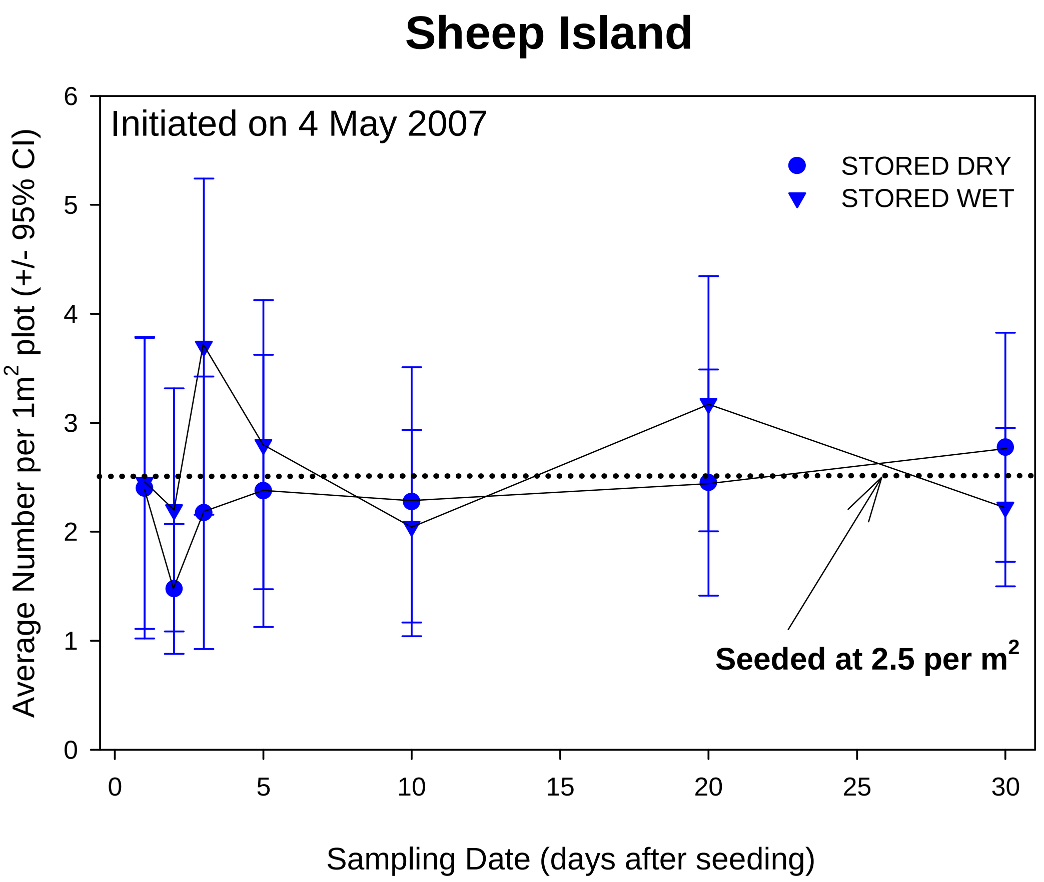


Table 1. Analysis of variance on the mean number of sea scallops per 1-m^2 quadrat on 7 dates from 4 May to 2 June 2007 at the Sheep Island enhancement site. (n = 5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Handling Treatment	1	20.44464286	20.44464286	0.59	0.4707
Sampling date	6	67.76785714	11.29464286	1.17	0.3429
Treatment x Date	6	57.81785714	9.63630952	1.00	0.4405
Transect	1	78.00178571	78.00178571	1.26	0.3053
Treatment x Transect	1	44.01607143	44.01607143	0.71	0.4321
Date x Transect	6	56.76071429	9.46011905	0.85	0.5398
Treatment x Date x Transect	6	38.39642857	6.39940476	0.58	0.7471
Plot(Treatment)	6	207.0392857	34.5065476	2.72	0.0131
Date x Plot(Treatment)	36	346.9857143	9.6384921	0.76	0.8414
Transect x Plot(Treatment)	6	372.6535714	62.1089286	4.90	<.0001
Date x Trans x Plot(Treat)	36	400.2714286	11.1186508	0.88	0.6738
Error	448	5673.200000	12.663393		
Corrected Total	559	7363.355357			

Only two of the eleven sources of variation were statistically significant, and these were not important in the overall scope of the project. The first source of variation that was statistically significant was Plot nested within Treatment ($P = 0.013$). This suggests that for at least one of the handling treatments that not all plots behaved similarly. Further decomposition of this source of variation indicated that plot-to-plot variation within both wet ($P = 0.0389$) and dry ($P = 0.0492$) treatments was statistically significant ($\alpha = 0.05$). The other significant source of variation occurred between some of the transect lines in some plots, but this variability is to be expected.

Results from the Moosabec Reach enhancement site were similar to those at Sheep Island with respect to overall effect of the handling treatments ($P = 0.413$), but require diver observations to help interpret results from Day 20 to Day 30 (Fig. 4, Table 2). Divers reported that on the final sampling date (8 June 2007), they saw live scallops near the periphery of some plots and outside the sink rope that delineated the plots. Scallops seemed to be responding to increasing rates of flow associated with astronomically high tides during the period before and after the full moon (31 May 2007). Nonetheless, divers reported that scallops were alive and indicated few deaths due to apparent mortality by decapods or other large predators. In addition, only one of the sixty scallops died (from the wet storage containers) that had been held at the Downeast Institute from among those seeded into bottom plots in Moosabec Reach. This independent estimate of handling mortality suggests, again, that future attempts to move sea scallops should use the easiest and least expensive method – dry storage in plastic fish totes.

Scallop growth was negligible over the 30-day trial at both sites (final mean SH at Sheep Island was 87.5 ± 2.01 mm [n = 199] compared to the initial mean SH of 86.4 ± 1.97 mm [n = 189]; final mean SH at Moosabec Reach was 90.0 ± 3.15 mm [n = 102] compared to the initial mean SH of 85.9 ± 1.54 mm [n = 309]). In addition, there was no significant handling effect on final mean length at either site ($P > 0.50$).

On 27 April 2008, we examined bottom plots at both enhancement sites using a single diver who used a meter-square quadrat. The diver was instructed to sample along two N-S lines within each 50-foot x 50-foot enhancement plot, and to place the quadrat randomly in five places along both lines (n = 10 samples per plot). In addition, the diver was instructed to count and record numbers of scallops per quadrat, and to take a single sample of live scallops from one of the ten quadrat samples within a plot.

Table 3 shows for the Sheep Island site that there was no significant difference from plot-to-plot in terms of scallop numbers, and the average number of scallops in the forty bottom quadrats was 0.975 (95% confidence interval = 0.58 to 1.36 per square meter, n = 40). This mean indicates that there has either been migration from the plots or some mortality because the last sampling conducted on June 2, 2007 demonstrated that over the initial 30-day period of enhancement, scallop densities at Sheep Island were constant at the seeding density of 2.5 animals per square meter.

The average density of scallops at the one enhancement plot in Moosabec Reach, however, was exactly 2.5 scallops per square meter (95% confidence interval = 0.81 to 4.19 per square meter, n = 10).

Figure 4. Fate of sea scallops, *Placopecten magellanicus*, seeded at a density of 2.5 m^{-2} in bottom plots at the Moosabec Reach enhancement site from 9 May to 8 June 2007. One plot (wet storage) were lost during the 30-day trial.

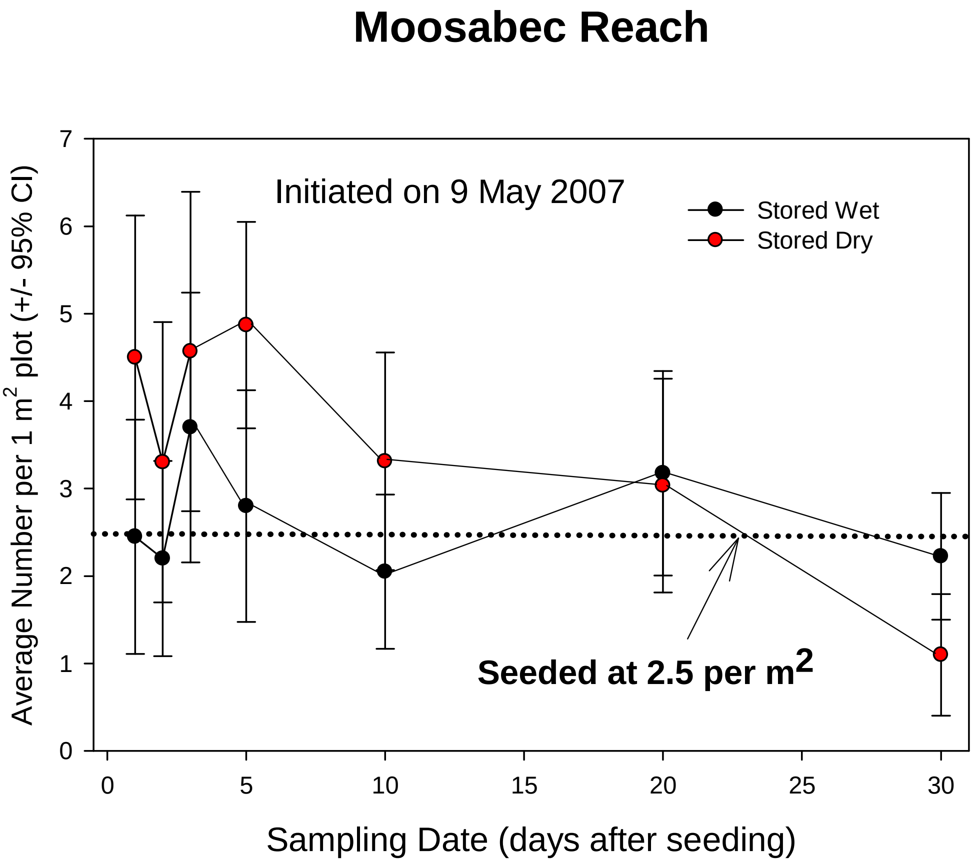


Table 2. Analysis of variance on the mean number of sea scallops per 1-m^2 quadrat on 7 dates from 9 May to 8 June 2007 at the Sheep Island enhancement site. (n = 4 or 5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Handling Treatment	1	18.30476190	18.30476190	0.80	0.4125
Sampling Date	3	132.7386691	44.2462230	3.85	0.0317
Sampling Date x Treatment	3	19.3547619	6.4515873	0.56	0.6488
Transect	1	16.73111511	16.73111511	0.12	0.7403
Treatment x Transect	1	29.34404762	29.34404762	0.22	0.6621
Sampling Date x Transect	3	44.97464029	14.99154676	0.47	0.7100
Date x Treatment x Transect	3	65.52023810	21.84007937	0.68	0.5781
Plot(Treatment)	5	114.6166667	22.9233333	1.30	0.2669
Date x Plot (Treatment)	15	172.4666667	11.4977778	0.65	0.8313
Transect x Plot (Treatment)	5	681.0916667	136.2183333	7.70	<.0001
Date x Transec x Plot(Treat)	15	482.1583333	32.1438889	1.82	0.0336
Error	224	3964.400000	17.698214		
Corrected Total	279	5746.996429			

Table 3. Analysis of variance on the mean number of sea scallops per 1-m^2 quadrat on 27 April 2008 at the Sheep Island enhancement site. (n = 10)

Sum of

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	9.77500000	1.39642857	0.91	0.5125
Error	32	49.20000000	1.53750000		
Corrected Total	39	58.97500000			

R-Square	Coeff Var	Root MSE	scallop Mean
0.165748	127.1754	1.239960	0.975000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
plot	3	7.67500000	2.55833333	1.66	0.1943
transect(plot)	4	2.10000000	0.52500000	0.34	0.8479

The shell height from 11 and four scallops was measured from the Sheep Island and Moosabec Reach sampling, respectively. The average size of scallops at Sheep Island was 103.9 mm (95% confidence interval = 98.3 mm to 109.5 mm, n = 11). The average size of scallops within the single Moosabec Reach plot was 105.7 mm (95% confidence interval = 100.5 mm to 110.8 mm). In addition, the amount of new shell growth that each animal laid down over the past year was estimated by reading back on each valve to an apparent disturbance line that likely coincided with the dragging, holding, and deploying date in May 2007. From that analysis, we determined that the average shell height of animals at Sheep Island had increased approximately 14.7 mm (95% confidence interval = 10.1 mm to 19.4 mm, n = 11) and those in the single Moosabec Reach plot grew approximately 24.7 mm (95% confidence interval = 21.2 mm to 28.1 mm, n = 4). Further, we asked whether the difference in this growth estimate could have occurred by random chance alone and performed a simple two-sample, two-tailed t-test on these growth means. The test indicated that this result could have happened by chance alone only 1.66% of the time, which is good evidence that the scallops in the single plot in Moosabec Reach grew appreciably faster than those in the four plots at Sheep Island. Caution should be exercised in interpreting these data. This is because only a single plot was sampled from Moosabec Reach, and we cannot know if this sample is truly representative of growth estimates from the other seven plots in that location. What we can say is that for the site sampled in Moosabec Reach, the animals in that plot grew nearly double what those from the four Sheep Island plots grew.

It is difficult to interpret these yearly results because the design of the bottom trials was to determine over a short time period, 30 days, what the fate of the transplanted scallops would be. The samples taken on 28 April 2008 generate questions that we are unable to answer at this time. For example, the density of sea scallops at the Sheep Island site in June 2007 was approximately 2.5 per square meter, whereas the density of sea scallops in the four plots at the Sheep Island site in April 2008 was approximately 1 per square meter, or a “loss” of nearly 60% since last year. What happened to these animals? Did some simply migrate outside the boundary of the 50-foot x 50-foot plots? Did some die of natural causes? Did some get preyed upon by seals, lobsters, crabs, or other bottom-feeding organism? The test was not designed to answer these important questions. On the other hand, we estimated initial density of sea scallops at Sheep Island prior to the enhancement (May 3, 2007), and found there was only 0.088 scallops per square meter. This means that after one year (using only the four plots rather than all eight), that there is still a 10-fold enhancement of scallops at Sheep Island.

Wild spat collections

September 2007 – May 2008

On 8-9 September 2007, we deployed 240 lines -- 120 on the east and west side of Great Wass Island (Beals, Maine; Lat. 44^{o} 28.83'N; Long. 67^{o} 35.90'W). Each line was anchored to the bottom using a typical cement block filled with cement. Five spat bags (0.75 m long x 0.45 m wide with 3 mm aperture and stuffed with a single piece of Netron® ca. 0.70 m long x 0.5 m wide) were arrayed on each line approximately 1.5 m apart. The bottommost spat bag was placed 3 m from the anchor, and the remaining four bags were each space 1.5 m apart from each other. That is, the uppermost bag was approximately 9 m from the cement anchor. A buoy was placed 1 m above the uppermost bag to ensure that the line remained upright during the time when bags were in the water. A surface buoy marked each line. Bags were deployed in early September, because we have found that this is approximately one month after gonad indices fall significantly (Beal 2004), which signals reproduction. One half of the lines and bags on each side of Great Wass Island were deployed in both shallow (< 20 m) and deep (>30) locations. These locations were chosen by collaborating fishermen, and in the analysis, location is considered a "fixed factor," whereas "lines within each location" were considered a "random" factor. Specific locations of each line were recorded using GIS.

Bags were collected 16-17 May 2008. Of the 600 bags deployed on each side of Great Wass Island, 224 and 237 (37.3% and 39.5%) were recovered from the east and west side, respectively. The contents of each bag and piece of Netron® were processed at the time of collection. All scallops from each bag were placed into uniquely labeled plastic bags and returned to the laboratory where the content of each was counted and all individuals measured (longest shell dimension: shell height – from the ventral margin to the hinge). The following linear model was used to answer specific hypotheses stemming from the sampling design:

$$Y_{ijkl} = \mu + A_i + B(A)_{j(i)} + C(AB)_{k(ij)} + D_l + AD_{il} + BD(A)_{jl(i)} + e_{m(ijkl)}$$

Where:

Y	=	dependent variable = ln(count per bag + 1);
μ	=	theoretical mean;
A_i	=	Side of Great Wass Island (east vs. west – factor is fixed);
B_j	=	Location within each side of Great Wass Island (12 "deep" and 12 "shallow" sites per side – factor is fixed);
C_k	=	Line within each location and side (factor is random);
D_l	=	Bag along each line (factor is fixed);
e_m	=	Experimental error

Number of scallops collected per spat bag was exceedingly low with less than 3 individuals per bag, on average (0 ± 95% CI = 2.8 ± 0.43 individuals per bag, n = 460 bags). Mean number of scallops varied significantly between sides of Great Wass Island (GWI; Table 4) as nearly 8x as many scallops were collected from bags on the western side of GWI (4.8 ± 0.74 ind./bag, n = 237) compared to the eastern side (0.6 ± 0.14 ind./bag, n = 223). On the east side of GWI, there was no significant difference in number of spat collected per bag between deep vs. shallow depths, but on the west side of GWI, significantly more spat were collected in deep vs. shallow locations (6.6 ± 1.07 ind./bag, n = 138 vs.

2.22 ± 0.69 ind./bag, n = 99; Table 4, Fig. 5). The position of the spat bag relative to the bottom was important, but the pattern differed from the eastern to western side of Great Wass Island (Table 4; Fig. 6). There was no position effect observed from locations on the eastern side of GWI, but on the western side, a general increase in spat per bag was observed from the bottommost to uppermost position along the lines. For example, mean number of individuals of spat per bag ± 95 % CI nearest the bottom was 2.7 ± 0.9 (n = 46) vs. 6.1 ± 1.8 (n = 47) and 5.7 ± 2.3 (n = 47) for the fourth and fifth bag from the bottom, respectively.

Mean scallop spat shell height varied significantly between sides of GWI (Fig. 7; Table 5). Scallop spat was approximately 25% larger on the western vs. eastern side of GWI (9.6 ± 0.26 mm, n = 179 bags vs. 7.5 ± 0.35 mm, n = 73 bags). There was no significant variation in spat size between locations on the eastern side of GWI, including the comparison between shallow vs. deep sites (Table 7). Mean spat shell height varied significantly from location-to-location on the western side of GWI, but there was no significant difference in shell height between depths (Fig. 8; Table 7).

Table 4. Analysis of variance on the ln(count + 1) of sea scallop spat from bags located on the east and west side of Great Wass Island (8-9 September 2007 to 17-18 May 2008). Six hundred spat bags (0.75 m long x 0.45 m wide with 3 mm aperture, and stuffed with a piece of Netron®) were initially deployed on each side of Great Wass Island. Five bags, with 1.5-m spacing between each bag, were arrayed along a single line that was anchored with a cement block filled with cement. The bottommost bag was approximately 3 m from the bottom, while the topmost bag was 9 m from the bottom. One-half of the bags deployed on each side of the island in September 2007 were placed in shallow (< 20 m) vs. deep (> 30 m) locations. 224 of the 600 bags were recovered from the east side of the island (37.3%) whereas 237 of the 600 bags were recovered from the west side of the island (39.5%).

Source of Variation	DF	Sum of Squares	Mean Square	F Value	Pr > F
Side	1	75.8715164	75.8715164	87.89	<.0001
Location(Side)	28	103.6144133	3.1308915	3.63	<.0001
Deep vs. Shallow (East)	14	10.2104605	0.7293186	0.85	0.6141
Deep vs. Shallow (West)	14	93.4039528	6.6717109	7.82	<.0001
Line(Side*Location)	68	58.0074143	0.8530502	3.31	no test
Bag	4	6.5750383	1.6437596	6.38	<.0001
Side*Bag	4	3.1367261	0.7841815	3.04	0.0179
Location*Bag(Side)	109	32.6026932	0.2991073	1.16	0.1731
Error	245	63.1475248	0.2577450		
Corrected Total	459	377.9071960			

Figure 5. Average number of sea scallop spat collected in "spat bags" on the eastern and western sides of Great Wass Island, Beals, Maine from 8-9 September 2007 to 17-18 May 2008. The figure shows that the pattern of scallop numbers from shallow to deep locations differed significantly between sides of the island (P < 0.0001; Table 3), with no differences observed on the eastern side, but a 3-fold difference between shallow and deep locations on the western side of the island.

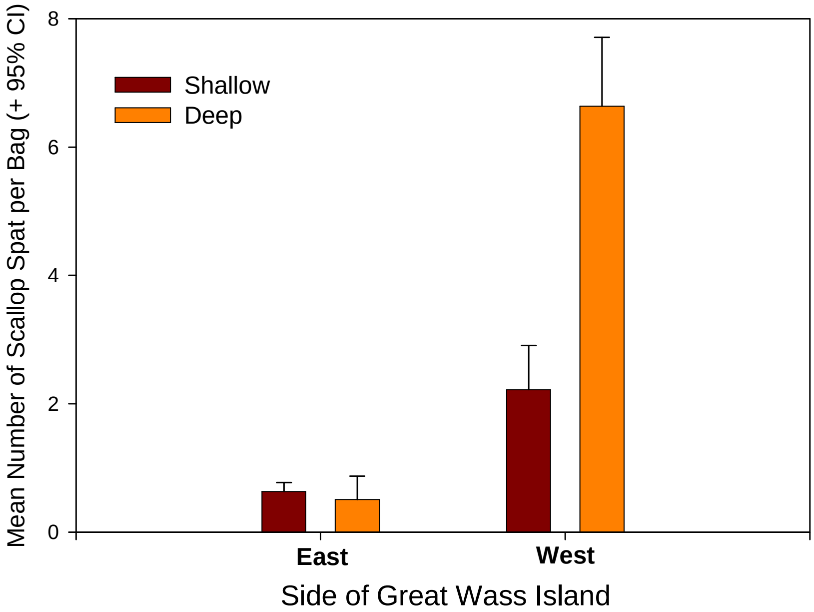


Figure 6. Relative importance of position of spat bag relative to the bottom on both eastern and western side of Great Wass Island (see Table 4).

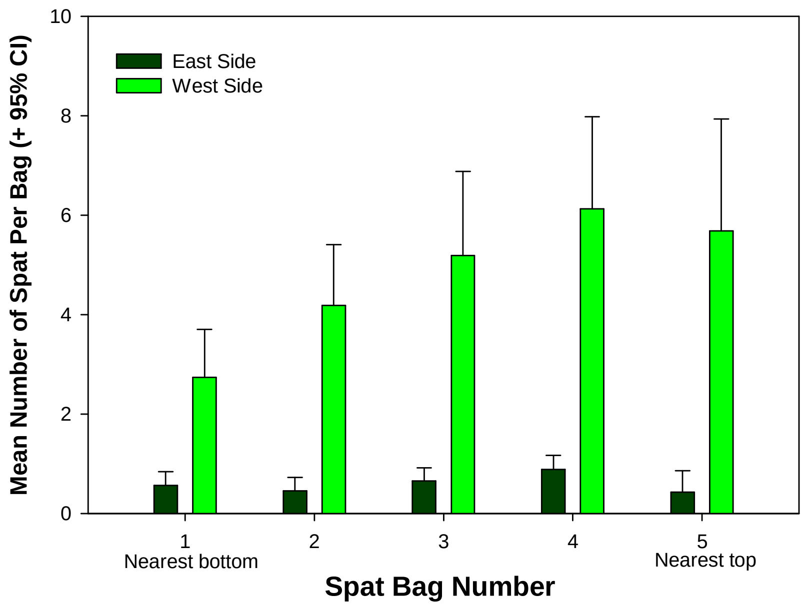


Figure 7. Frequency distribution of sea scallop spat shell height collected from spat bags on the eastern and western side of Great Wass Island, Beals, Maine on 17-18 May 2008. Bags were deployed on 8-9 September 2007.

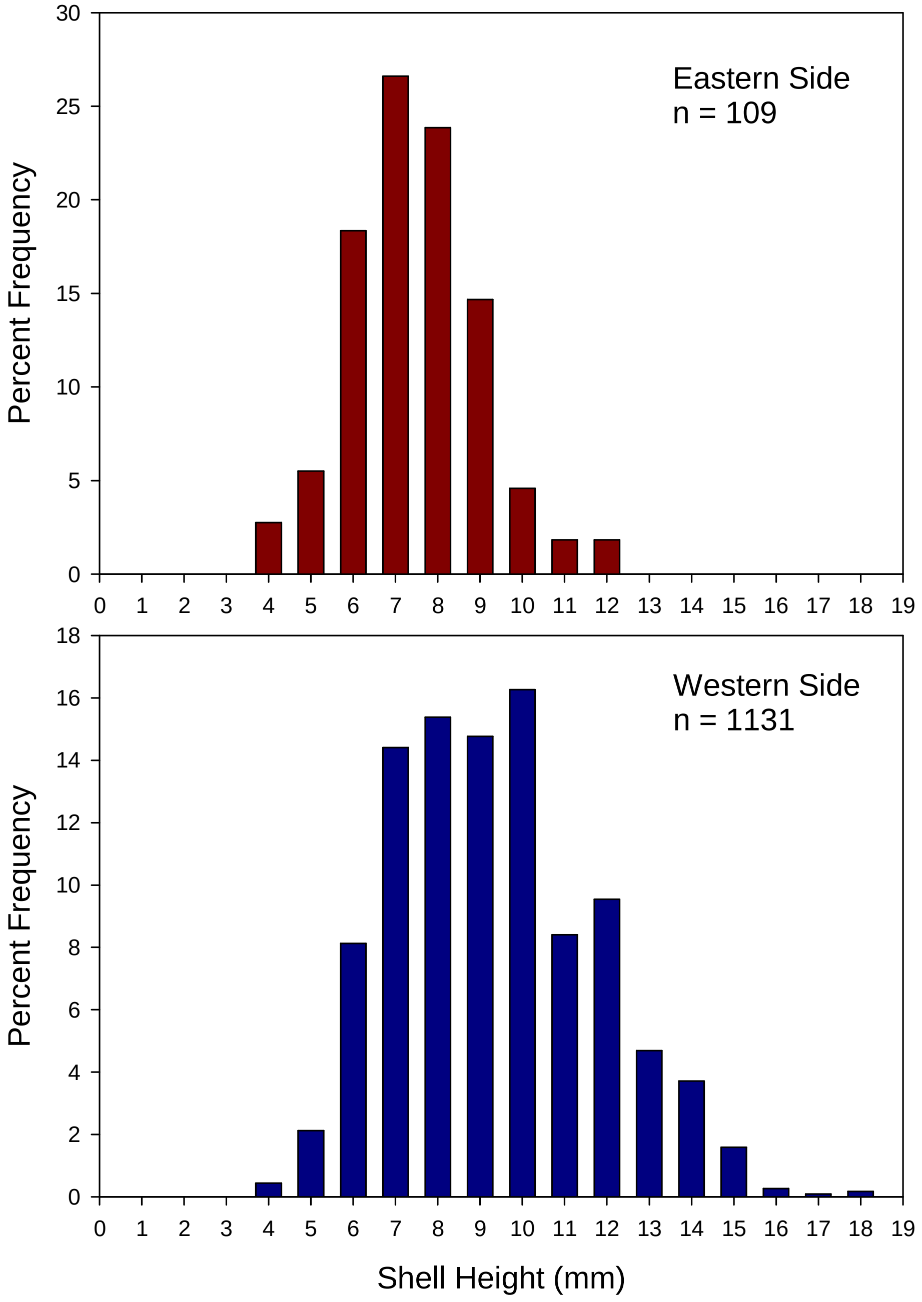
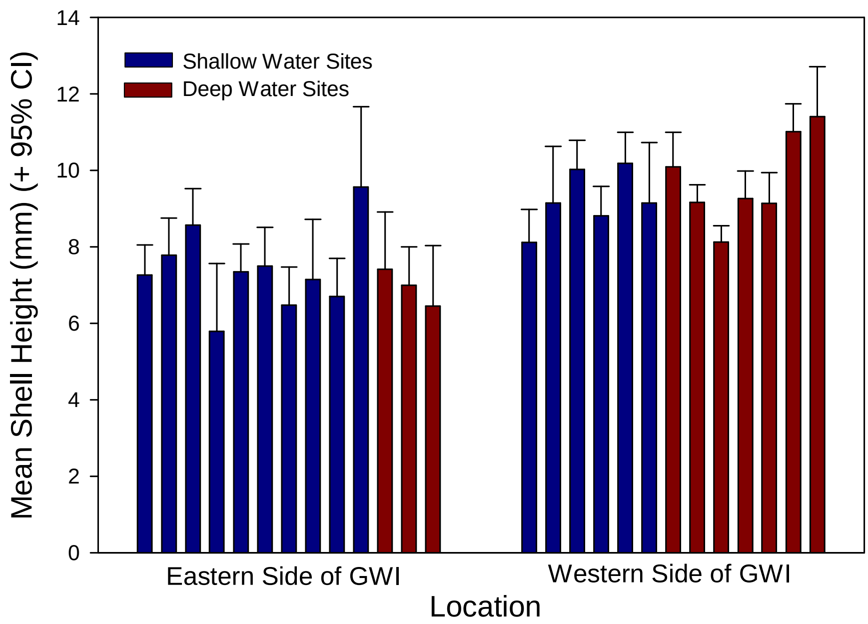


Table 5. Analysis of variance on the untransformed sea scallop spat shell height data from the spat collection (September 2007-May 2008) trials on the western and eastern side of Great Wass Island.

Source of variation	DF	Sum of Squares	Mean Square	F Value	Pr > F
Side	1	213.4916210	213.4916210	83.93	<.0001
Location(Side)	24	197.7747082	8.2406128	3.24	0.0001
Location (East)	12	50.1347895	4.1778991	1.64	0.1057
Location (West)	12	147.6399186	12.3033266	4.84	<.0001
Shallow vs. Deep (East)	1	1.2924329	1.2924329	0.51	0.4789
Shallow vs. Deep (West)	1	7.2929816	7.2929816	2.87	0.0956
Line(Side*Location)	58	147.5379871	2.5437584	1.12	0.3098
Bag	4	9.6632315	2.4158079	1.06	0.3798
Side*Bag	4	1.4636641	0.3659160	0.16	0.9577
Location*Bag(Side)	61	127.8032811	2.0951358	0.92	0.6328
Error	99	225.3401023	2.2761626		
Corrected Total	251	923.0745953			

Figure 8. Mean shell height of sea scallop juveniles collected from spat bags located on the eastern and western side of Great Wass Island, Beals, Maine from September 2007 to May 2009.



August 2008 – May 2009

To determine whether sea scallop spat collection patterns observed in 2007-2008 are generalizable, we deployed spat bags at the same locations on both sides of Great Wass Island on 30-31 August 2008, and retrieved the bags on 30-31 May 2009. These trials enabled us to determine if temporal variation (i.e., year-to-year) is greater than spatial variation. Our methods during the August 2008 deployment of gear were identical to those described above for the 8-9 September 2008 deployment. When bags were collected on 30-31 May 2009, each was inspected separately by emptying the contents of a single bag and the piece of Netron® into a plastic fish tote. Scallop spat were picked from the tote and placed into a labeled bag. Bags were taken to the University of Maine at Machias and stored in a walk-in cooler (5^oC) until the scallops within each could be counted and measured. Because the number of scallops in the bags was significantly higher than the previous year, as many as fifteen randomly sampled scallops were measured (to the nearest 0.1 mm using Vernier calipers). To randomize the scallops from a particular sample (=bag), all scallops were arrayed in a matrix within a white enamel pan. Then, a random number table was used to choose fifteen scallops from the array. If a sample had fifteen or fewer scallop juveniles, then all individuals were measured. Statistical analyses (as described above) were performed on the ln(count + 1) and shell height data.

Of the 600 bags deployed on both sides of GWI in August 2009, 184 and 199 (30.6% and 33.2%) were retrieved from the eastern and western side, respectively, in May 2009. Although these retrieval rates are somewhat lower than rates from the May 2008 collection, sufficient data exists to obtain a picture of what occurred during the second year of the scallop spat collection study.

Unlike results from the previous year, no significant differences in average number of spat per bag occurred between the eastern and western side of Great Wass Island (Table 6, P = 0.6530; East = 17.0 ± 2.24 individuals per bag, n = 184; West = 20.1 ± 3.33 individuals per bag, n = 199). Overall, average number of scallop spat per bag was 18.6 ± 2.04 individuals per bag (n = 383), which was approximately 6.5x as many scallop juveniles that were observed the previous year. One must ask why scallop settlement intensity is so relatively low in and around the Great Wass Island region? For example, in Passamaquoddy Bay, New Brunswick, Canada, Robinson et al. (1992) found the number of spat varied greatly throughout the Bay with a maximum settlement of > 3,000 spat per bag. Earlier studies in the same location Dadswell and Parsons (1991) resulted in 100 to 400 spat per bag. In 2008-2009, the maximum number of spat bag per bag was 112 (Western side of Great Wass Island at a deep-water site). Together, the two years of data suggest that scallop populations are suffering from poor annual recruitment. This may be a result of too few adults remaining on bottom to spawn, or it could be other factors such as intense predation on the larvae while members of the zooplankton community.

Significant variability was observed between locations on each side of Great Wass Island (Table 6). Some of this variability was due to differences observed between shallow and deep sites on each side of GWI. For example, 130% and 230% more sea scallop juveniles occurred in spat bags at deep-water vs. shallow-water sites on the eastern and western side of GWI, respectively (Fig. 9). In addition, height of spat bag above the bottom affected number of scallop juveniles; however, the relationship varied significantly from one side of GWI to the other (P = 0.0015, Table 6; Fig. 10). A positive, linear relationship occurred between average number of spat per bag and distance from bottom for bags deployed on the western side of GWI. And, although there was a tendency for increasing number of spat with distance from bottom for bags deployed on the eastern side of GWI, the relationship appeared to flatten out after bag #2, or above 4.5 m from the bottom (Fig. 10). Average height of sea scallop spat varied significantly between sides of Great Wass Island (Table 7), and the pattern was similar to that observed the previous year (Fig. 11). That is, scallop spat was approximately 35%

larger on the western (10.9 ± 0.29 mm, n = 182) vs. eastern side (8.1 ± 0.21 mm) of GWI. No differences in mean shell height were observed between shallow vs. deep locations on either side of GWI (Table 7). No overall effect was observed due to position of spat bag on mean shell height, but there was a significant Bag x Side interaction (Table 7). It appears the reason for this significant interaction term is due to a slight decrease in shell height in the uppermost bags on the western vs. eastern side of Great Wass Island (Fig. 12).

Table 6. Analysis of variance on the ln(count + 1) of sea scallop spat from bags located on the east and west side of Great Wass Island (30-31 August 2008 to 30-31 May 2009). Six hundred spat bags (0.75 m long x 0.45 m wide with 3 mm aperture, and stuffed with a piece of Netron®) were initially deployed on each side of Great Wass Island. Five bags, with 1.5-m spacing between each bag, were arrayed along a single line that was anchored with a cement block filled with cement. The bottommost bag was approximately 3 m from the bottom, while the topmost bag was 9 m from the bottom. One-half of the bags deployed on each side of the island in August 2008 were placed in shallow (< 20 m) vs. deep (> 30 m) locations. 184 of the 600 bags were recovered from the east side of the island (30.6%) whereas 199 of the 600 bags were recovered from the west side of the island (33.2%).

Source of variation	DF	Sum of Squares	Mean Square	F Value	Pr > F
Side	1	0.2244059	0.2244059	0.20	0.6530
Location(Side)	34	331.7982569	9.7587723	8.91	<.0001
Location (East)	16	129.7354120	8.1084632	7.40	<.0001
Deep vs. Shallow (East)	1	62.3343015	62.3343015	56.89	<.0001
Location (West)	18	202.0628449	11.2257136	10.25	<.0001
Deep vs. Shallow (West)	1	73.3384598	73.3384598	66.94	<.0001
Line(Side*Location)	46	50.3961981	1.0955695	4.45	no test
Bag	4	47.5801269	11.8950317	48.34	<.0001
Side*Bag	4	4.5483092	1.1370773	4.62	0.0015
Location*Bag(Side)	133	44.4601954	0.3342872	1.36	0.0319
Error	160	39.3711218	0.2460695		
Corrected Total	382	518.3786143			

Figure 9. Average number of spat per bag (+ 95% CI) on eastern and western side of Great Wass Island on 30-31 May 2009. ANOVA revealed that there were significantly more scallops in bags located in deep vs. shallow water (Table 6).

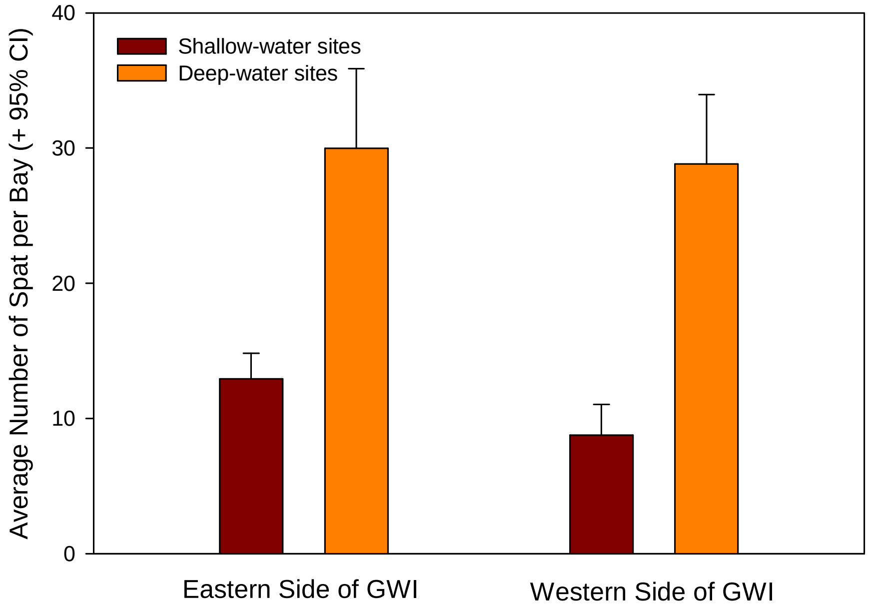


Figure 10. Relationship between number of sea scallop spat per bag and distance of bag from the bottom for bags deployed on both sides of Great Wass Island, Beals, Maine in August 2008 and retrieved in May 2009.

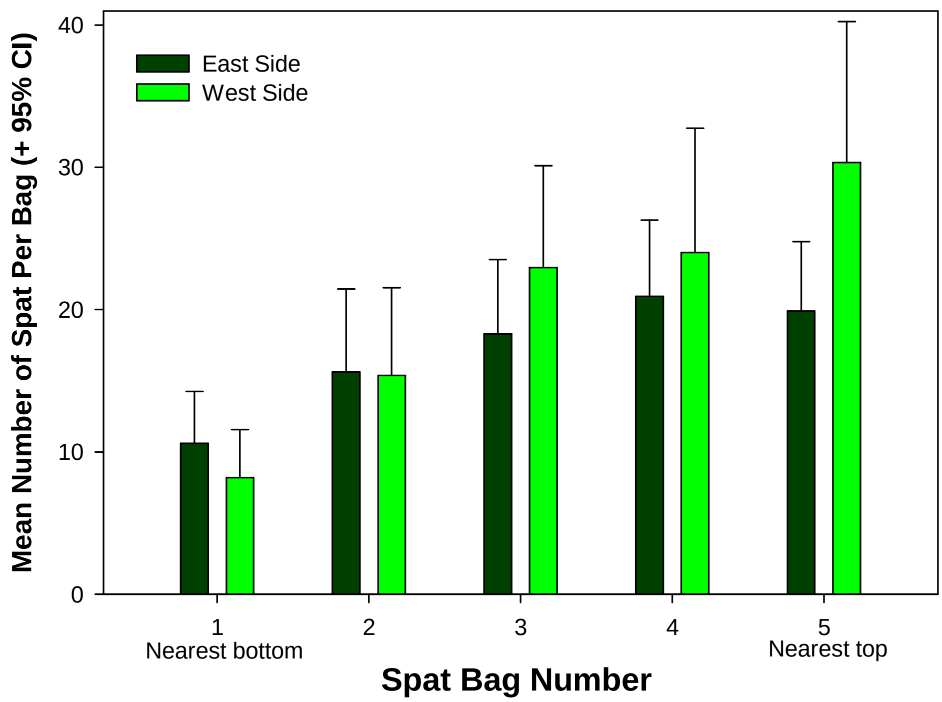


Table 7. Analysis of variance on the untransformed mean shell height of juvenile sea scallops collected in spat bags on 30-31 May 2009 from both east and west sides of Great Wass Island, Beals, Maine. Bags were deployed on 30-31 August 2008. See method for description of "deep vs. shallow locations."

Source of variation	DF	Sum of Squares	Mean Square	F Value	Pr > F
Side	1	1159.747654	1159.747654	35.06	<.0001
Location(Side)	34	1216.320848	35.774143	1.08	0.3974
Location (East)	16	146.534216	9.158388	0.28	0.9962
Deep vs. Shallow (East)	1	12.244182	12.244182	0.37	0.5460
Location (West)	18	1069.786632	59.432591	1.79	0.0558
Deep vs. Shallow (West)	1	18.168501	18.168501	0.55	0.4621
Line(Side*Location)	46	1521.528917	33.076716	11.46	no test
Bag	4	26.529935	6.632484	2.30	0.0618
Side*Bag	4	30.816363	7.704091	2.67	0.0346
Location*Bag(Side)	120	607.305352	5.060878	1.75	0.0006
Error	146	421.494475	2.886948		
Corrected Total	355	4983.743545			

Figure 11. Size-frequency distribution of sea scallop spat from collection bags deployed on the eastern and western side of Great Wass Island, Beals, Maine on 30-31 May 2009. Bags were deployed on 30-31 August 2008.

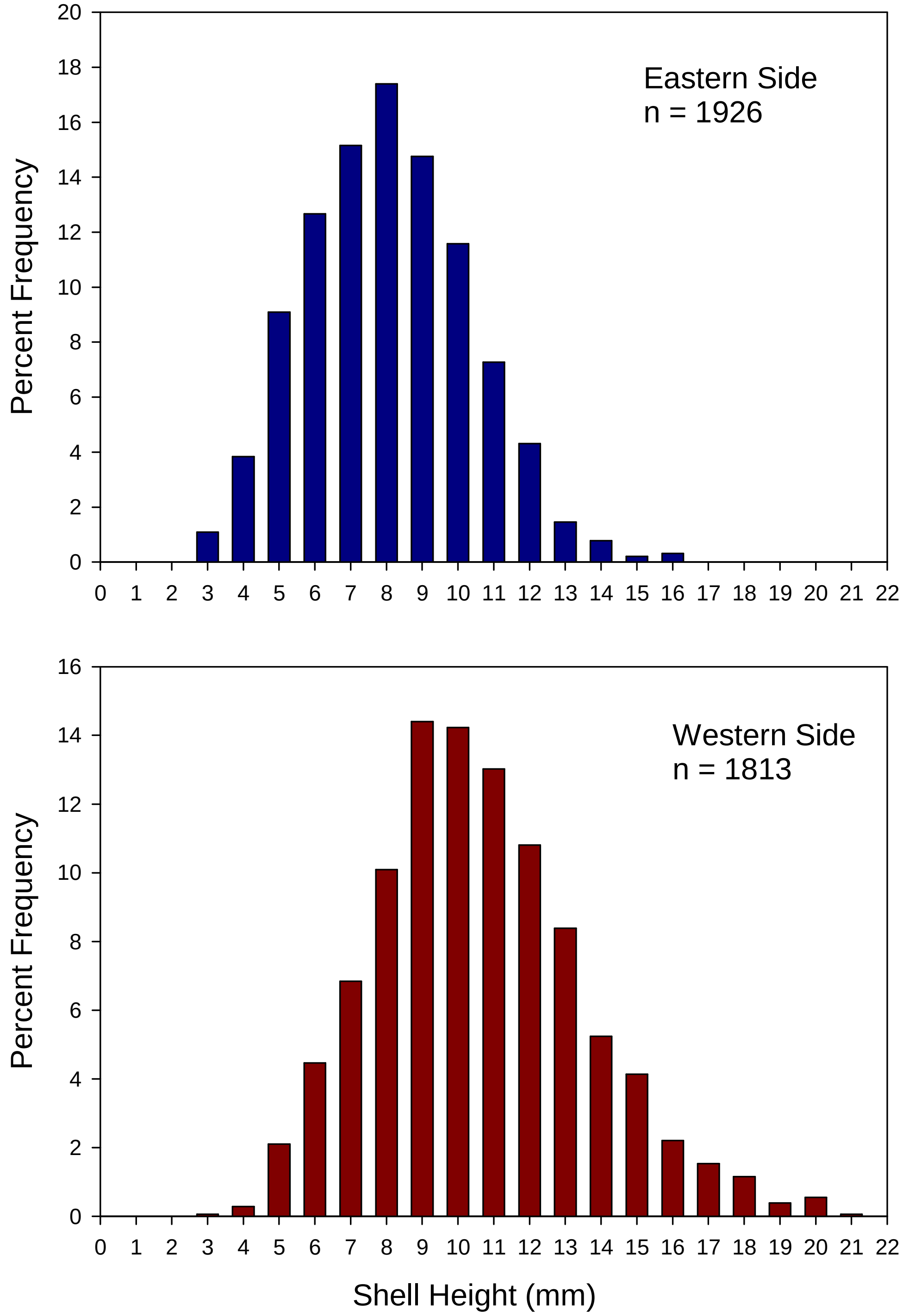
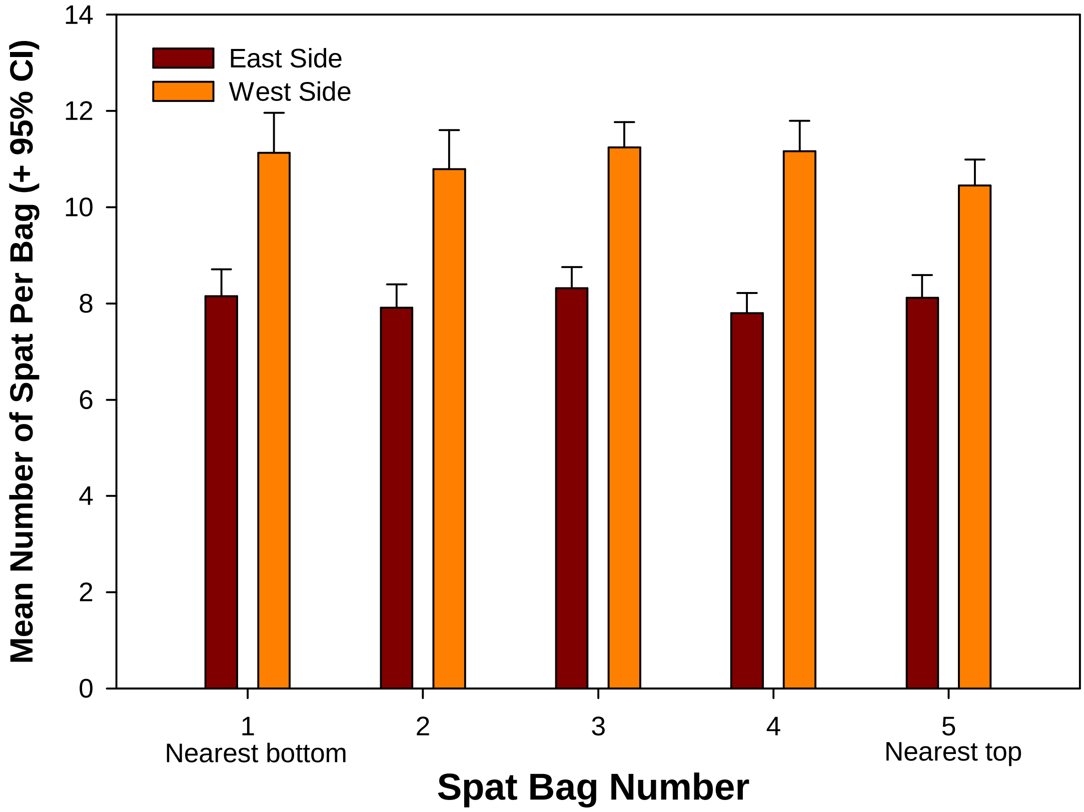


Figure 12. Relationship between sea scallop shell height and position of spat bag above the bottom on both sides of Great Wass Island, Beals, Maine.



Data

The data we have collected to date have been analyzed using SAS software. The format that we have used to determine growth and survival at both sites has been placed into SAS files. All data are contained in files on the CD that accompanies this Final Report.

Impacts and Applications

The project has had a great impact on the project participants and the fishermen that these individuals fish within the Beals-Jonesport region. They are encouraged by results of the closed area work, and wish to expand the effort to include new sites. Hence, they worked on a 2008 NEC consortium proposal that was submitted in December 2007. This proposal was not funded.

Partnerships

All fishermen listed in the participant list, plus two others have been directly involved in the project. There have been three scientists involved directly. Fishermen have been involved by using their boats as research platforms for data collection, and they have communicated the findings to others in the local community.

Presentations

A presentation was made by the PI to the Maine Sea Scallop Advisory Committee on June 14, 2007. The title of the presentation was the same as the title of the project. It occurred at the third floor meeting room at the office complex of the Maine Department of Marine Resources in Halowell, Maine. Additional presentations were made on Saturday, March 1, 2008 at the Fishermen's Forum in Rockport, Maine, on June 26, 2008 to the Maine Sea Scallop Advisory Committee at their monthly meeting held at the University of Maine at Machias, and on December 5, 2008 at the Northeast Aquaculture Conference and Exposition in Portland, Maine. All presentations are included on the CD that accompanies this Final Report.

Student participation

Eight undergraduate students from the University of Maine at Machias have been involved in the project to date.

Images

All images that have been taken using a digital camera are contained on the CD that accompanies this Final Report.

References

Dadswell, M.J. and Parsons, G.J., 1991. Potential for aquaculture of sea scallop, *Placopecten magellanicus* (Gmelin, 1791) in the Canadian Maritimes using naturally produced spat. In: S.E. Shumway and P.A. Sandifer (Editors), An International Compendium of Scallop Biology and Culture. World Aquaculture Workshops, No. I. The World Aquaculture Society, Baton Rouge, pp. 300-307.

Robinson, S.M.C., Martin, J.D., Chandler, R.A., Parsons, G.J. and Couturier, C.Y., 1992. Larval settlement patterns of the giant scallop *Placopecten magellanicus* in Passamaquoddy Bay, New Brunswick. Can. Atl. Fish. Sci. Adv. Comm. Res. Dot., No. 92/l 15, 26 pp.