Habitat Characterization and Sea Scallop Resource Enhancement Study in a Proposed Habitat Research Area

Final Report
Prepared for the 2013
Sea Scallop Research Set-Aside

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Project Summary:

Scallop seed from a natural seed bed was harvested in the Great South Channel on Georges Bank and transplanted to an experimental seed bed in Closed Area I (CAI) which has been identified as a potential Dedicated Habitat Research Area (DHRA). The encompassing goal of this project was to demonstrate the feasibility of a seeding program to enhance and stabilize scallop recruitment on Georges Bank while documenting the factors that affect seed survival.

The success of the transplanting experiment was evaluated with optical surveys using drop cameras operated by the University of Massachusetts, Dartmouth School for Marine Science and Technology (SMAST) and an off-bottom towed benthic sled (HabCam II operated by Arnie's Fisheries). The goal was to use images to evaluate scallop survival, scallop growth, and dispersal of scallop seed, as well as changes in population density of scallops and predators after the seeding operation.

Because our survey methods were not adequate for tracking the transplanted scallops after seeding, we were not able to evaluate scallop survival, growth, or dispersal. Haphazard transects indicated that the seeded scallops may have moved to the north and west of the drop site before landing on the sea floor. Changes in population densities were modeled using negative binomial regression with date (days after seeding) as a continuous factor. Date was not a significant predictor for scallop, skate, or crab densities over the course of the grid surveys. A significant change in sea star densities was observed, with date being significant predictor of sea star densities. However, we do not believe scallop seeding was the cause of this change.

We did a basic cost analysis based on the number and sizes of scallops harvested per day for seeding, approximated meat harvest, and vessel costs. Using numbers from the literature and our data, we estimated that a survival rate of more than 14.2 % would cover the cost of seeding.

Trips for this project year (NA13NMF4540009**):**

Dates	Vessel	Purpose	Type
May 20-24, 2013	F/V Tradition	Trip 1: Before seeding	video survey
June 5-8, 2013	F/V Liberty	Trip 2: Immediately after	video survey/tagging
June 5-8, 2013	F/V Ranger		seeding
June 15, 2013	F/V Guidance	Trip 3: 10 days after	video survey
June 27, 2013	F/V Wisdom	Trip 4: 21 days after	video survey
July 12, 2013	F/V Kathy Marie	Drive-by transect	HabCam
Sept 6-9, 2013	F/V Tradition	Trip 5: 3 months after	video survey/ROV

Project Objectives:

1. Characterize the benthic environment (substrate analysis, benthic fauna, predator biomass, etc) in a location within the southern portion of CAI on Georges Bank, which is currently closed to fishing, in order to identify an area that is suitable for seed relocation.

2. Initiate a seeding program to investigate the survival and growth of small (55-75mm) scallops transplanted from an area of high density seed, to an area with a low initial scallop biomass and low predator incidence as identified in objective 1.

3. Monitor the seeded scallops and environment (drop camera and ROV) at set stations and regular intervals to ascertain natural mortality, growth, and other factors that influence scallop production in order to demonstrate the efficacy and net gain to the scallop fishing industry as well as the health of the scallop stock.

4. Conduct a simple potential cost/benefit analysis of the seeding operation based on the data collected during this experiment.

Introduction

Atlantic sea scallops (*Placopecten magellanicus*) are the focus of an incredibly valuable fishery in the New England area. Yet, recruitment failures have been common in the past (Stokesbury et al. 2012). To manage these natural fluctuations, many scallop fisheries around the world have adopted seeding and nurturing of scallops under natural conditions (mariculture) to enhance the supply and quality of scallops and diversity of fishing opportunities (Bourne 2000; Brzezinski 2008). Seeding supplements natural recruitment and increases resilience to future environmental and anthropogenic pressures (Brzezinski 2008). The high productivity on Georges Bank makes it a good candidate for scallop enhancement and initial studies have been positive, but there are still obstacles with scallop retention (Smolowitz et al. 1998).

The current rotational management program relies on natural recruitment processes, making it dependent on incoming year class strength. Recruitment is highly variable and unpredictable on Georges Bank. The impacts of biotic (predation, fishing pressure, incidental fishing mortality) and abiotic variables (substrate, habitat, and oceanographic dynamics) on recruitment are poorly understood. It is important to gain a better understanding of the factors that influence the early life history stages of scallops in order to promote recruitment processes through management.

Although management continues to develop strategies to optimize scallop yield in the northwest Atlantic in a sustainable manner, implementing relatively small interventions could greatly increase scallop yield. Seeding in an area of low fishing effort could supplement natural recruitment and increase resilience to future environmental and anthropogenic pressures. Dense beds of scallops enable more concentrated fishing efforts, resulting in higher fuel efficiency, lower bycatch rates due to shorter tows, and minimal substrate disturbance due to fishing. Therefore, if small scallops were harvested from an area with low scallop survival and transplanted to an area with higher scallop survival and better growth conditions, costs to the industry could be minimized while potentially reducing bycatch through decreased fishing effort. In addition, seeding followed by regular monitoring could provide valuable information regarding scallop growth under documented conditions that can be applied to other fishing grounds.

Scallop resource enhancement was pioneered in the Mutsu Bay region of Japan (Aoyama 1989). The Yesso scallop (*Pecten yessoensis*) fishery in that area was subject to significant fluctuations in abundance, a factor common to most wild scallop fisheries including sea scallops. In 1935, Japanese researchers started developing a program to decrease recruitment variability. The early scientific efforts concentrated on ways to collect scallop spat (the life history stage following settlement). By 1953, Japanese fisheries cooperatives were collecting spat to re-seed fishing grounds. Two years later, they started to culture the spat for short periods of time before re-seeding in order to increase scallop survival. In 1964, a breakthrough occurred in spat collector design that significantly increased the number of spat collected. Increases in spat availability led to improved methods for raising large numbers of scallops in captivity to commercial size (Ito and Byakuno 1989). Today, seventy percent of Japan's scallop harvest is cultured. The harvest is stable from year to year and is an order of magnitude larger than the previous wild harvest fishery. There are over 1,900 scallop harvesting firms in the Mutsu Bay region alone, and many other regions also produce cultured scallops. Since the 1970's, countries in all parts of the world have begun scallop culture operations based on the Japanese model (Paul et al. 1981; Ventilla 1982; Reyes 1986; Naidu and Cahill 1986; Aoyama 1989; Pinfold 2001).

There has been some research already supporting scallop mariculture on Georges Bank. Successful transportation and seeding of scallops on Georges Bank was demonstrated in the Seastead Project, a three-year (1995-1998) collaboration between scientists and the sea scallop fishing industry to examine potential scallop enhancement and production strategies (Smolowitz et al. 1998). As a part of this project, a 24-square-kilometer research area, located 15 kilometers south of Martha's Vineyard, was closed to mobile gear and dedicated to scallop culture and enhancement research. In 1997, approximately 40,000 wild caught scallops, ranging in shell height from 40-100 mm, were placed in bottom cages, suspended nets, and loose on the bottom. The scallops were monitored for growth and mortality. A year later, an additional 80,000 scallops were directly seeded on the bottom and monitored using an underwater video camera sled. The scallops in the cages were hauled and measured. Sub-samples of all groups of scallops were consistently evaluated for health and condition during the project. Economic evaluation of the culture strategies suggested that bottom seeding was economically viable. The Seastead Project illustrated the feasibility of seedbed enhancement and demonstrated effective methods for transplanting and monitoring seed, which will be utilized in the proposed study.

Wild fisheries are one of the very few industries in the world that rely on minimal to no human interaction for enhancement or supplementation of the current population for future gains. While recent rotational management strategies have been successful in maintaining high yield, the impact of changing oceanographic and climate trends on the scallop population is unknown. There is no guarantee that recruitment and spawning stock biomass (SSB) will remain high with the potential for increased predation, ocean acidification, and ocean warming in future years. The proposed project seeks to demonstrate that not only is it possible to supplement the current sea scallop stock on Georges Bank, but that it is also possible to enhance the survival and growth of seed scallops that may not survive if left to nature alone.

This project used oceanographic and photographic monitoring to compare environmental conditions at a natural and transplanted seedbed. It demonstrated techniques that could be applied to weaker scallop stocks in the northwest Atlantic and tested a concept that could serve as a valuable management tool in other regions.

Methods

Table 1. Site Information

Site	Latitude	Longitude	Depth (m)	Bottom Temp (C)
Collection Site (NW CAI)	41.51	-69.34	90	5.8
Drop Site (NE DHRA)	40.94	-68.55	50-55	11

Identification of Seed Relocation and Collection Sites

SMAST conducted a preliminary trip and surveyed 254 stations to identify a potential reseeding site and 12 stations to identify potential seedbeds to target for juvenile scallops (**Figure 1**). A site at the northwest corner of CAI was selected as the seed collection site (**Figure 1**). Average scallop density at this seed collection site was tenfold higher than average densities of scallops at the reseeding site (**Table 2**). A site in the northeast corner of the DHRA was identified as a good location for reseeding (**Figure 2**). Crab and sea star average densities at the reseeding site were lower than those at the collection site (**Table 2**).

Table 2. Average (± SD) densities per square meter of scallops, crabs, sea stars, and skates at the seed collection and relocation sites

Site	Scallops	Crabs	Sea stars
Collection Site (NW CAI)	0.109 ± 0.210	0.141 ± 0.214	0.016 ± 0.070
Drop Site (NE DHRA)	0.009 ± 0.059	0.004 ± 0.036	0.005 ± 0.039

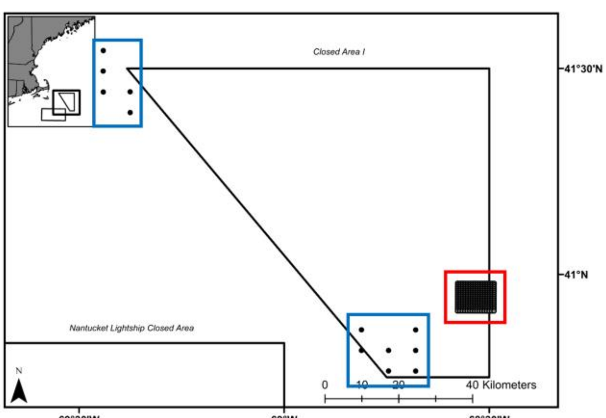

Figure 1. Location of the SMAST survey trip to identify a potential reseeding site (red box) and a potential seedbed for scallop collection (blue boxes).

Seeding Operation

In June 2013, approximately 2,100 bushels (~ 320,000 scallops) were harvested northwest of CAI in the Great South Channel (~ 41° 31.7 N, -69° 21.5 W) and were released southwest of the CAI Access Area (40° 56.41 N, -68° 32.40 W) (**Table 1**, **Figure 2**). Scallops ranged from 55-

100 mm in shell height (SH) and a bushel contained between 150-300 scallops. Approximately 5,000 scallops were measured and tagged in order to provide a baseline for growth rate estimates (**Figure 3)**.

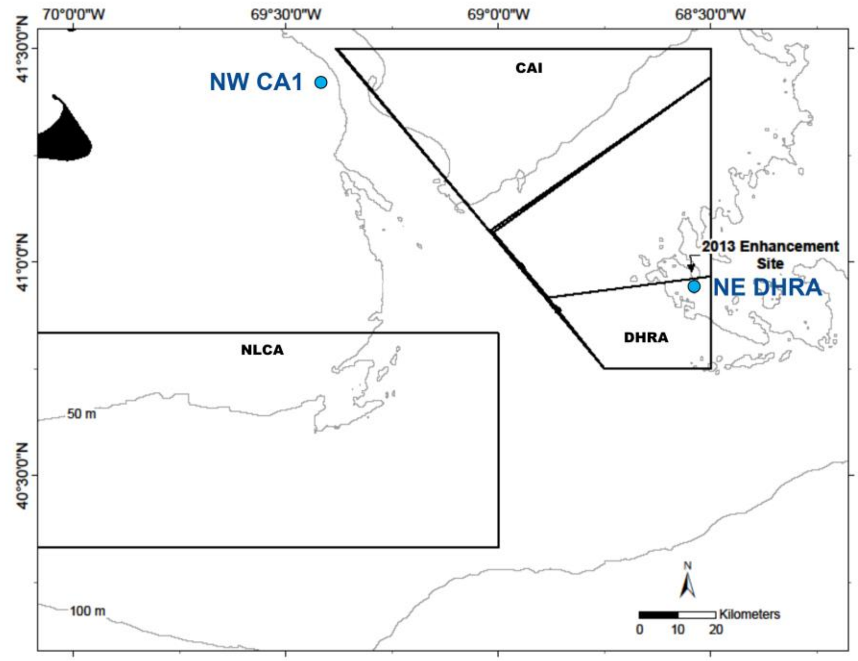

Figure 2. Map of sites selected for this study. NW CAI was the seed harvesting site for this project, and NE DHRA was the drop site where scallops were released. 50 m and 100 m bathymetric lines are shown.

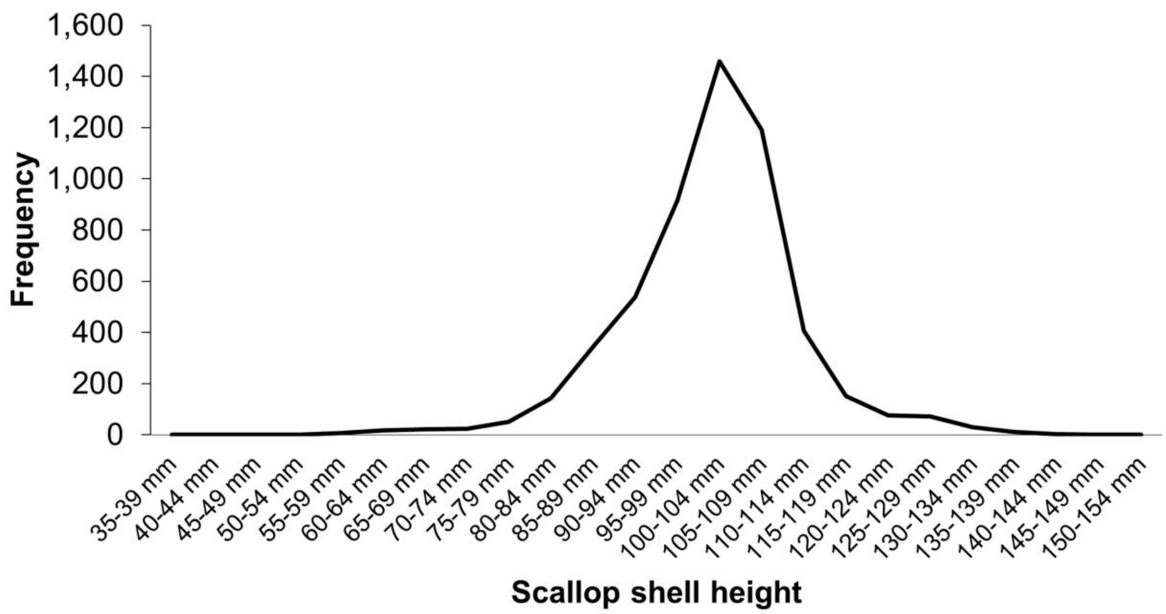

Figure 3. Length frequency distribution of measured scallops.

Scallop Surveys

The enhancement site was monitored prior to seeding, immediately after seeding (Day 0), 10 and 21 days after seeding, and three months after seeding in order to record changes in scallop and predator density, as well as the success of the transplant in terms of survivorship. The five optical survey trips took place between mid-May and early September. The first trip surveyed 254 stations to identify a potential enhancement site and 12 stations to identify potential seedbeds to target for juvenile. After the enhancement site was identified, four optical surveys were conducted in the area after seeding

The area surrounding the drop sites was monitored using the SMAST video pyramid deployed from a commercial fishing vessel (Stokesbury et al. 2004). The pyramid supports four cameras and eight lights. Two downward facing video cameras mounted on the sampling pyramid provide 2.84 m^2 and 0.60 m^2 quadrat images of the sea floor (Stokesbury et al. 2004). Another video camera, mounted parallel to the seafloor, provides a side profile of the quadrat area to aid in species identification. Lastly, a high-resolution digital still camera (12.3 megapixels) collects a single frame image of 1.06 m^2 used to identify seed and juvenile scallops, verify species identification, quantify habitat characteristics, and measure sea scallop shell heights.

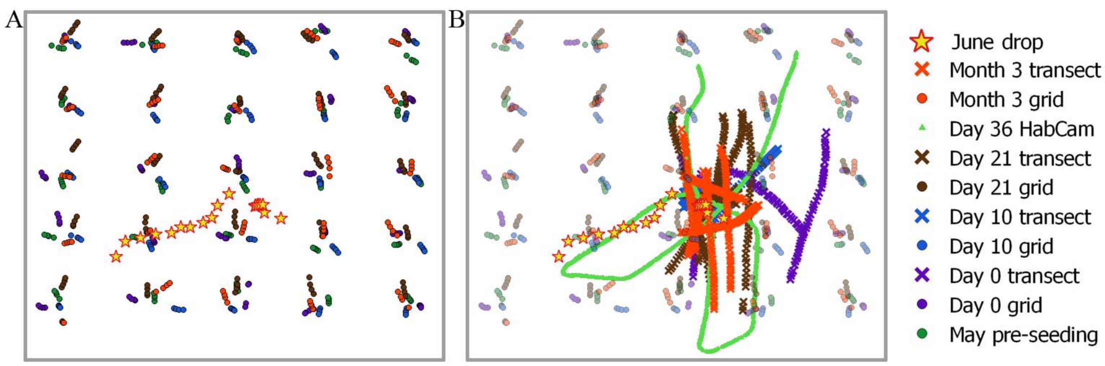

Figure 4. The locations of the drop sites (yellow stars) with (A) grid survey stations (colored circles) and (B) transect survey sites (colored crosses). The additional Habcam survey transect is shown in (B) with green triangles. Other grid stations that were added in the later grid surveys are not shown.

Each trip surveyed stations on a 0.5 km^2 grid. Four quadrats near the center of the grid were imaged using the drop camera, giving a total sample area of 11.36 m^2 per grid station. The exact grid survey locations varied from trip to trip because video drop locations were selected as the vessel drifted near the grid center (**Figure 4A**). The last two grid surveys sampled more stations over a larger area to account for the potential spreading of the transplanted scallops, though these stations were not included in the statistical analysis. Quadrats were also surveyed along transects to search for scallops at a finer spatial resolution. The survey vessel was then allowed to drift with the tide near the drop site as the video pyramid was repeatedly dropped (**Figure 4B**).

After each survey, the video footage was reviewed in the laboratory and a still image of each quadrat was digitized and saved. Within each quadrat, the number of scallops, skates, sea stars, and crabs were counted in each 2.84 m^2 image. For density calculations, the camera view area was increased to 3.2 m^2 to account for additional area covered by scallops that lie on the edge of the image (O'Keefe et al. 2010). This expansion was reviewed and accepted in the 50th Stock Assessment Workshop (SAW), and is based on the average shell height of scallops in the area. The length and width of each image was increased by the mean shell height of measured scallops within the survey area using the equation:

(1) Expanded View Area = (l + (mean SH/2)) x (w + (mean SH/2))

where l and w are quadrat length and width and SH is shell height. Mean densities and standard errors were calculated for the images from the survey grids using equations for a multistage sampling design (Krebs 2014).

A Habcam transect was conducted through the enhancement site in July as part of another project to evaluate the use of this tool in future efforts (**Figure 4B**). Scallops in a subset of images were measured to determine the sizes of scallops in dense groups close to the original drop site. The field of view for each image was determined based on the altitude of the ROV, and scallops were measured in Adobe Photoshop CS2.

Statistical Analysis

Statistical analysis was done using a negative binomial regression model in the package "MASS" (generalized linear model "glm.nb") in R (R Core Team 2014; Ripley et al. 2015). Like most animal survey count data, the scallop and predator counts from the drop camera survey included many stations with zero counts (**Figure 5**). When zero-enhanced overdispersed data sets are analyzed using parametric ANOVA or non-parametric Friedman methods, the results are unsuitable and can lead to incorrect data interpretation. Negative binomial regressions are one of the methods commonly used to analyze such data sets (Welsh et al. 2000; Zhou et al. 2014).

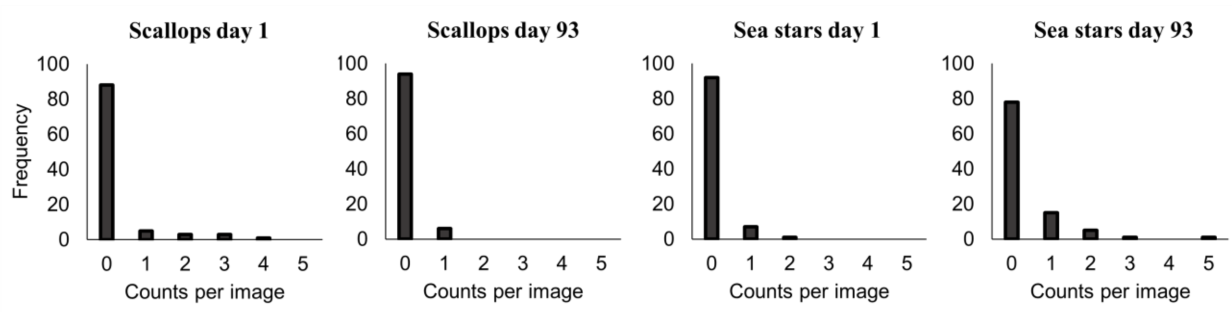

Figure 5. Examples of count frequency histograms from the drop camera grid survey. Scallop and sea star counts for day 0 right after seeding and the 3-month post seeding survey are shown.

The scallop and predator count data was modelled using date (days from seeding event) as a continuous factor and grid station as a categorical factor. The grid factor was treated as a categorical factor, without the distance from seeding site being considered. The initial model included both factors and the interaction effect. The model that better fit the data was chosen based on the Akaike Information Criteria (AIC).

Modeling Scallop Dispersal after Release

Weight in water and volumetric displacement were measured from live scallops (n = 78) of similar size as the seed released (82-113 mm SH) brought back from CAI on the December 2013 bycatch trip. An average wet density of 1.550672 kg/m^3 was calculated from these measurements, the acceleration of a scallop sinking as 0.338351 m/s^2, and the speed of scallop descent as 20.30108 m/s. The dispersal pattern at the drop site was then simulated for scallops one week after release based on current in the area of the drop site.

Results

Site Description

Water temperature at the harvest site was approximately 5.7° C in early June, whereas bottom temperature at the enhancement site was 11.0° C. The harvest site is much deeper (84.2 m) than the enhancement site (51.4 m), which may partly explain the difference in bottom temperature. Currents at the drop site were extremely strong. The current velocity at the time of seeding was approximately 0.5 m/s, which includes tidal currents. Residual currents were about 4.1 cm/s.

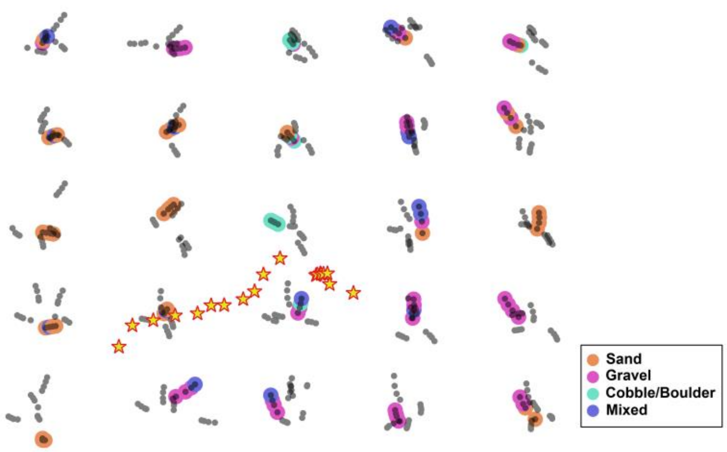

Figure 6. Sediment-type map of the grid survey quadrats during the September survey.

Sediment analysis was done on the 2.84 m^2 images from the Month 3 September grid survey. Sediment in each image was characterized as sand, gravel, cobble, or boulders, based on grain size. Almost all images had more than one sediment type. For **Figure 6**, quadrats were characterized as having one sediment type if a single type covered more than 50% of the image, and cobble and boulder were grouped together. If no sediment type covered the majority of the image area, the quadrat was classified as having mixed sediment. The sediment type changed on the scale of a single image, a single grid, and over the area of the entire grid survey. No additional analysis was done because of this variation over all three scales and because only six scallops were counted during the accompanying survey.

Video Survey Results

The statistical analysis was done to determine if changes in scallop, skate, sea star, and crab densities could be predicted based on date (days since seeding) and drop camera survey grid. Changes in animal densities over the five survey dates are shown in **Table 3** and **Figure 7**.

Table 3. Average densities and standard errors for predators and scallops from the grid survey. Standard errors were estimated using equations for a multistage sampling design (Krebs 2014).

	Days after Reseed	Average density per square meter (standard error)			
		Scallops	Skates	Sea stars	Crabs
Pre-seed		0.025 (0.009)	0.025 (0.01)	0.013 (0.007)	0.019 (0.008)
Trip 1	0	0.075 (0.026)	0.063 (0.014)	0.028 (0.013)	0.0 (0.0)
Trip 2	10	0.031 (0.014)	0.041 (0.014)	0.038 (0.012)	0.0 (0.0)
Trip 3	21	0.0 (0.0)	0.066 (0.017)	0.006 (0.004)	0.0 (0.0)
Trip 4	92	0.019 (0.007)	0.031 (0.010)	0.103 (0.023)	0.0 (0.0)

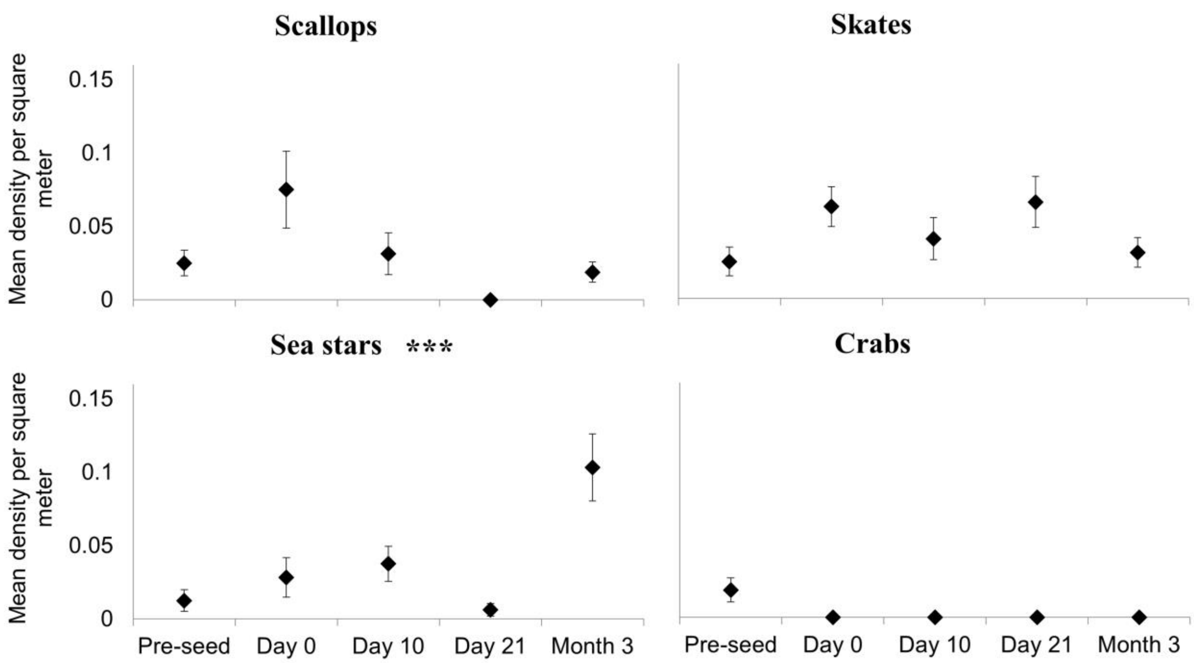

Figure 7. Mean densities and standard errors for scallops and predators during the pre-seeding and post-seeding grid surveys. The negative binomial regression model was only significant for sea stars (* indicates p < 0.001). No scallops were counted on Day 21 and no crabs were counted on Day 0 through Month 3.**

For all four animals, the model without grid factor included was selected based on assessment by AIC (**Table 4**). Date was not a significant predictor for scallop, skate, or crab densities over the course of the five grid surveys. There was a slight but not significant increase in scallops during the survey immediately after seeding. A significant change in sea star densities was observed, with the date being significant predictor of sea star densities ($p < 0.001$). The increase in the number of images with counts of one or more can be seen in **Figure 5**. However, because date was not a significant predictor of sea star densities if the month 3 counts were excluded from the analysis ($p = 0.357$), we do not believe scallop seeding was the cause of this.

Table 4. Results of the negative binomial regression analysis predicting densities of scallops and predators based on days after seeding (date). Only the final model, chosen by AIC, is shown. Date was a significant predictor for sea stars but not for any other animals.

Species	Theta	Effect	Estimate	SE	Z value	p value
Scallop	0.1166	(intercept)	-2.136	0.234	-9.111	< 2E-16
		date	-0.011	0.007	-1.581	0.114
Skate	0.976	(intercept)	-1.857	0.153	-12.144	< 2E-16
		date	-0.003	0.004	-0.885	0.376
Sea star	0.356	(intercept)	-2.815	0.230	-12.220	< 2E-16
		date	0.018	0.004	-4.710	2.48E-06
Crab	did not converge	(intercept)				
		date				

We believe that the survey grid covered too large of an area, extending well beyond the range of scallop dispersal after seeding. The fixed grid survey design seems to have missed the patchy high-seed densities detected by the transect survey. The transect survey was more localized around the enhancement site and large numbers of scallops were observed in the immediate area around the drop location (**Figure 8** and **Table 5**).

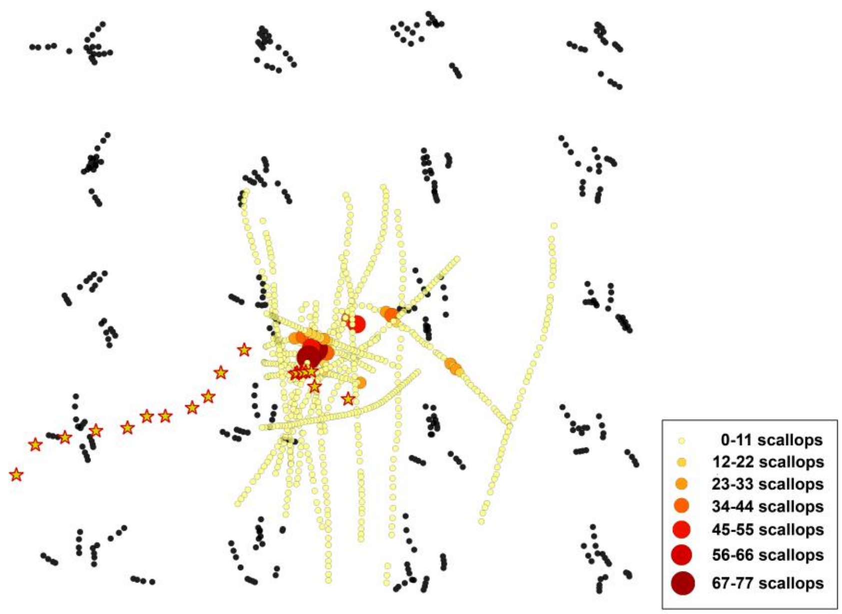

Figure 8. All SMAST transect survey quadrats showing the location of large numbers of scallops close to the drop site.

Table 5. Average counts per image and standard deviation of those counts for the transect surveys.

	Days after Reseed	Drops	Average counts per 3.2 square meters (standard deviation)			
			Scallops	Skates	Sea stars	Crabs
Trip 1	0	112	2.285 (6.071)	0.160 (0.436)	0.259 (0.626)	0.063 (0.278)
Trip 2	10	123	2.187 (8.579)	0.415 (0.677)	0.163 (0.371)	0.260 (0.939)
Trip 3	21	247	1.522 (6.524)	0.215 (0.449)	0.045 (0.207)	0.571 (1.549)
Trip 4	92	248	1.879 (8.126)	0.129 (0.348)	0.214 (0.568)	0.081 (0.273)

No pre-seeding survey was done in the transect quadrats close to the drop site, so we do not know if these locations had high densities of scallops before seeding. Yet we were able to determine shell heights of the scallops in the Habcam images from this area near the drop site. These scallops had an average shell height of 63 mm (± 13 mm), falling within the lower range of the scallops that were measured prior to seeding. Examples of the high-density scallop patches are shown in **Figure 9**. Few larger scallops were seen in the images, indicating they may have dispersed much further from the drop site.

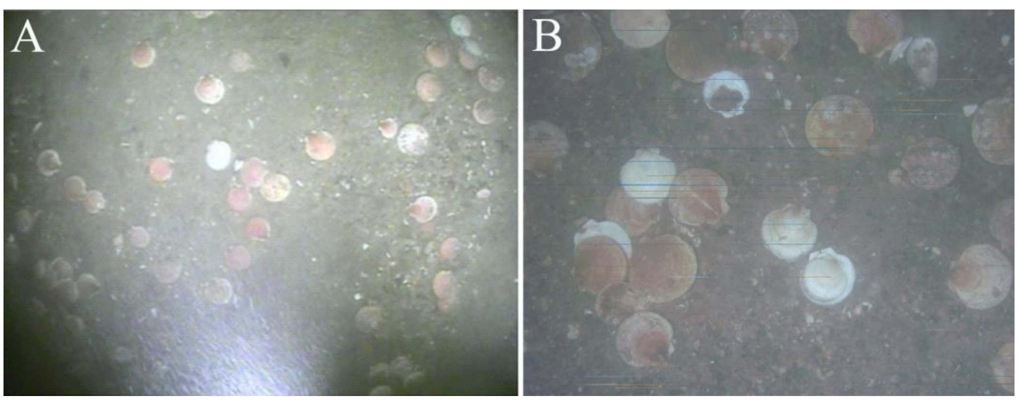

Figure 9. (A) Still image from a transect survey after seeding using the SMAST video pyramid (image area = 2.84 square meters) (B) Habcam image showing a high density of scallops in the immediate area around the drop site one month after seeding (image area = 0.63 square meters). The scallops in this image have shell heights ranging from 69-93 mm.

Scallop Dispersal Simulation

Results from the scallop dispersal model did not predict the locations of the seeded scallops. Model results suggested the scallops would end up southwest of the drop site (**Figure 10**). Yet our transect surveys showed that the scallops likely ended up at and slightly to the northeast of the drop site (**Figure 8**). The model treated scallops as passive drifting particles moving with the general circulation patterns in the region. These conflicting results suggest this simplification is not appropriate for modelling the bottom locations of surface seeded scallops.

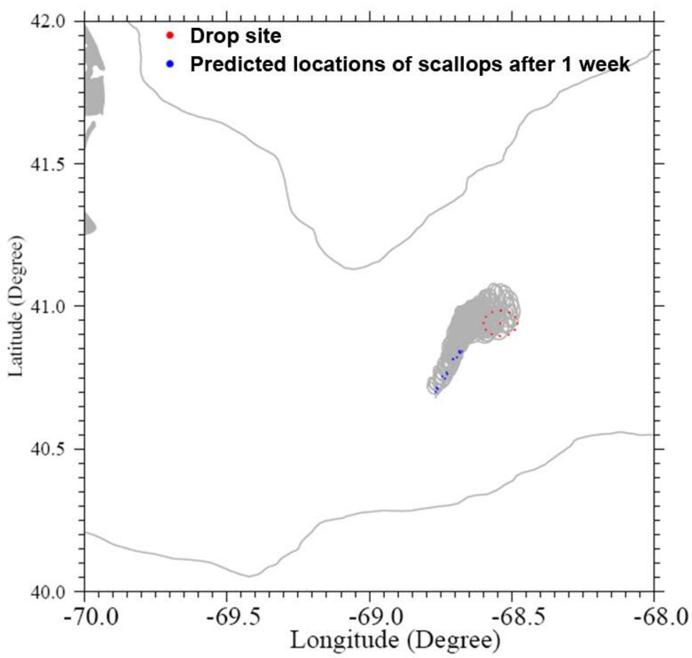

Figure 10. Results of the scallop dispersal simulation showing the likely end point for scallop transport after one week based on the location of the drop site and currents in the area.

<u>Cost Analysis</u>

Estimating a cost/benefit is difficult with scallops because of the variability in price and growth of scallops. During our experiment a vessel was able to harvest 282,000 scallops in two days of harvesting. The estimated average size of the caught scallops based on the 5 mm size classes was 102mm. A scallop of this size produces approximately 0.0475 lbs of scallop meat (Hennen and Hart 2012). Thus the estimated meat harvest from the 282,000 scallops would be 13,408 lbs. At the Scallop Research Set Aside predicted scallop meat price of $10.50, this catch is estimated to be worth $140,789.50 (NFSC 2014). The cost of hiring a boat for seeding was $4000 per day. If seeding took 5 days ($20,000), then a survival rate of more than 14.2 % would cover the cost of seeding.

Conclusions

Our transect survey results suggest that scallop density may have increased at the drop site after seeding, and that these scallops were still present three months after release. However, the design of the transect surveys did not allow us to determine if this was a statistically significant increase. Over a larger area, our grid survey did not indicate that scallop density increased after seeding. Future projects should focus on systematically surveying a smaller area to confirm our observations. These future projects could also be improved by marking the scallops used for reseeding so that scallops identified in post-seeding surveys could be positively identified as the scallops relocated for the experiment.

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