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

Final Report
Prepared for the 2014
Sea Scallop Research Set-Aside

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Submitted by
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G. **Project Summary:**

This project proposed to continue monitoring the seedbed that was established in CAI during the 2013 Scallop Enhancement RSA as well as to transplant scallop seed from NLCA to the same site. First, we evaluated the long-term success of the previous year's transplanting experiment based on survival, growth, and dispersal of scallop seed. Then we transplanted seed to the CAI transplanted seedbed to increase scallop density at a productive and protected site. Overall the project was a success. All of the objectives were met with minimum modification. We seeded approximately 1.64 million scallops on Closed Area I, measured high densities of scallops immediately after seeding, and observed very little mortality. Environmental conditions measured on site supported the selection of the area as scallop habitat. Scallop densities decreased during the post-seeding surveys, dropping from the high values observed 4 days after seeding. Dispersal rates were higher than expected on the seeded sites, and the drop camera survey was no longer able to detect a significant increase in scallop density after the first post-seeding survey.

H. **Purpose:**

The current rotational management program relies on natural recruitment processes, making it dependent on incoming year class strength. Larval dispersal patterns on Georges Bank seem to be highly variable, frequently leading to high spat abundances recruiting to low production areas and high production areas receiving little recruitment. While large year classes have sustained the fishery in the past, recruitment failure has been more common on Georges Bank in recent years (Stokesbury et al. 2012). The impacts of biotic (predation, fishing pressure, incidental fishing mortality) and abiotic (substrate, habitat, and oceanographic dynamics) variables 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 of low survival and transplanted in an area of higher survival and better growth, costs to the industry could be minimized while reducing bycatch. In addition, seeding in the proposed area will provide valuable information regarding growth 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 lead to improved methods of 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; Reyes 1986; Naidu and Cahill 1986). Some collect spat; others use hatcheries to produce the spat. Canada has been working on culturing the sea scallop and is near achieving a successful scallop aquaculture industry. While other countries develop aquaculture and resource enhancement strategies, the United States continues to import cultured scallops. In this project, we propose to transplant 35-55 mm seed (rather than spat) collected from the NLCA, which is about 60 kilometers south of the enhanced seedbed in CAI. Successful transportation and seeding of scallops 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/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 proved 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.

In June 2013, as part of the 2013 Scallop Enhancement RSA Project (NA13NMF4540009), approximately 2,100 bushels (~ 320,000 scallops) were harvested northwest of CAI in open area (~ 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). A total of 5,000 scallops were also measured and tagged in order to measure growth rate. 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. However, the fixed survey grid used for the 2013 project covered too large of an area, missing the patchy high-seed densities detected by the haphazard transect surveys conducted near the drop site. Consequently, statistical analysis of the grid survey data did not show any significant increases in scallop densities.

The goal of this project was to further develop tools for the management of scallop stocks along the U.S. Northeast coast. Because of the 2013 results, the systematic survey focused on a smaller area to confirm our 2013 observations. The techniques included using oceanographic and video monitoring to compare benthic environments and to demonstrate seeding techniques for rebuilding and strengthening scallop stocks. The main objectives were to:

1. Continue monitoring the Closed Area I (CAI) seedbed that was transplanted in 2013 to determine scallop survival rate, growth rate, dispersal, and predator density one year after seeding.

2. Perform another seeding operation transplanting seed from southeast Nantucket Lightship Closed Area (NLCA) at the CAI seedbed and monitor environmental conditions at both sites.

3. Evaluate the success of the transplant using SMAST's video pyramid by quantifying scallop and predator densities as well as scallop survival rate.

4. Compare seedbed characteristics (oceanographic conditions, habitat, and predator abundance) at transplanted CAI seedbed to the harvested seedbeds (NW CAI 2013 source bed and NLCA 2014 source bed) to uncover reasons behind transplant success or failure.

5. Deploy spat collectors to determine whether settlement is occurring in the enhanced seedbed.

I. **Approach:**

Trips for this project year (NA13NMF4540011):

Vessel	Date	Purpose
F/V Regulus	May 9 – 13, 2014	Seeding
F/V Anticipation	May 9 – 13, 2014	Seeding/Spat Collector Deployment
F/V Zibet	May 14 – 19, 2014	Immediate Post-Seed Survey
F/V KATE II	June 13 – 17, 2014	1 Month Post-Seed Survey
F/V Westport	July 12 – 15, 2014	REMUS
F/V Sally&Katherine	July 23 – 27, 2014	Haul Spat Collectors
F/V Diligence	August 8 – 12, 2014	3 Month Post-Seed Survey
F/V Sea Holly	Dec 5, 2014	Haul Spat Collectors

Location Selection (CFF)

Site selection was based on three criteria for scallop resource enhancement: favorable production, supporting regulations, and low user conflict (Halvorson et al., 1999). Georges Bank meets each of these criteria and has additional characteristics making it prime for scallop resource enhancement. Historically, natural scallop production on Georges Bank has been high, with meat production near 5000 metric tons per year and more than 30% of the US production (NEFSC 2014). The distribution and abundance of scallops in New England waters from 1994-2003, determined from NMFS survey tows, are shown in **Figure 1A**. Spawning stock estimated area also includes multiple areas with regulations on bottom-tending gear (Closed Area I, Closed Area II, and Nantucket Lightship Area). These regulations provide a level of protection to potential resource investments and lower conflicts with other fisheries and industries. Additionally, a lucrative scallop market and industry already exist in the area, with market prices near $13 per pound (price data from BASE New England Display Auction).

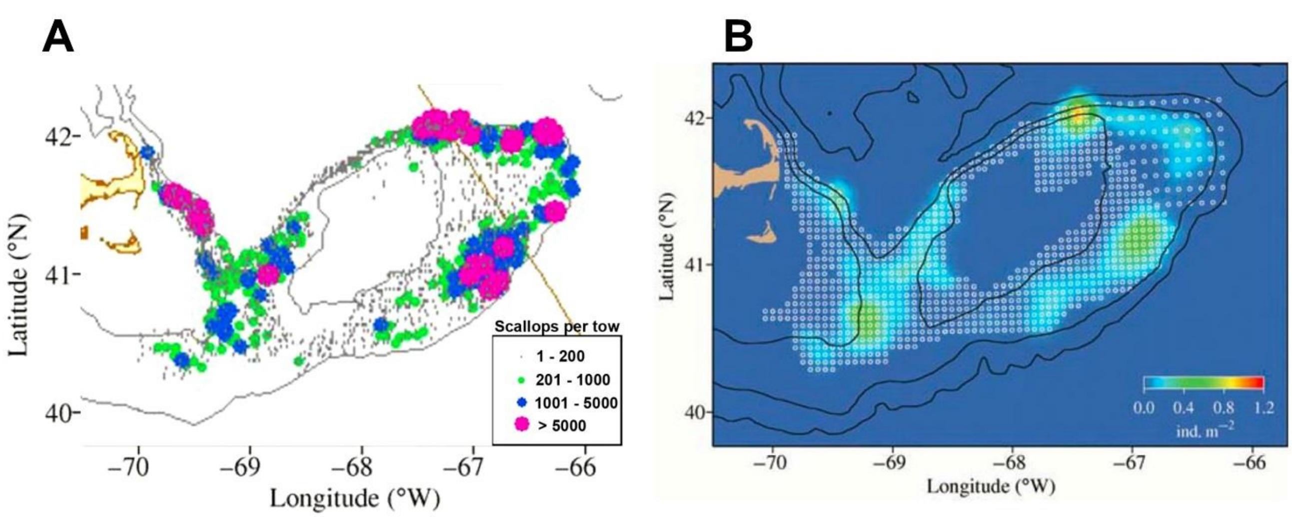

Figure 1: Atlantic sea scallop distributions. A) Distribution and abundance of scallops from NMFS survey tows 1994-2003 (Hart and Chute 2004**). B) Sea scallop spawning stock estimated from video surveys in 1989 and 2003 (**Tian et al. 2009**).**

Georges Bank has physical characteristic that also take advantage of secondary benefits of scallop resource enhancement. Because the first planktonic larval stages of *P. magellanicus* drift with the current before settling, the distribution of newly-settled juvenile scallops is determined largely by prevailing currents. On Georges Bank, the ocean currents retain scallop larvae over Closed Area I (CAI) and much of Closed Area II (CAII) (Tian et al. 2009). **Figure 2** shows the general circulation pattern over Georges Bank and the average larval retention in the same region based on simulations using a Finite-Volume Coastal Ocean Model and sea scallop survey data. Since enhancement projects should focus on sites where larvae and scallop food resources are retained (Sinclair et al. 1985; Sponagle et al. 2002; Brzezinski 2008), much of Georges Bank is well suited for such efforts.

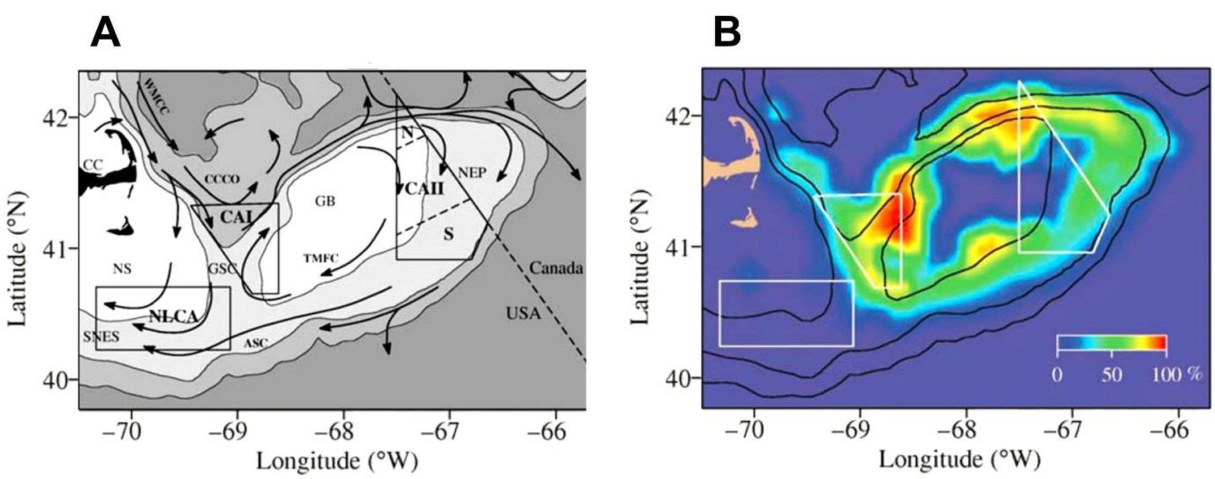

Figure 2: A) General circulation pattern over Georges Bank (Tian et al. 2009**). B) Average larval retention on Georges Bank based on computer simulations (**Tian et al. 2009**).**

The sites selected were in a section of Georges Bank approximately 92 km southeast of Nantucket Island, MA. The experimental plots consisted of one harvest site (~ 41° 31.7 N, -69° 52.4 W), and three experimental seeded sites, 2014 South (40° 53.7' N, -68° 49.38' W), 2014 North (41° 0.96' N, -68° 54.72' W), and 2013 (40° 94' N, -68° 55' W) (**Figure 3**).

Oceanic conditions at the seeding sites suggested the seeded area would be a more productive scallop habitat. The harvest site was approximately 90 m deep, while seeded sites were shallower (50 – 78 m). Shallower areas tend to produce higher meat to shell height in sea scallops due to the presence of more primary producers and warmer water temperatures (MacDonald and Thompson 1986). The currents at the harvest site also seemed high for suitable scallop habitat. Scallop growth can be affected by currents conditions, and currents of approximately 10 cm/sec or more have been shown to inhibit growth (Kirby-Smith, 1972; Wildish and Saulnier, 1993). Information from the Finite-Volume, primitive equation Community Ocean Model (FVCOM) of the areas showed lower currents at the seeded plots (Chen et al. 2006) (**Figure 4**).

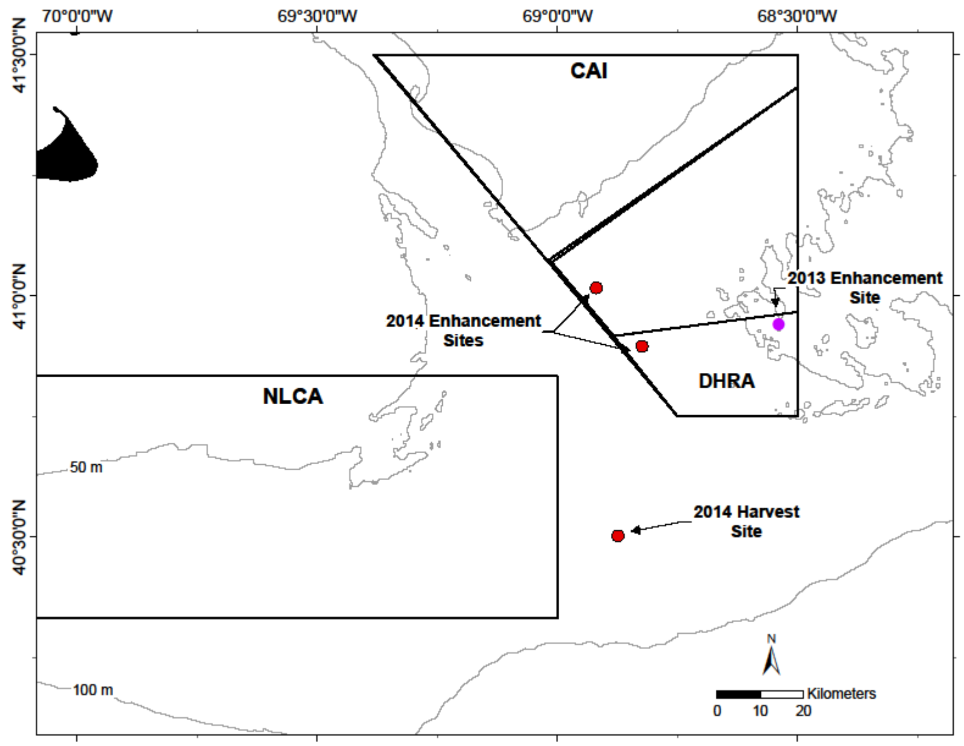

Figure 3: 2014 Harvest and Enhancement Sites (red points) in relation to the 2013 Enhancement Site.

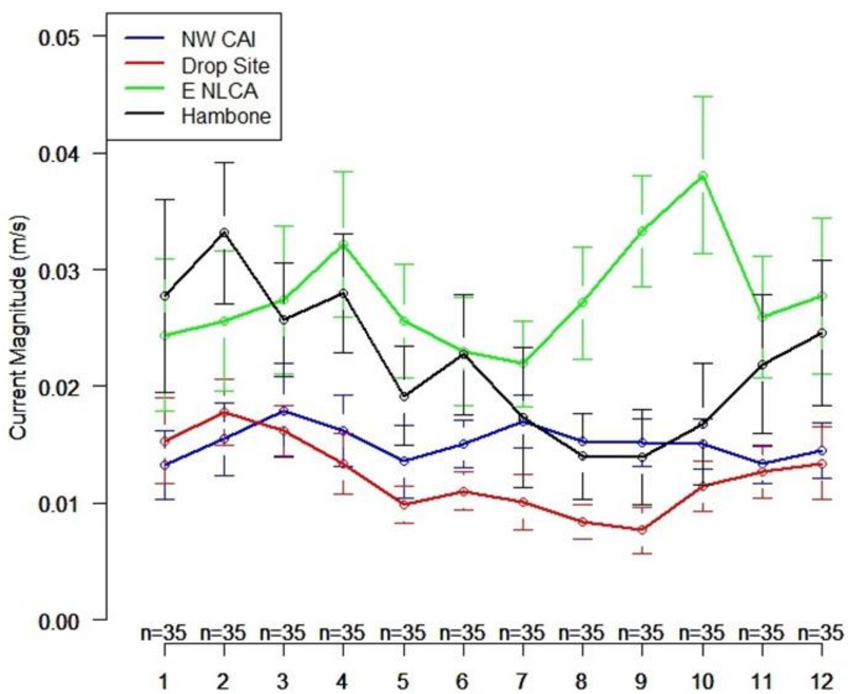

Figure 4: Current magnitude estimates NW CAI-N, 2013 Drop Site, E NLCA, Hambone. Lines represent mean monthly currents from 1973-2013 derived from the FVCOM (Chen et al. 2006).

Harvest Operation (CFF)

During the 2014 seeding operation, two commercial scalloping vessels were used to harvest and transport scallops. Each vessel towed a 4.57 meter wide New Bedford style dredge with a 100 mm mesh liner in the dredge bag (**Figure 5**). Each day the vessels conducted approximately 6 tows, with each tow being 50 minutes long. The catch was sorted and shoveled into plastic totes and stored on deck. To improve survival, the totes were covered with tarps and sprayed with water from the deck hose via a splitter. Time on deck for the scallops between harvest and seeding was less than11 hours.

Figure 5: New Bedford style dredge with a 100 mm mesh liner sewn into the bag.

Efforts to increase scallop survival rate involved transplanting a higher quantity of seed as well as transplanting scallops earlier in the year than seeding efforts in the 2013 Enhancement Project (NA13NMF4540009). The quantity of seed was increased significantly from the previous year's seeding operation by targeting much smaller juvenile scallops (35-55 mm shell height) than the 55-100 mm seed transplanted in 2013. We attempted to optimize seed condition by seeding earlier in the year when bottom water temperatures were cooler so as to maximize scallop survival rate (**Figure 6**). We also took careful precautions to shade scallops from direct sunlight with canvas drop cloths as well as to keep running seawater on them with a hose and sprinkler system (**Figure 7**). This seed holding system was very successful at keeping scallops alive and in good condition.

At the end of each day harvesting the vessels cruised to the seeding plots. Once at the center of the plot, the engine was cut and the vessel was allowed to drift. The scallops were then shoveled over the side of the vessel. Scallops were observed swimming in the water column following release. A subsample of seed scallops were kept in a running seawater tank for 18 hours to evaluate their condition and to qualitatively assess potential survival following seed transfer. The scallops responded by actively swimming indicating excellent vital condition, and none of the scallops in the subsample died over the 18-hour testing period.

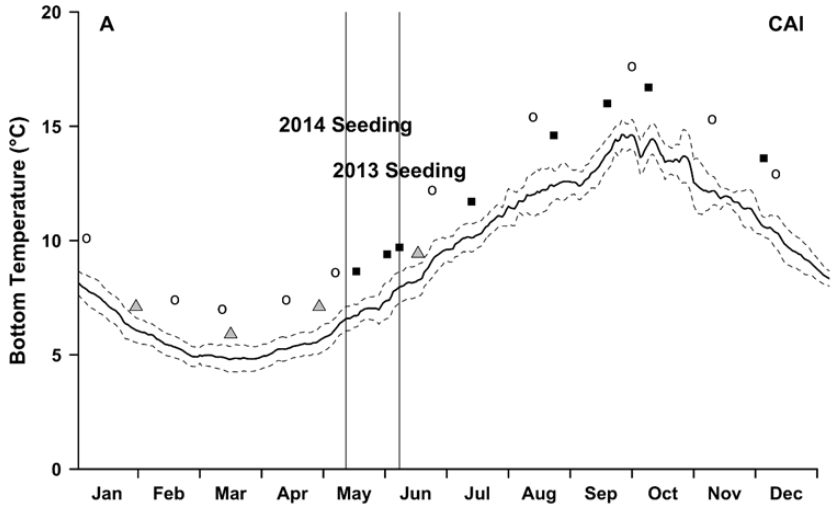

Figure 6: Mean bottom temperatures at 41.07 N, -68.70 W (near drop sites). FVCOM mean daily estimates from 2000 to 2009 (± 95% CI); measured bottom temperature from May to November 2011 (solid squares), January to November 2012 (hollow circles) and January to July 2013 (grey triangles) (Chen et al. 2006).

Figure 7: Picture of seed holding system aboard the F/V Regulus on the May 9-13, 2013 seeding trip. Seed was held in fish totes on the stern with canvas drop clothes providing shade and a hose/sprinkler system running sea water over the totes to keep the seed cool and moist. This system was very successful at keeping the seed alive and in good condition.

Site Monitoring

SMAST Pyramid Surveys

The seeded plots were surveyed using the SMAST video pyramid, a system supporting four cameras and eight lights, which was deployed from a commercial fishing vessel **(**Stokesbury 2002; Stokesbury et al. 2004). The vessel stopped at pre-determined stations in a 0.25 km^2 grid pattern at each site, and the pyramid was lowered to the sea floor (**Figure 8**). Two downward facing video cameras mounted on the sampling pyramid provided 2.84 m^2 and 0.60 m^2 quadrat images of the sea floor (Stokesbury 2002; Stokesbury et al. 2004). Another video camera, mounted parallel to the seafloor, provided a side profile of the quadrat area to aid in species identification.

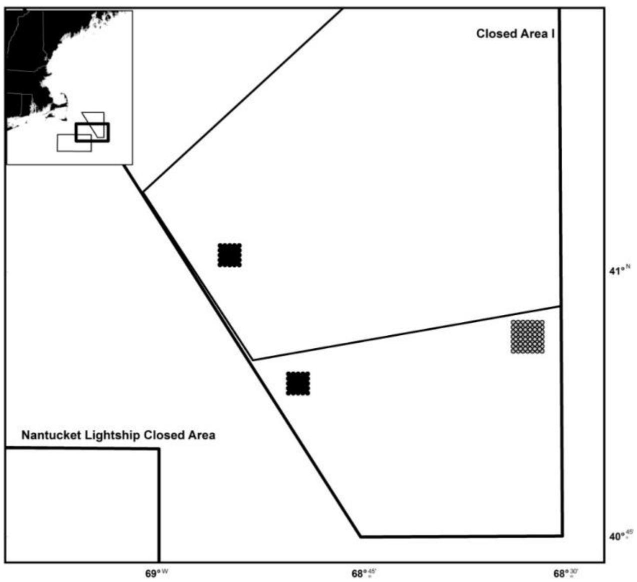

Figure 8: Areas surveyed by SMAST in 2014 for the scallop enhancement project. The first trip surveyed the 2013 enhancement site (grey area), while the three other trips surveyed the 2014 enhancement sites (black areas).

The pyramid was used to sample each site on the grid four times. At each site, after making contact with the sea floor and capturing images, the pyramid was raised until the sea floor could no longer be seen. The vessel was allowed to drift approximately 50 m and the pyramid was lowered to the sea floor again to obtain images of a subsequent quadrat. Sampling four quadrats at each station increases the sampled area to 11.36 m^2. For each quadrat, the time, depth, number of live and dead scallops, and latitude and longitude were recorded. After each survey, the saved video footage was reviewed in the laboratory and a still image of each quadrat was digitized and saved. Within each quadrat, macro-invertebrates and fish were counted and the substrate was identified. Sponges, hydrozoa/bryozoa, and sand dollars were recorded as present or absent within each quadrat.

Sediments was visually identified following the Wentworth particle grade scale from the video images, where the sediment particle size categories are based on a doubling or halving of the fixed reference point of 1 mm; sand = 0.0625 to 2.0 mm, gravel = 2.0 to 256.0 mm and boulders > 256.0 mm (Lincoln et al. 1992). Gravel was divided into two categories, granule/pebble = 2.0 to 64.0 mm, and cobble = 64.0 to 256.0 mm (Lincoln et al. 1992). Shell debris was also identified.

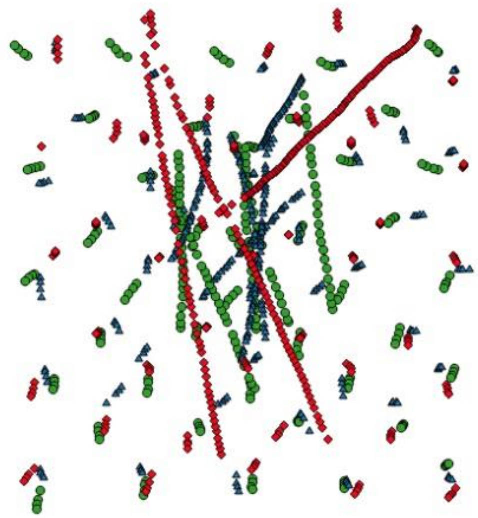

Figure 9: Locations of the grid and transect stations for the northern HBW site in May (green), June (blue), and August (red). The grid and transect station pattern was similar for the southern site.

After the seeding event, three SMAST video surveys (May 15, June 14, and August 9, 2014) were performed at each of the enhancement sites. On each survey, two complimentary approaches were employed to monitor the enhancement sites. First, a grid survey was conducted. Based on 2013 survey results, the survey resolution was increased to 0.25 km (from 0.5 km), which allowed us to better define the extent of the enhanced bed. Second, 3-5 transects were surveyed a drift strategy through the original site coordinates on each trip using (**Figure 9**). Approximately 280 stations were sampled using the grid sampling design, while 1,280 points were sampled using the transect design.

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) $$\text{Expanded View Area} = (l + (\text{mean SH}/2)) \times (w + (\text{mean SH}/2))$$

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).

Woods Hole Oceanographic Institution (WHOI) Surveys

In mid-July we surveyed the enhancement sites with the WHOI Remote Environmental Monitoring UnitS (REMUS) to test the effectiveness of an automated underwater vehicle (AUV) as a monitoring tool (**Figure 10**). REMUS 100 is a small AUV (160 cm long and weighing 37 kg). The vehicle is capable of 22 hours of operation at a speed of 1.5 m/s or approximately 8 hours at 2.6 m/s.

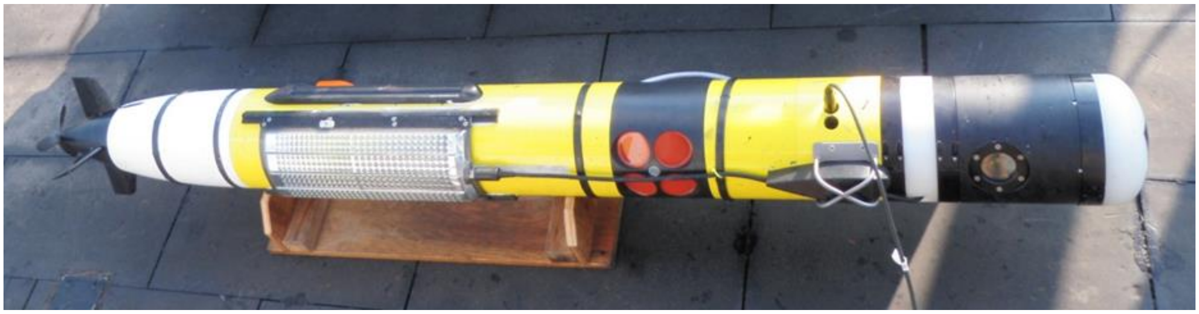

Figure 10: REMUS-100 AUV with WHOI made camera and LED array deployed on July 12-15, 2014 aboard the F/V Westport.

The REMUS survey covered a small area near the northern HB W drop site and a larger area near the southern NW DHRA site (**Figure 11**). Parallel survey tracks ran north-south, with tracks spaced approximately 20 meters apart.

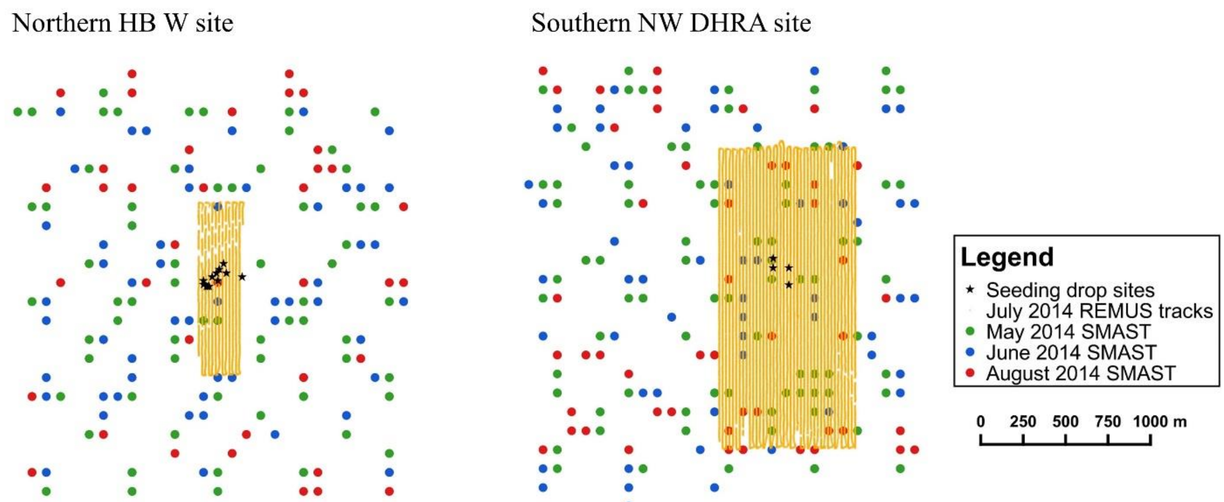

Figure 11: REMUS survey tracks over the northern and southern seeding sites.

<u>Statistical Analysis</u>

To examine changes in counts of scallops, skates, sea stars, and crabs after scallop seeding, we used 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 SMAST drop camera survey included many grids with zero counts. 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).

The scallop and predator count data was modelled using date (days after seeding event) as a continuous factor and station as a categorical factor. The station 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).

The presence of seven different sediment types (sand, sand ripples, shell debris, silt, gravel, cobble, and rock) was scored in the drop camera images, and changes in the presence of each sediment type was modeled using a logistic regression (R generalized linear model “glm” with link=logit). The initial model included site (northern HB W or southern NW DHRA) and date, and the model that better fit the data was chosen based on the AIC.

Scallop counts were also modeled using the negative binomial regression model in the R package “MASS” with site, date, and sediment type presence or absence as factors. The final model that better fit the data was chosen based on the AIC.

Spat collection (CFF)

Offshore spat collection efforts have generally involved spat bags that are suspended from a mooring in the water column (Cliche et al 1997), however it is difficult to keep suspended bags stationary in high current conditions such as those on Georges Bank. Therefore, we resorted to using benthic, rigid collectors (lobster traps) that are more durable and can be weighted. Spat collectors consisted of lobster traps modified by removing the heads and all twine inside the trap, while leaving the bricks and weights. The lobster traps were then lined with 4mm ADPI oyster bags were then cut laterally and attached with both hog rings and cable ties. Two pieces of spat collection material were connected inside the trap with hog rings. Each spat collection bag consisted of a 4' piece of Netron turned inside out and put inside a 3mm bag that was cinched shut (**Figure 12**).

Figure 12: Lobster traps were converted to hold the two orange spat collector bags.

The traps were then connected together in strings of five. A 6' bridle was attached to each trap, and a mainline was tied into the bridle. The mainline was 1/2" sinking rope, with 17 fathoms between each trap. At one end, the last trap was then tied to 15' of 5/8" mooring chain, which was then shackled onto one of three weights (150 lb mushroom anchor, 200 lb mushroom anchor or 10' piece of iron I-beam). The 30-fathom buoy line (also 1/2" sinking line) was then connected to the 5/8" mooring chain with an eye (with the rope braided back onto itself) and a 1/2" shackle. The other end of the 30-fathom buoy line was connected to a bridle, attached to a L4 poly ball and a 5-meter-high highflier marked with CFF contact information. The 3:1 line-to-depth ratio was sufficient to keep the buoy afloat. In addition, spat collection bags (3 mm spat bags filled with 4' of Netron) were braided into the buoy line, and zip-tied on for security at 3', 6', 9', 12' and 15' depth.

This benthic spat collector design also provided an in situ structure upon which to deploy environmental sensors. Temperature data loggers (TidbiT v2, Onset Computer Corporation, Bourne , MA) and current meters (SeaHorse Tilt Current Meter Model 1p100M, OkeanoLog, North Falmouth, MA) were secured to one trap in each string to continuously record water temperature and current velocity and direction.

On May 9, 2014, four spat collectors were deployed from a commercial scalloping vessel. One was centered at each enhancement site and one was 0.5 nautical miles north of each site (**Table 1** and **Figure 13**). The spat collectors were sampled and redeployed on July 25, 2014, and sampled and retrieved on Dec 12, 2014.

Table 1: Spat collector string locations. Locations are in degrees minutes seconds and depth is in fathoms.

North Site	Lat (Deg Min Sec)	Long (Deg Min Sec)	Depth (fm)
1st	41 00 59	68 54 43	38
2nd	41 01 30	68 54 44	40
South Site			
3rd	40 53 42	68 49 24	39
4th	40 54 13	68 49 22	40

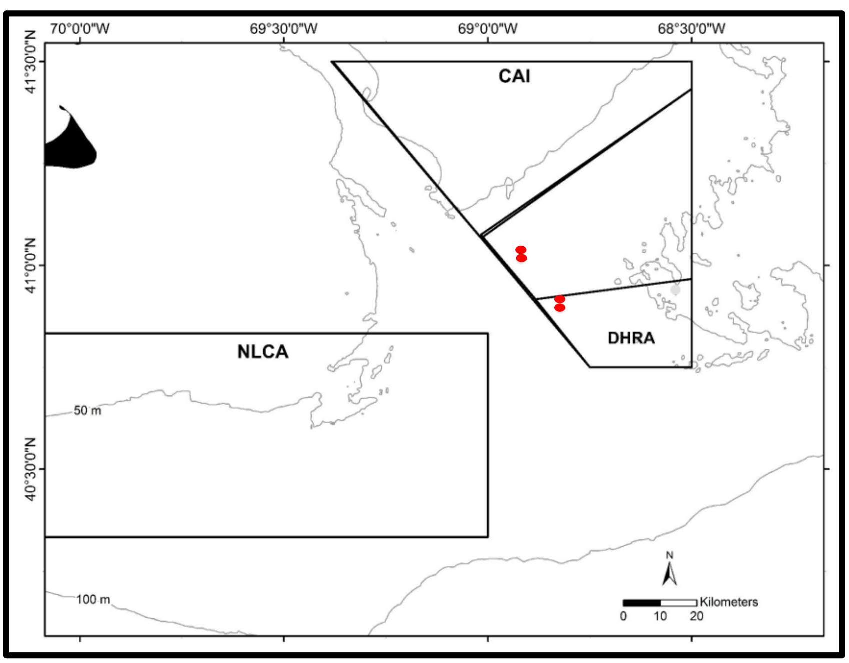

Figure 13: 2014 Spat Collection Locations (red points). 50 m and 100 m bathymetric lines are shown.

J. Findings:

Video Survey Results: Scallop and predator numbers

The drop camera images were annotated by personnel at SMAST. Animals were counted and substrate types were noted as present or absent in each image. The changes in scallop numbers at the different stations can be seen in **Figure 14**. Changes in mean densities of scallops and three predators (skates, sea stars, and crabs) over the three survey dates are shown in **Tables 2** and **3** and **Figures 15** and **16**. Mortality in seeded scallop was assumed to be low. Overall, only four clappers were observed in grid surveys and three clappers were observed in the transect surveys compared to over 500 and approximately 700 scallops respectively observed by each survey method. This supports the notion that the observed scallop declines in the study areas were due to dispersal, but cannot eliminate the possibility of mortality after dispersal especially considering the overall size of the survey area.

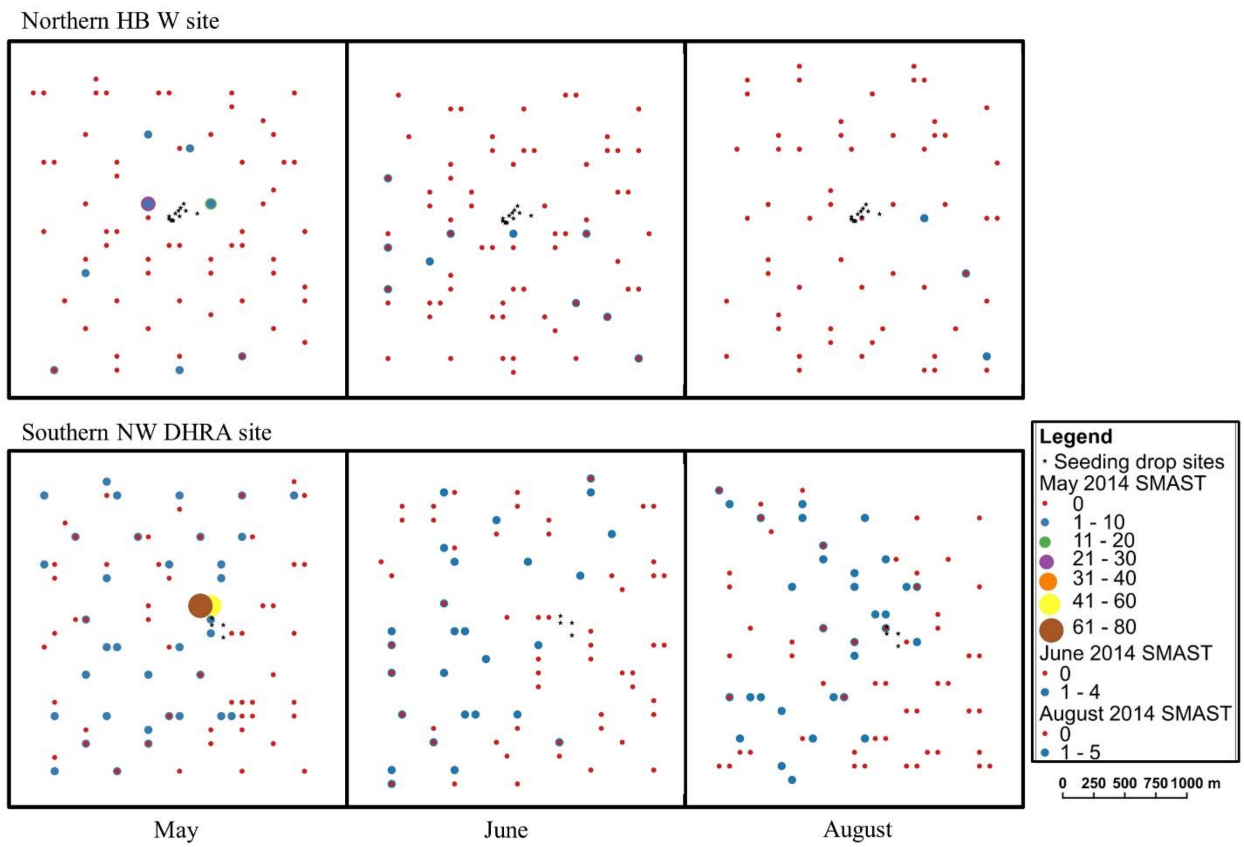

Figure 16: Changes in scallop numbers during the three drop camera surveys.

Table 2: Average densities and standard errors for predators and scallops from the grid survey at the northern HB W site. Standard errors were estimated using equations for a multistage sampling design (Krebs 2014).

northern HB W	Days after Reseed	Average density per square meter (standard error)			
		Scallops	Skates	Sea stars	Crabs
Trip 1	4	0.139 (0.089)	0.010 (0.005)	0.006 (0.003)	0.019 (0.009)
Trip 2	35	0.032 (0.011)	0.023 (0.008)	0.006 (0.003)	0.006 (0.004)
Trip 3	93	0.007(0.005)	0.021 (0.007)	0.0 (0.0)	0.013 (0.005)

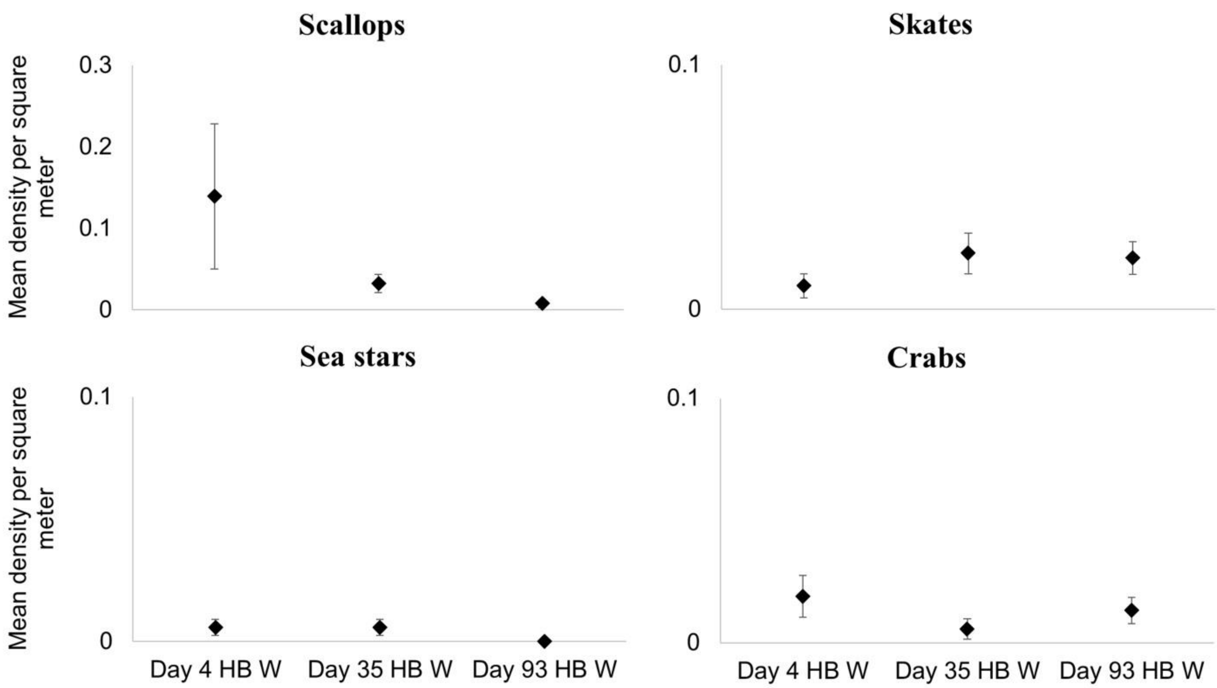

Figure 15: Mean densities and standard errors for scallops and predators during the post-seeding grid surveys on the northern HB W site. The decrease in scallop numbers was significant. Other changes in animal densities were not significant.

At the northern HB W site, the mean density of scallops decreased after the early peak soon after seeding, while skate mean densities increased slightly (**Table 2** and **Figure 15**). Sea star mean densities remained low throughout the surveys, and crabs mean densities fluctuated but remained low as well. At the southern NW DHRA site, scallop mean densities also decreased after the initial post-seeding peak (**Table 3** and **Figure 16**). Skate mean densities decreased slightly, while sea star and crab mean densities increased. Statistical analysis using negative binomial regression was done to determine if changes in scallop, skate, sea star, and crab numbers could be predicted based on date (days since seeding) and drop camera survey station.

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

southern NW DHRA	Days after Reseed	Average density per square meter (standard error)			
		Scallops	Skates	Sea stars	Crabs
Trip 1	**4**	**0.467 (0.305)**	**0.027 (0.007)**	**0.036 (0.010)**	**0.027 (0.009)**
Trip 2	**35**	**0.109 (0.025)**	**0.017 (0.006)**	**0.028 (0.010)**	**0.041 (0.022)**
Trip 3	**93**	**0.143 (0.029)**	**0.016 (0.005)**	**0.088 (0.022)**	**0.073 (0.025)**

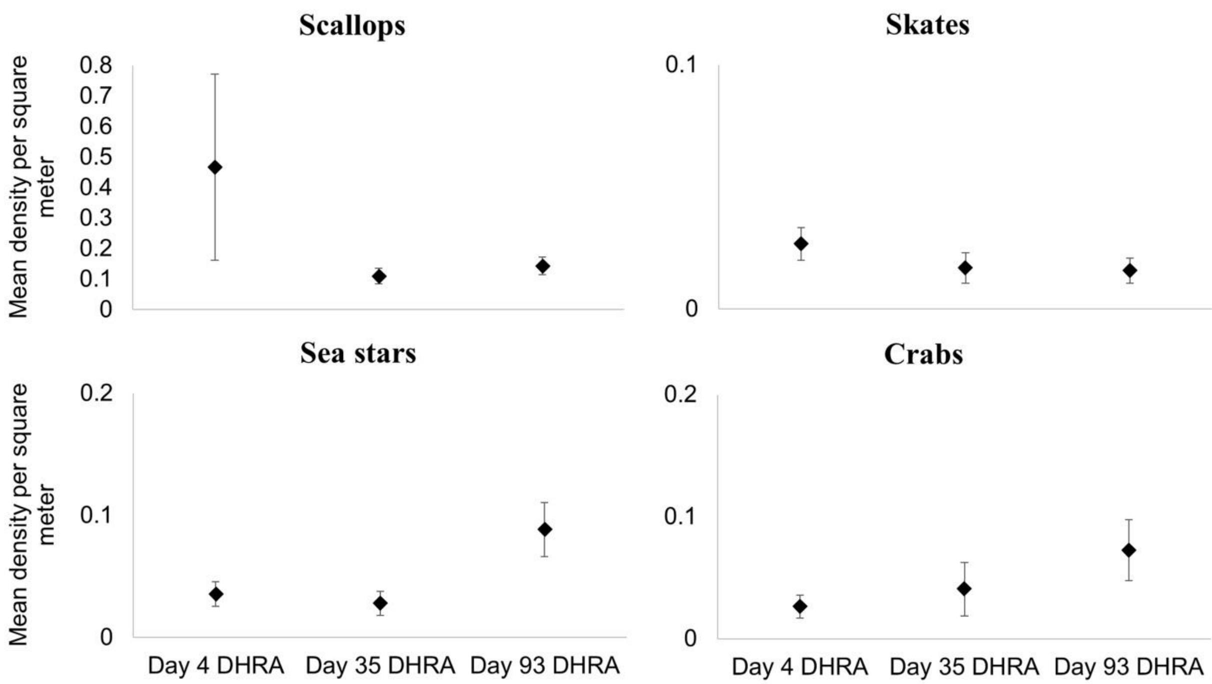

Figure 16: Mean densities and standard errors for scallops and predators during the post-seeding grid surveys on the southern NW DHRA site. The decrease in scallop numbers and the increases in sea star and crab numbers were significant.

For all four animals at the northern HB W site, the model without a station factor included was selected based on assessment by AIC (**Table 4**). Date was a significant predictor for the decrease in scallop numbers over the course of the three grid surveys. Date was not a significant predictor for changes in skate or crab numbers. The model for sea star numbers did not converge.

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

Species	Theta	Effect	Estimate	SE	Z value	p value
Scallop	0.039	(intercept)	-0.810	0.389	-2.084	0.037
		date	**-0.033**	**0.009**	**-3.754**	**1.7E-04**
Skate	0.328	(intercept)	-3.157	0.347	-9.098	< 2E-16
		date	0.006	0.005	1.106	0.269
Sea star	did not converge	(intercept)				
		date				
Crab	0.125	(intercept)	-3.078	0.389	-7.908	2.6E-15
		date	-0.003	0.007	-0.418	0.676

The negative binomial regression results for the southern NW DHRA site were more varied (**Table 5**). Date was a significant predictor for the increases in sea star numbers. Date and station were significant predictors for the increase in crab numbers. Three stations had significant effects on the changes in crab numbers, and examination of the raw count data confirmed that crab numbers increased the most at these three stations. The model for skates did not converge.

Station and station crossed with date were significant predictors for scallop numbers. Station 24 in particular had a significant effect on the decrease in scallop numbers, and the dense grouping of scallops near the drop site four days after seeding can be seen in **Figure 16**. Over 40 scallops were counted in a 3.2 square meter area immediately after seeding, but these high numbers were not encountered during the later surveys.

In summary, scallop numbers decreased in stations close to the drop site but were low in other stations throughout all surveys. Crab numbers increased overall and even more so in three stations, and sea star numbers increased overall.

Video Survey Results: Sediment at the two sites and scallop numbers

Because each sediment type was scored a present or absent in each drop camera image, this data was analyzed using a logistic regression model. The results of this analysis confirmed that there were significant differences in the absence or presence of each sediment type between the two sites (**Table 6**). Date was also a significant predictor for the presence of shell debris, silt, gravel, and cobble (**Table 6**). All four of these sediment types were more likely to be present in August than in May. Overall, the northern HB W sites had more shell debris and sand ripples, while the southern NW DHRA site had more gravel and cobble.

The number of scallops was modeled using negative binomial regression that included date (days after seeding), site (northern HB W or southern NW DHRA), and sediment types as factors (**Table 7**). As expected, the model confirmed that site and date were significant predictors for scallop numbers, with the southern NW DHRA site and first survey date after seeding having the highest scallop numbers. The presence of shell debris and gravel were also predictors for increased scallop numbers.

Table 5: Results of the negative binomial regression analysis predicting densities of scallops and predators at the southern NW DHRA site based on days after seeding (date). Only the final model, chosen by AIC, is shown, and only the grids with a significant effect (note this is p-value ≤ 0.1) on animal numbers are included in the table. Date was a significant predictor for sea star numbers, and date and grid were significant predictors for crab numbers. Date alone was not a significant predictor for scallop numbers, but grid and grid crossed with date were. The model did not converge for skates.

Species	Theta	Effect	Estimate	SE	Z value	p value
Scallop	3.31	(intercept)	-2.136	0.234	-9.111	< 2E-16
		station15	2.484	1.280	1.941	0.052
		station18	2.952	1.302	2.267	0.024
		station20	2.279	1.287	1.770	0.077
		station21	2.582	1.307	1.975	0.048
		station24	6.268	1.232	5.089	3.6E-07
		station42	3.725	1.263	2.949	0.003
		station18*date	-0.079	0.038	-2.076	0.038
		station21*date	-0.054	-0.028	-1.911	0.056
		station24*date	-0.107	0.023	-4.647	3.4E-06
		station42*date	-0.068	0.029	-2.330	0.02
Skate	did not converge	(intercept)				
		date				
Sea star	0.229	(intercept)	-2.454	0.247	-9.949	< 2E-16
		date	0.012	0.004	3.178	0.001
Crab	0.626	(intercept)	-3.260	1.132	-2.880	0.004
		date	0.014	0.004	3.210	0.001
		station 7	2.269	1.215	1.868	0.062
		station32	2.022	1.228	1.647	0.1
		station39	3.014	1.189	2.536	0.01

Table 6: Results of the logistic regression analysis for the presence of different sediment types. Only the final model, chosen by AIC, is shown. Site was a significant predictor for the presence of all sediment types. Date was also a significant predictor for shell debris, silt, gravel, and cobble.

Substrate	Effect	Estimate	SE	Z value	p value
Sand	(intercept)	0.873	0.099	8.824	< 2E-16
	north/south	0.572	0.151	3.800	1.5E-04
Sand ripple	(intercept)	-0.836	0.099	-8.824	< 2E-16
	north/south	-0.598	0.151	-3.954	7.7E-05
Shell debris	(intercept)	3.231	0.317	10.192	< 2E-16
	north/south	-1.005	0.332	-3.026	0.003
	date	0.010	0.005	2.196	0.028
Silt	(intercept)	-2.970	0.204	-14.560	< 2E-16
	north/south	0.321	0.173	1.859	0.063
	date	0.026	0.002	10.763	< 2E-16
Gravel	(intercept)	-1.661	0.145	-11.456	< 2E-16
	north/south	0.968	0.143	6.787	1.2E-11
	date	0.009	0.002	4.901	9.5E-07
Cobble	(intercept)	-2.885	0.231	-12.505	< 2E-16
	north/south	0.836	0.224	3.724	2E-04
	date	0.005	0.003	1.659	0.097
Rock	(intercept)	-3.607	0.281	-12.831	< 2E-16
	north/south	0.697	0.346	2.017	0.044

Table 7: Results of the negative binomial regression analysis for predicting the number of scallops based on the date, site, and sediment type. The final model, chosen by AIC, is shown. Site, date, and shell debris were significant predictors for scallop numbers. Gravel was also included in the model based on AIC assessment.

Species	Theta	Effect	Estimate	SE	Z value	p value
Scallop	0.130	(intercept)	-2.322	0.570	-4.077	4.6E-05
		north/south	1.569	0.229	6.856	7.1E-12
		date	-0.021	0.003	-6.279	3.4E-10
		shell debris	1.122	0.554	2.025	0.043
		gravel	0.438	0.235	1.863	0.063

Video Survey Results: REMUS surveys

Images from the REMUS surveys conducted in July were reviewed to determine if scallops and predators were present in the images. Because less than 0.1% of the images included scallops, no additional analysis was done. However, scallops could be identified and measured in the REMUS images when present (**Figure 17**).

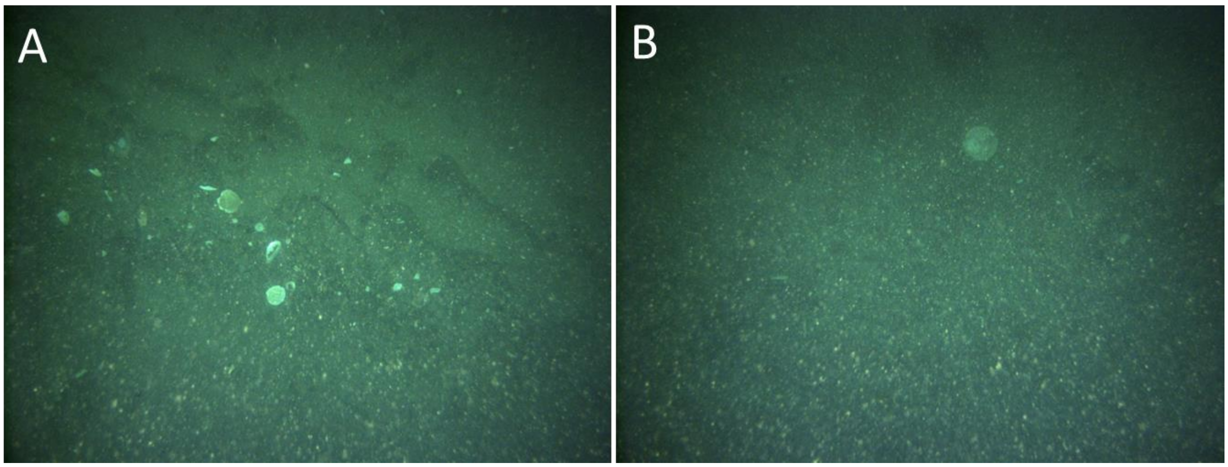

Figure 17: Images from REMUS survey showing scallops. A) Shell debris and a ~ 95 mm shell height scallop in an image taken 3.24 meters above the sea floor. B) A ~145 mm shell height scallop in an image taken 3.41 meters above the sea floor.

Spat Collectors

During first attempt at sampling of the spat collectors on June 7, 2014, it was discovered that scallop vessel winches are not appropriate to continuously haul pot warp. The procedure proved too dangerous and we quickly realized the need to charter an offshore lobster boat. On July 25, 2014, strings were successfully hauled on a 65’ offshore lobster boat. When brought aboard, the trawl was hauled back as a snarled ball of line and traps. We concluded that the collectors were set poorly from the scallop vessels, but the collectors were still effective despite the poor gear handling.

Spat bags inside collectors at the northern site were empty. There were a few predators (crabs, ocean pout, and sea stars) in the trap, but they would not have been able to access spat inside the spat bags. Spat bags inside the modified lobster traps at the southern site contained spat between 1-8 mm SH (n = 12) (example in **Figure 18**). The spat were attached to gillnet substrate with byssus threads inside 3 mm oyster spat bags within the lobster traps. All spat bags attached to the buoy line came off during the deployment period. A line of traps from the Northwest DHRA were lost (5 traps). The spat collector strings were redeployed.

The second collection in December had better results. Of the 15 remaining traps, 12 contained spat. Each trap contains two spat bags, and the average spat count per bag was 24 ± 9 (n = 30, standard error). These results are to be expected, post-larval settlement is also highly variable both spatially, ranging from 0-3,500 spat per bag, and temporally, depending on spawning time and oceanographic conditions (Cliche et al 1997). At the 4th site 4 of the 5 traps were full of mud, and contained no spat.

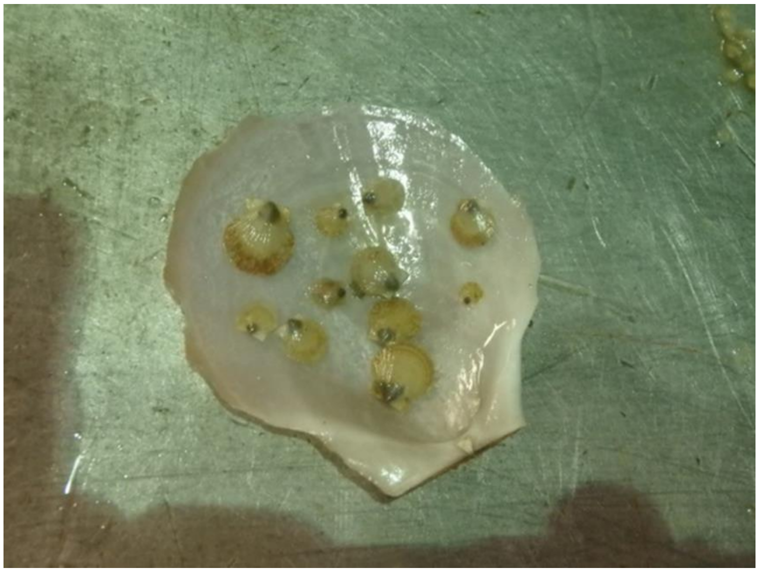

Figure 18: Example of spat collected in July.

<u>Oceanic Conditions</u>

Velocity Observations and Model Results
Four SeaHorse Tilt Current Meters were deployed on Georges Bank in Great South Channel from mid-July through early December, 2014. Site locations are shown in **Figure 19.**

The current meters sampled in bursts every 5 minutes for 60 seconds at 8Hz. By averaging 480 samples, 1 minute averages every 5 minutes were generated. For comparison with FVCOM, hourly averages were also produced. Data collected during this multi-month deployment had gaps as shown in the summary (**Figure 20**). Instruments with serial numbers (SN) 4, 5, 7 have good data intervals suitable for analysis. Instrument SN6 does not appear to have any good data – it was probably wedged under the cage or entangled with the rope.

For comparison to the FVCOM model, data were extracted from the archive at the link: http://www.smast.umassd.edu:8080/thredds/dodsC/models/fvcom/NECOFS/Archive/NECOFS_GOM3_2014/catalog.html. The closest FVCOM node to sites 1 and 2 is the node [41212] at -68.93541718, 41.02611923. The closest to sites 3 and 4 is the FVCOM node [41212] at -68.93541718, 41.02611923. The currents were very similar at both sites (northern and southern), with the phase angle (decreasing with time) of the near bottom currents showing clockwise rotation of the velocity vectors (**Figure 21**). Both SeaHorse and FVCOM show similar speeds near bottom (**Figure 22**) up to 60-80 cm/s, and the SeaHorse showed speeds about 20% higher than the finite-volume model.

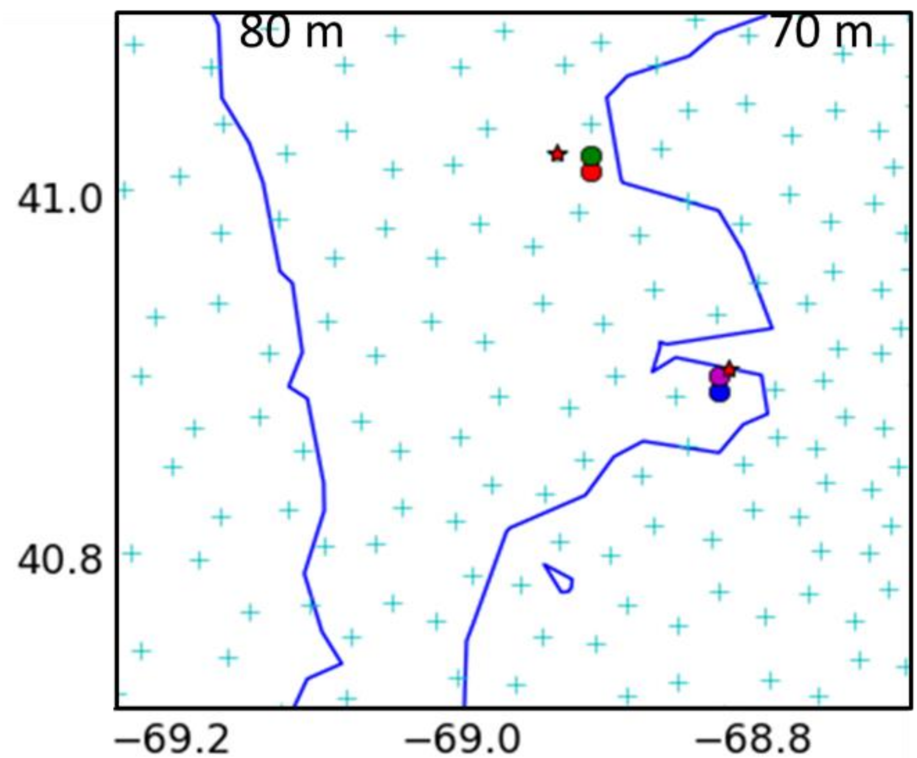

Figure 19: Deployment (Spat Collector) sites according to notes in Table 1: northern 1 - red, 2 – green; southern 3 – blue, 4 – cyan. Stars – closest FVCOM cell. Benthic contour lines mark 70 and 80 meters.

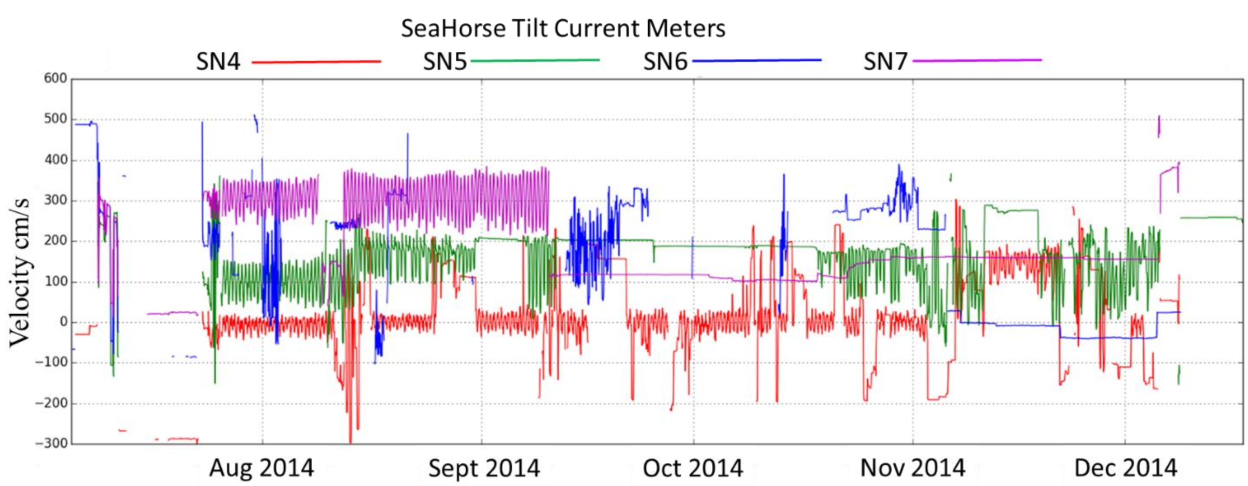

Fig. 20: SeaHorse northward velocity component summary plot: red SN4, green SN5, blue SN6, magenta SN7. (source: SeaHorseVNsummary.png) Each subsequent record is shifted by 100 cm/s.

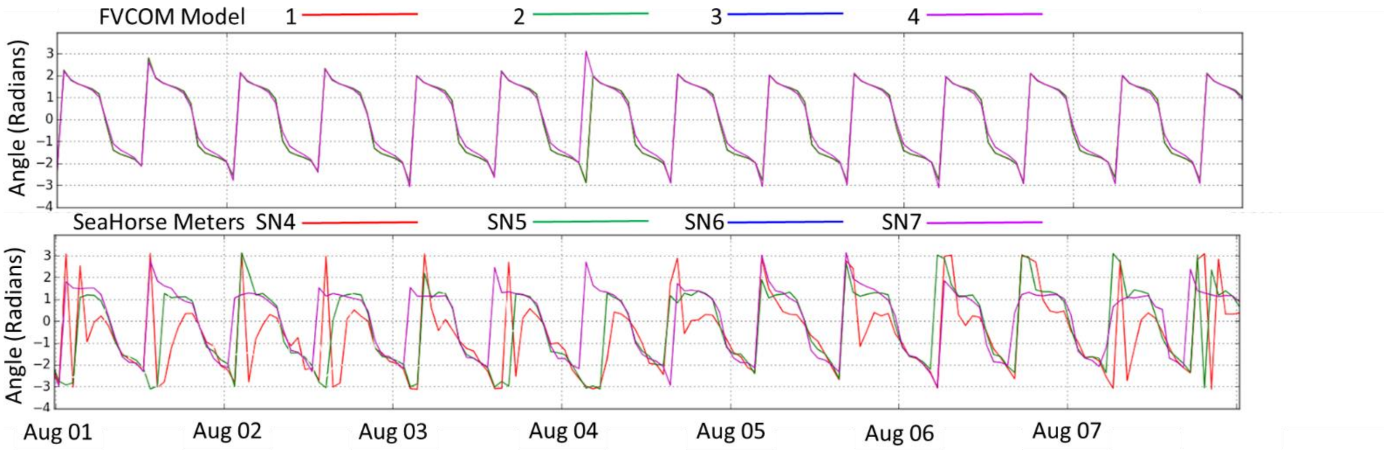

Figure 21: The phase angle of the near bottom velocity currents during Aug 1 – Aug 8, 2014: FVCOM (upper panel) and SeaHorse Instruments (lower panel).

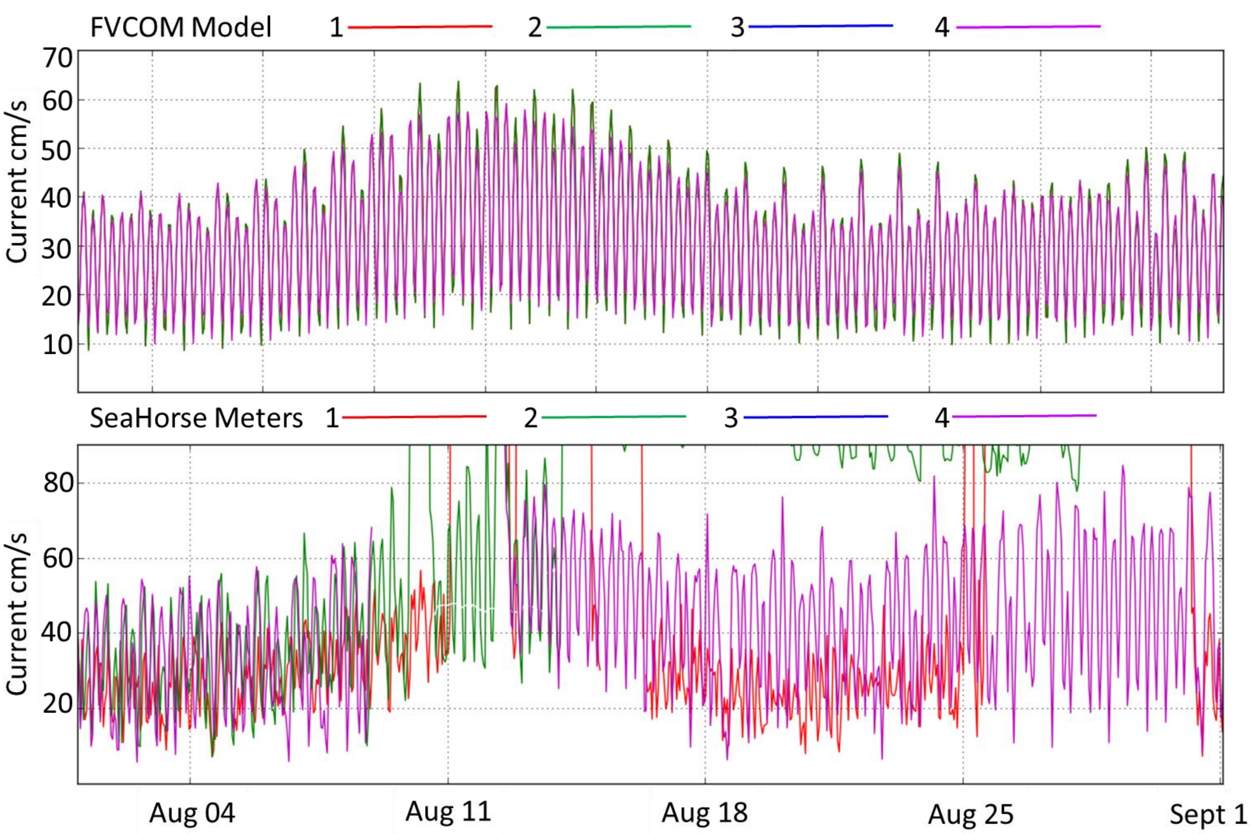

Figure 22: The flow speed: FVCOM (upper panel) and SeaHorse (lower panel) during August 2014.

Dependence of velocity on bottom distance

Due to friction in the water column, the velocity profile is not uniform with depth. According to observations (Lynch an Naimie 1993, see page 2243) at site "M" in the Great South Channel, the major ellipse velocity is 70 cm/s near surface and 60 cm/s near bottom which is very close to the present observations. Usually there is logarithmic boundary layer with a height about 30 cm near the bottom. The SeaHorse measures velocity at the effective height of three quarters of the pipe length above the pivot, which would be 80cm (including the length of tether). In addition the instruments were mounted on top of spat collectors (which presumably are about 30 cm high). Therefore the SeaHorse measures the near bottom current outside of the bottom logarithmic layer and at height of about 110 cm, so it is reasonable to make comparisons with the FVCOM velocity at the lowest model layer. At the Site 1, for example, the model depth was at h =70.28 m while the depth of the velocity layer was at 69.40 m (-siglay*h). Thus the model represents the velocity at 90 cm above bottom (**Figure 28**).

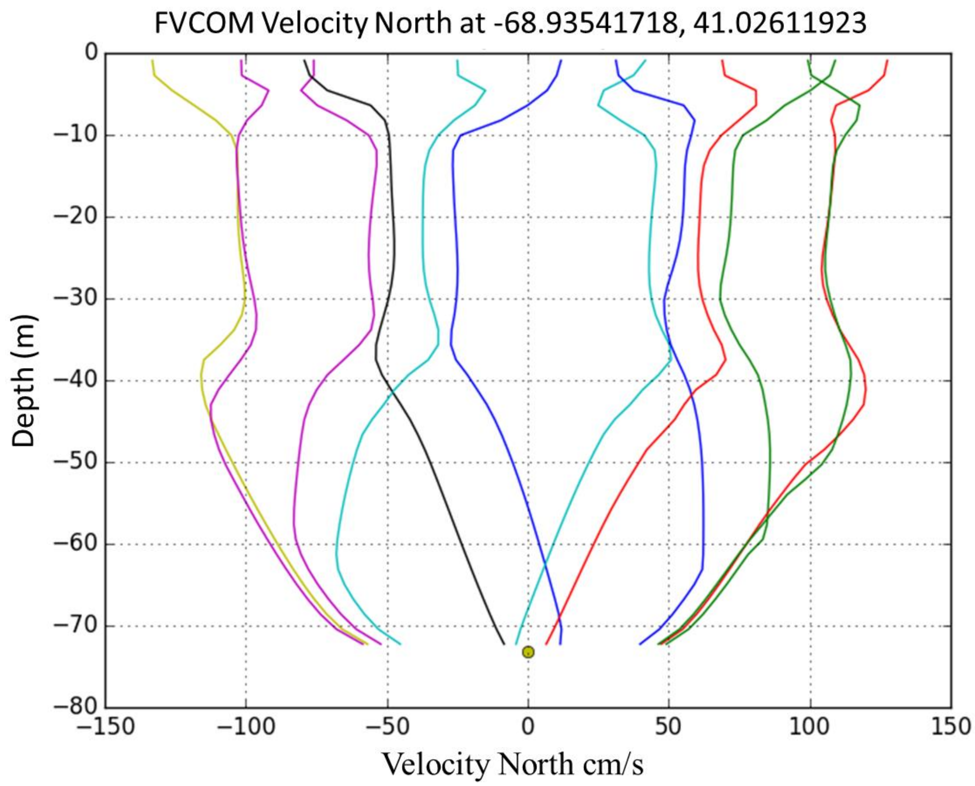

Figure 28. Vertical profile of the northward velocity component according to FVCOM during August 14, 2014. Profiles are shown every 2 hours. The dot indicates the bottom.

Duration of Low Speed Events

The tidal velocity in the Great South Channel has elliptic character: clockwise with major axis amplitude 60 cm/s and minor axis amplitude -20 cm/c. Therefore current ideally should never slacken below 10 cm/s (**Figure 29**). The calculation of fraction F of time the speed fell below specified threshold (10, 20, 30 cm/s) during August of 2014 is summarized in **Table 8**. Each current meter is listed, SH4 is SN1309004, etc., and the FVCOM at Site 1 is also listed. For example, the SeaHorse 7 row indicates that the currents slacked below 10cm/s only 2% of time and below 20cm/s for 13% of time during August 2014. Note that these are currents at about 1 meter above the bottom and at the very bottom the current diminishes.

Table 8: The fraction of the time current was below 10, 20, and 30 cm/sec in August 2014 for each Seahorse tilt current meter and the FVCOM model.

	Portion of Time at Current Velocity		
Instrument	< 10 cm/s	<20cm/s	<30cm/s
SeaHorse 4	0.0142	0.2102	0.5959
SeaHorse 5	0.0079	0.1007	0.2122
SeaHorse 7	0.0227	0.1261	0.2735
FVCOM	0.0107	0.2419	0.4569

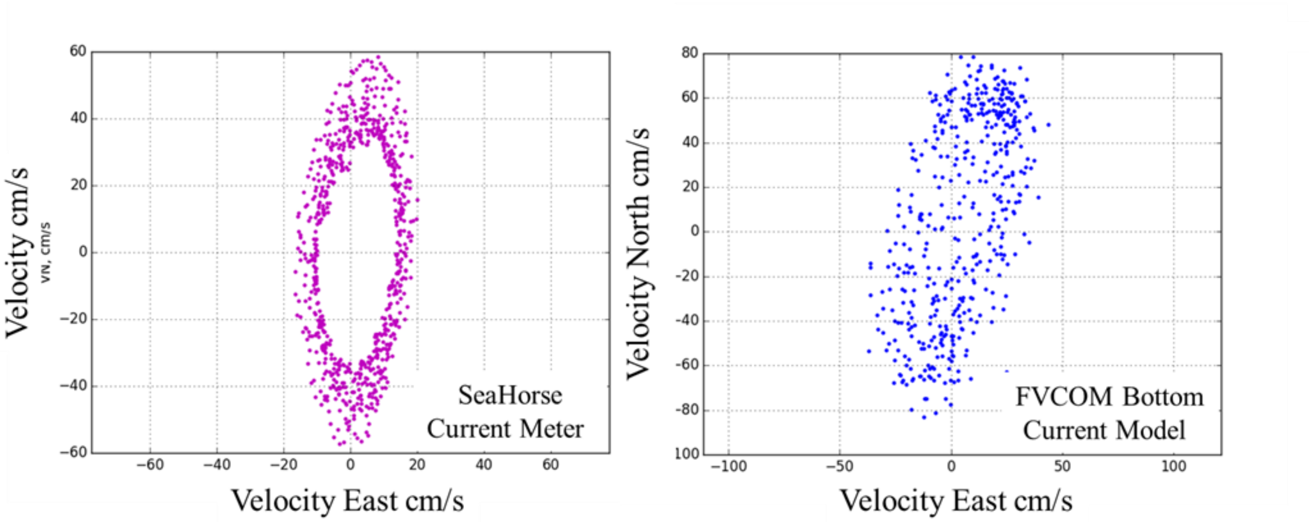

Figure 29: Scatter plot of eastward and northward velocity components VE-VN comparison during August 2014: both the SeaHorse meter and FVCOM model show clockwise elliptical current of similar amplitude.

Temperature Data Loggers

Three TidbiT v2 were retrieved from the experimental sites: two from the northern site and one from the southern site. Temperature was significantly different between sites (t-test, $p < 0.0001$). The southern site was slightly warmer for the duration of the experiment with an average temperature of 14.555 ± 0.009 °C (mean ± standard error). The northern site had an average temperature of 13.924 ± 0.011 °C (mean ± standard error). Weekly temperatures at the sites were usually within one degree Celsius of each other (**Table 9**). The profile of temperature change over time was very similar for all three data loggers. The only notable differences were a few points of substantial acute dips in temperature at the northern sites (**Figure 30)**. When the weather events for these time frames was investigated, it was noticed that the dip coincided with major weather events in the northern Atlantic (**Figure 31**). The cold upwelling could be a result of passing hurricanes (**Figure 32**).

Table 9: Weekly average temperatures (°C) and standard error at the northern and southern enhancement sites.

	North		South	
	Average of Temp	Stderr	Average of Temp	Stderr
07/26/2014 - 08/01/2014	12.85	0.01	13.41	0.01
08/02/2014 - 08/08/2014	12.70	0.01	13.30	0.01
08/09/2014 - 08/15/2014	13.51	0.02	13.77	0.01
08/16/2014 - 08/22/2014	14.29	0.01	14.41	0.01
08/23/2014 - 08/29/2014	14.52	0.01	14.80	0.01
08/30/2014 - 09/05/2014	15.15	0.01	15.50	0.01
09/06/2014 - 09/12/2014	16.14	0.01	16.05	0.01
09/13/2014 - 09/19/2014	17.11	0.00	16.09	0.01
09/20/2014 - 09/26/2014	17.07	0.01	17.48	0.01
09/27/2014 - 10/03/2014	16.13	0.01	14.88	0.04
10/04/2014 - 10/10/2014	16.22	0.01	14.69	0.04
10/11/2014 - 10/17/2014	16.14	0.00	16.15	0.01
10/18/2014 - 10/24/2014	16.45	0.02	15.11	0.05
10/25/2014 - 10/31/2014	15.24	0.01	12.30	0.02
11/01/2014 - 11/07/2014	12.89	0.03	11.26	0.02
11/08/2014 - 11/14/2014	13.14	0.01	11.96	0.01
11/15/2014 - 11/21/2014	12.91	0.01	11.90	0.01
11/22/2014 - 11/28/2014	11.86	0.01	10.98	0.00
11/29/2014 - 12/05/2014	11.78	0.01	10.65	0.01

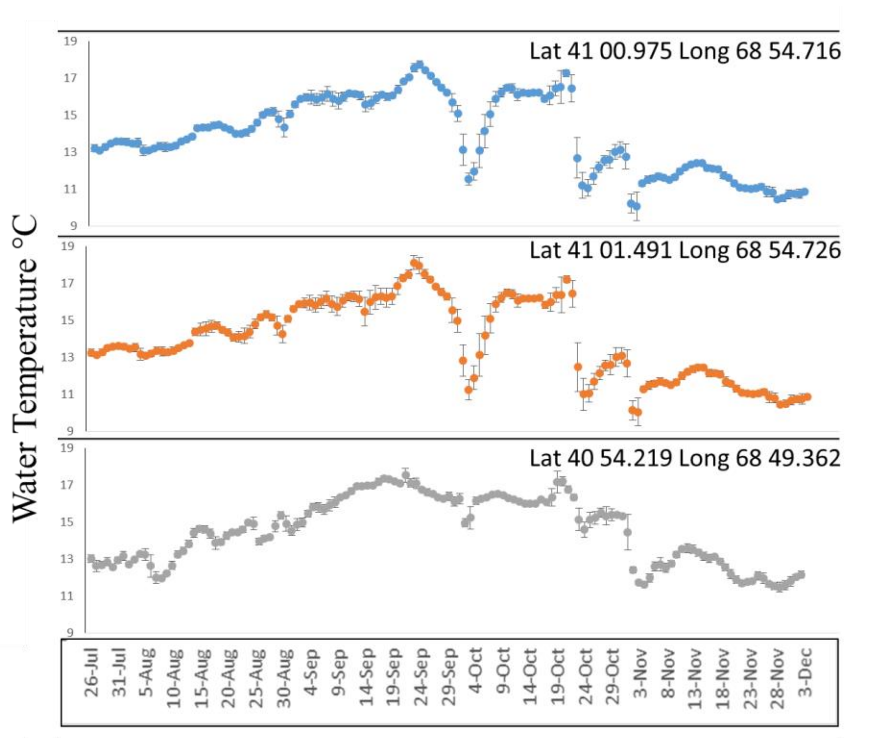

Figure 30: The profiles of temperature change recorded on the three TidbiT v2 data recorders for July – Dec. The two northern sites are blue and orange, the southern site is gray.

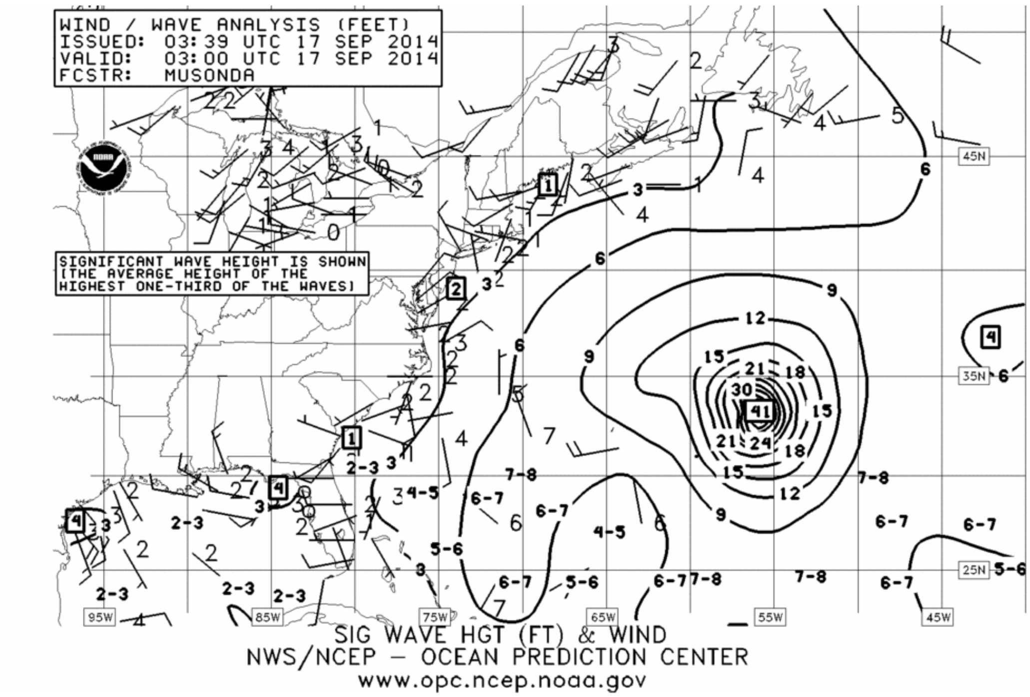

Figure 31: NOAA weather report for Sept 17, 2014 showing the wave heights and wind speeds.

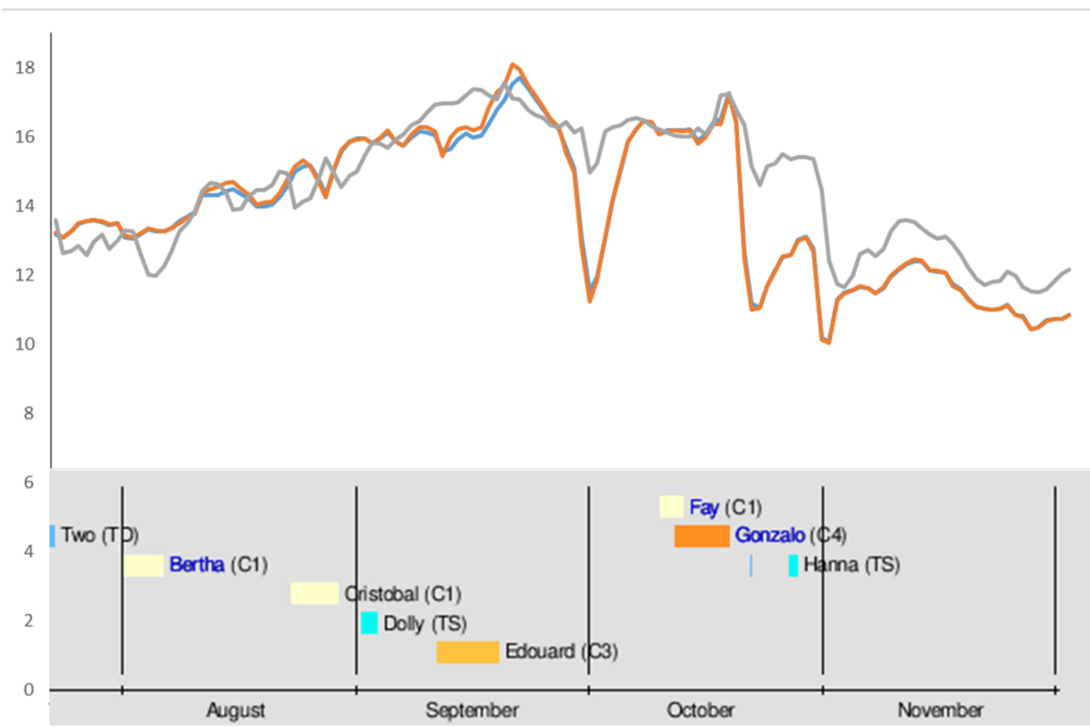

Figure 31: Profile of temperature changes at experimental sites overlaid with the timeline of 2014 Atlantic hurricanes. Image from: http://en.wikipedia.org/wiki/Timeline_of_the_2014_Atlantic_hurricane_season

Evaluation:

Overall the project was a success. All of the objectives were met with minimum modification. We seeded approximately 1.64 million scallops on Closed Area I, with an average shell height of approximately 87mm. Meat weight estimates for this size group are near 11.35g per scallop and at the Scallop Research Set Aside predicted scallop meat price of $10.50 per lb., this catch is worth $430,886 (NFSC 2014). The benefit of seeding younger scallops with low meat weight is their growth rate, which is near 50 – 80% for >5 year old scallops (Moring 1986). Even at the growth rate of 50%, this amount of scallops would be worth ~$970,000 in two years. The cost of hiring a boat for seeding was $4000 per day. If seeding took 6 days ($24,000), then a survival rate of more than 2.5 % would cover the cost of seeding. This is an improvement over the needed survival rate predicted by our 2013 project due to the use of small mesh nets to catch more and smaller scallops. There are many factors that affect scallop growth, with depth of growth being one significant factor. The difference in meat weight of same age class scallops grown at 90 m instead of 60 m can be approximately 20% heavier at the shallower site. If an operation similar to ours seeded scallops from a 90 m site to 60 m site, this could give a $194,000 return on seeding, not taking into account scallop mortality. In addition to improved meat weights, if the scallops are seeded into a management area, the investment can be protected to insure a return. The sea scallop fishery is only allowed 30.86 days at sea in 2015, giving the fleet plenty of down time to participate in seeding (NOAA 2015). This makes scallop enhancement a viable option for management to maintain and improve the fishery.

1. Continue monitoring the Closed Area I (CAI) seedbed that was transplanted in 2013 to determine scallop survival rate, growth rate, dispersal, and predator density one year after seeding.

However, it was impossible to determine the long-term consequences of an enhancement effort over the course of three months of monitoring. Since the 2013 seeding was promising, we monitored this site a year after seeding in order to gain a better understanding of the long-term feasibility of scallop resource enhancement on Georges Bank. Scallop densities remained low at the 2013 Enhancement site, with 64 scallops counted at 512 stations (mean density = 0.039 scallops/square meter). This was comparable to the numbers of scallops encountered at the site in all but the immediate post-seeding survey (0.019 – 0.035 scallops/square meter).

2. Perform another seeding operation transplanting seed from southeast Nantucket Lightship Closed Area (NLCA) at the CAI seedbed and monitor environmental conditions at both sites.

We successfully seeded approximately 1.64 million scallops from the NLCA to CAI seedbeds. Due to logistic issues with monitoring both sites beyond the initial harvest and seeding, it was decided to use established sea scallop physiological and environmental limits as a comparison for the seeded sites.

During the analysis of environmental conditions, we investigated bottom type, current velocity, and temperature. For bottom type, it was found the presence of shell debris and gravel were significant predictors of increased scallop numbers. This is similar to finding of other scallop bottom habitat preference (Thouzeau et al. 1991; Kostylev et al. 2003). Current meters we deployed at the sites found the currents nearly 20% higher than predicted by the FVCOM model, with velocities near 60 – 80 cm/s. This is far above the threshold current velocity that scallops can optimally feed, strong currents of 10cm/s or more can inhibit scallop feeding (Wildish and Kristmanson 1988; Wildish and Saulnier 1992). Usually scallops overcome strong current by focusing on feeding during slack tides (Wildish and Kristmanson 1988; Wildish and Saulnier 1992). The elliptical nature of the tides in CAI make the slack tide near nonexistent, and in August we measured current velocities below 10cm/s only 2% of the time. Since the FVCOM model and our current meters are not able to give a measure of current at very bottom where scallops live, current may not be a good indicator of hospitable habitat. The scallops have historically existed in the area (Hart and Chute 2004; Tian et al. 2009), and either the current is much less intense along the bottom, or scallops may be choosing areas with bottom types that slow the current (shell hash and gravel). Temperature at the enhancement sites were below temperatures expected to cause mortality in scallops (>18°C) (Culliney 1974). Temperatures were highest in September with measurements above 17°C.

Our environmental sampling revealed some interesting information about the dynamics of the system in CAI. During the deployment of the data collectors, a number of hurricanes occurred. Hurricane Edouard rolled all of our current meters over and caused a water temperature drop of almost 4 degrees in 48 hours. The ocean is a dynamic system, but for a storm to affect the bottom nearly 75 meters below with such intensity is eye opening.

3. Evaluate the success of the transplant using SMAST's video pyramid by quantifying scallop and predator densities as well as scallop survival rate.

The SMAST survey functioned well as a survey tool. It was able to detect the changes in scallop density post seeding and give an indication of changes in predator densities over the course of the experiment. The survival rate of the seeded scallops was more difficult to quantify with method. Overall, only four clappers were observed in grid surveys out of 500 identified scallops. Loss due to dispersal and the size of the survey area may be covering up mortality.

The WHOI REMUS 100 showed great promise as a survey tool. We were able to use images collected by REMUS for another RSA funded project (NA14NMF4540082 "Estimating Incidental Mortality in the Sea Scallop Fishery").

4. Compare seedbed characteristics (oceanographic conditions, habitat, and predator abundance) at transplanted CAI seedbed to the harvested seedbeds (NW CAI 2013 source bed and NLCA 2014 source bed) to uncover reasons behind transplant success or failure.

Due to logistic issues with monitoring both sites beyond the initial harvest and seeding, it was decided to use established sea scallop physiological and environmental limits as a comparison for the seeded sites.

Seeding did appear to increase the density of scallops at the enhanced sites since the density immediately after seeding was significantly higher than during later months. However, it was only temporary. The decrease in density could be from two causes, dispersal and/or predation. Georges Bank has many characteristic that make it optimum scallop habitat. Chlorophyll a is plentiful with sustained levels of 2 µg/l (O'Reilly and Zetlin 1998). Water temperature is cool and the water column is well mixed year round (Bisagni and Sano 1993), and our temperature data indicated the sites never became warm enough to cause mortality. The current may be high in some sites, but scallops seem to overcome this disadvantage and are historically present (Hart and Chute 2004; Tian et al. 2009). There were live scallops post seeding and there was little indication of actual mortality in the seeded scallops from the subsequent SMAST surveys. The SMAST surveys were no longer able to identify elevated scallop densities by day 35 after seeding. The surveys also indicated changes in predator densities, which could account for some loss. Scallop escape behavior could be causing dispersal rates higher than we expected. Adult scallop are mostly immobile, with any large migration caused by prevailing currents (Posgay 1981). This indicates that the seeding was a success, but the scallops moved out of our survey area. A more intensive tracking of the scallops could reveal the cause of the changes in density post seeding.

5. Deploy spat collectors to determine whether settlement is occurring in the enhanced seedbed.

Our deployed spat collectors did have spat settlement. From May to June there was very little recruitment. From June to Dec there was a much larger spat set. This indicated settlement occurring at the sites. Sea scallop spawning on Georges Bank is thought to happen around September-October (Posgay and Norman 1958). Our collectors indicate there may be some "leaking" at other time of the year.

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